Politecnico di Milano
Dipartimento di Scienze e Tecnologie Aerospaziali

SPACE SHEPHERD
USING SPACE SYSTEMS TO SAVE HUMAN LIVES

Francesco Topputo, Mauro Massari, Riccardo Lombardi, Marco Gianinetto,
Andrea Marchesi, Martina Aiello, Stefano Tebaldini, Francesco Banda

Scientific Report

DSTA-SR 16-01

2016

SPACE SHEPHERD

1. MIGRATION PHENOMENON 2
  1.1 EVOLUTION OF SMUGGLING FLOWS TO ITALY 3
  1.2 NOWADAYS 5
  1.3 THE LAST YEAR 8
2 THE AIS SYSTEM 11
  2.1 JURIDICAL BACKGROUND 13
  2.2 SAT-AIS 15
3 OBSERVATIONS SCHEDULING 17
  3.1 PROBLEM FORMULATION 21
  3.2 MONITORING OF SEA 22
  3.3 MONITORING OF HARBORS 24
  3.4 TRACKING 25
4 SHIP DETECTION 27
  4.1 STATE OF THE ART OF SHIP DETECTION IN OPTICAL REMOTELY SENSED IMAGES 27
  4.2 STATE OF THE ART OF SHIP DETECTION IN SAR REMOTELY SENSED IMAGES 31
  4.3 METHODS 32
    4.3.1 Dataset 32
    4.3.2 Ship detection in optical images 36
    4.3.3 Ship detection in SAR images 42
  4.4 ESTIMATION OF ROUTE PARAMETERS 45
5 RESULTS 47
  5.1 SHIP DETECTION IN OPTICAL IMAGES 47
    5.1.1 Ship detection in high spatial resolution images 47
    5.1.2 Ship detection in medium spatial resolution images 50
  5.2 SHIP DETECTION IN SAR IMAGES 52
  5.3 SATELLITE SCHEDULING 54
  5.4 SEA MONITORING 54
  5.5 HARBORS MONITORING 56
  5.6 TRACKING 57
6 DISCUSSION 60
  6.1 VESSEL DETECTION 60
  6.2 OBSERVATIONS PLANNING 63
ACKNOWLEDGEMENTS 64
REFERENCES 65

1. MIGRATION PHENOMENON

The Mediterranean Sea has become in the last two decades the most porous border between Europe and its neighbors. From 1 January 1998 till 30 September 2014, 840904 migrants were recorded by border authorities entering the EU illegally by sea [Fargues, P. and Bonfanti S., 2014]. In 2014, an enormous rise in the number of arrivals occurred. This must be attributed to a conjunction of factors: certainly the massive rescue operation ("Mare Nostrum") launched by Italy starting from October 2013, but also the mounting waves of displaced people in the Middle East and the breakdown of the last barrier between Africa and Europe with the collapse of the state in Libya [Fargues, P. and Bonfanti S., 2014].

After 1990, immigration replaced natural increase (the difference between births and deaths) as the major component in population growth in the European Union. Alongside legal migration, this growth has seen a concomitant rise in criminal activity to facilitate the illegal transportation of migrants through Mediterranean Sea [Coluccello, S. and Massey, S., 2007). Unfortunately, these journeys may end up in tragedies, due to travel, diseases, weather and vessel conditions. The number of dead and missing people on irregular maritime routes towards Italy has enormously increased in 2014 (Figure 1.1), reaching the highest peak ever from the beginning of this phenomenon in 2000 [Fargues, P. and Bonfanti S., 2014].

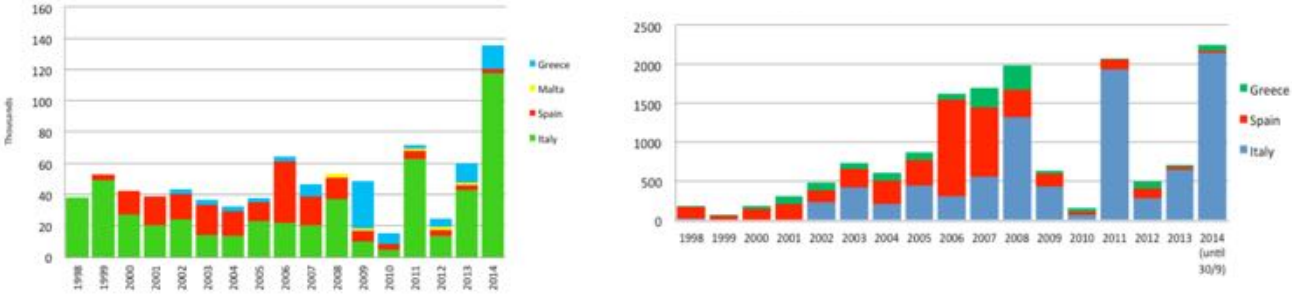


Figure 1.1 – On the left, migrants smuggled by sea to the EU 1998 – 2014 [Fargues, P. and Bonfanti S., 2014]; on the right, dead and missing people on irregular maritime routes to the EU 1998 – 2014 [Fargues, P. and Bonfanti S., 2014].

Italy is a main country of arrival, and often transit, for irregular migrants travelling by sea. With its 7600 kilometers of coastline, it is often considered the easiest way to enter in Europe for irregular migrants and criminal smuggler organizations [Sørensen, N., 2006]. The Sicily Channel has always been a route, but in the second half of the 2000s, it became the most travelled route, with Tunisia and Libya as main ports of departure, later on joined by Egypt (Figure 1.2). According to the data produced by the Italian Ministry of Interior, 494555 migrants were smuggled to Italian shores between 1 January 1999 and 31 August 2014 [Fargues, P. and Bonfanti S., 2014]. Most migrants (261768 people) who have landed in Italy in the past 15 years were not citizens of any Mediterranean country, but they come from Sub-Saharan African and even from the Middle and the further East [Fargues, P. and Bonfanti S., 2014]. The Sicilian southern coast is the most widely interested by those unloads: the most frequently used routes begin in the Lybian cities of Al Zwarha, Al Khums, Misurata or Sabratah (near Tunisian border) and usually end in the south-eastern Sicilian coast, between Licata and Marzamemi or in Capo Passero (Portopalo).

1.1EVOLUTION OF SMUGGLING FLOWS TO ITALY

According to a research that focuses on the evolution of smuggling flows to Italy, the crossings from North Africa to Sicily started from Tunisia in the first half of the 1990s and continued to expand [Monzini, P., 2008].

At first, some of these crossings were of a spontaneous nature, while professional smugglers planned others. Since 2000, the frequency and numbers of arrivals from North Africa have risen to unprecedented levels. Most of these crossings originate in the Libyan Arab Jamahiriya, mainly in an area close to the border with Tunisia. Coming from the eastern side (at the border with Egypt), migrants from the Horn of Africa and even from Asian countries (Bangladesh, Iraq, Pakistan and Palestine) began to use the Libyan Arab Jamahiriya as a transit point, leaving from the border areas between it and Egypt [Monzini,P., et al., 2004; United Nations Office on Drugs and Crime, 2006]. The shortest crossing from Libyan coasts (which extends for more than 1700 km) to Italian coasts starts in Al Zwarha and ends in Lampedusa Island. Lampedusa, being in the middle of the Sicily channel about 80 miles (approx. 130 km) from Tunisia and little bit more from Libya and having partially sandy coasts, constitutes the ideal landing place (see Figure 1.2). The travel between the two shores could take about 10-12 hours using dinghies and wooden or fiberglass boats with a good engine and without particular nautical instrumentation, or even fishing motorboats. The longest travel begins in Egypt, near the Nile delta and ends in the eastern Sicilian coasts in about 3-4 days [Monzini, P., 2008].

The north Tunisian coast extending down to the city of Misurata in Libya are favourable points of departure for travel to Sicily and its islands. Most departures are from points located within the area between Cap Bon and Sfax, as well as from the Libyan-Tunisian border to the city of Misurata or even Styre. In Libya, the main harbors are Zuwarah, Tripoli and Zilten. In Tunisia, the routes proceed in two directions; the northern route departs from the port of La Goulette and Cap Bon and heads for the south-western Sicilian shores in the region of Mazara del Vallo or the island of Pantelleria. Boats taking the southern route leave from a coastal zone situated between Sousse and Sfax and head for the Italian islands of Linosa and Lampedusa or directly to Sicily. The Libyan shores are much further south of Sicily than the Tunisian coast (the distance between Sicily and Libya is about 300 miles, while between Sicily and Tunisia is about 200 miles), which implies a longer trip but also fewer controls. The two main seaports of Zuwarah and Zilten see the departure of an increasing number of boats heading for Sicily. The main arrival area is by far the island of Lampedusa, followed by the islands of Pantelleria, Linosa and Sicily itself [Sørensen, N., 2006]. A summary of the major migration routes is shown in Figure 1.2.

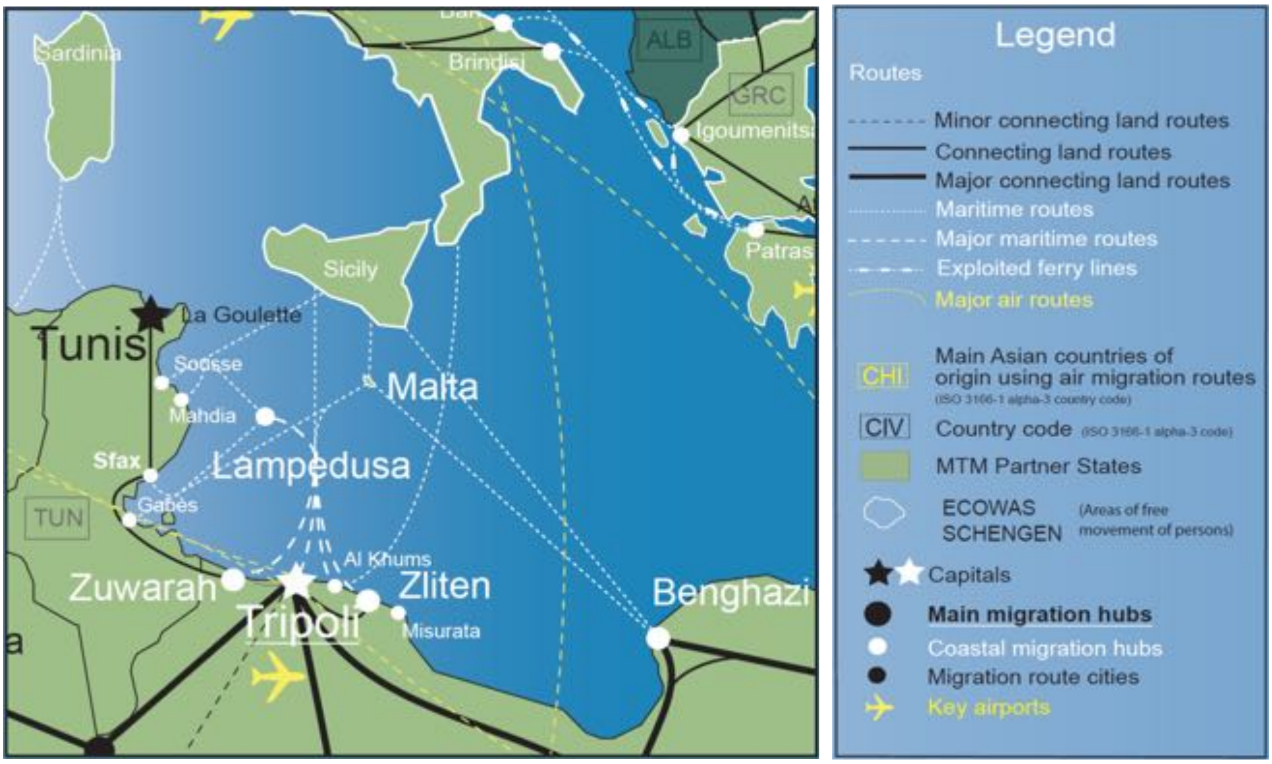


Figure 1.2 – Major routes in Central Mediterranean - Map on Irregular and Mixed Migrations, 2010 (source: www.imap-migration.org).

From the beginning of this phenomenon, smugglers began to use reusable or even disposable (cheaper than the previous as they do not require maintenance and a smuggler driving them) dinghies carrying 10-15 people each time. Since 2004, six-meter fiberglass or wooden boats (Figure 1.3) have begun to arrive on the Sicilian coasts, particularly from Lebanon and Egypt. These boats seems to be mass-produced, can carry about 25 people, and using a 40 hp engine can travel at 5 knots and complete the Sicilian channel crossing in about 4-5 days. Regarding the boats found in the Sicily channel during 2006, the Italian Coastguard declared that 71% was smaller than 8 m, 25% was between 8 m and 15 m, and only 4% was longer than 15 m [Monzini, P., 2008].

In 2007, the little boats were suddenly replaced with bigger fishing motorboats, about 20-25 meters long, usually carrying Egyptian migrants which were then transferred on smaller dinghies far from the coast to avoid Italian authorities controls. From 2008 till today the trend has been to use big crumbling boats or old fishing boats, commonly called rust-buckets (or “carrette del mare”) (Figure 1.4), usually of North African production and lacking of flag and name [Monzini, P. et al., 2004]. With those boats, the travel from Egypt to the Sicilian coast (usually near Portopalo), passing through the Maltese territorial waters, could last even 7/9 days [Monzini, P., 2008].

Figure 1.3 - Fiberglass (left) and wooden (right) boats 6 meters long (source: Monzini, P., 2008).

1.2NOWADAYS

Different information about migrant smuggling events happened during the last two years (2013/2014) have been retrieved from recent Italian newspapers and press releases from the Marina Militare, Guardia Costiera, and Guardia di Finanza. It is possible to infer that that the major routes are still the same of the past years, but some changes happened about the ships used.

During the last two years (2013/2014) the commonest ships used by the smugglers are the rust-bucket, 15-meters wooden boats (www.marina.difesa.it, 27/03/2014; www.marina.difesa.it, 12/03/2014) or very old 15-20 meters African fishing boats, usually at their last travel. These ships are able to carry about 100-200 people depending on their size and, eventually, on the number of decks (www.marina.difesa.it, 23/10/2014; www.lastampa.it, 3/01/2014). These are widely used because the smugglers can have a higher profit with a lower risk of shipwreck, so they can remain unnoticed with a minor attention by media. Some news items reported the use of fishing motorboats[1] of about 25-30 m (Figure 1.5), able to carry on board about 200-250 people (www.ilsecoloxix.it, 14/05/2014; www.ilsecoloxix.it, 02/07/2014) or even more as 350 people (www.ilfattoquotidiano.it, 25/08/2014). Another type of boat commonly used is the rubber dinghy, usually about 10-15 m long (Figure 1.6) with a load of approximately 100 people (www.marina.difesa.it, 28/02/2014; www.marina.difesa.it, 21/07/2014; www.marina.difesa.it, 19/12/2013)[2].

---

[1] Treccani encyclopedia reports the definition of fishing motorboat as a ship 30 tons heavy usually travelling with a speed of 8 knots (http://www.treccani.it/enciclopedia/motopeschereccio/)

[2] There exist two ISO norms regarding the highest power on dinghies (www.forumnautico.it):

- ISO 6185-1-2-3 for dinghies shorter than 8 m: (10 x Lh x Bh) – 33 [KW] (x1,36 [hp]);
- ISO 14496 for dinghies longer than 8 m: (16 x Lh x Bh) – 67 [KW] (x1,36 [hp]).

Figure 1.4 – Examples of "carretta del mare" of 15-20 meters in length (sources: www.massimosestini.it, 07/07/2014 for the photo on the left; www.corriere.it 30/06/2014, for the photo on the right).

Figure 1.5 – Examples of fishing motorboats of 20-25 meters in length (sources: www.ilsitodipalermo.it, 10/06/2014 for the photo on the left; www.marina.difesa.it, 24/05/2014 for the photo on the right).

Figure 1.6 – Examples of dinghies of 10-15 meters in length (source: www.marina.difesa.it, 17/12/2013 for the photo on the left; www.marina.difesa.it, 21/07/2014 for the photo on the right).

Recently, a different form of migrant smuggling is using very big boats, called mother ships (Figure 1.7). These vessels are usually big fishing motorboats or small cargo boats, more than 30 m long (www.gdf.gov.it, 12/09/2013; www.ilsole24ore.com, 15/10/2013; www.lastampa.it, 30/01/2014), able to carry a load of more than 200 people (and even 500). The migrants are then transferred from the mother ship onboard of smaller ships, or sometimes the mother ship tows the migrants' ship up to the territorial waters limit, and in then the ship is left drifting (Figure 1.8). Boats of this tonnage, typically passengers, cargo or merchants ships, usually travels with an average speed of about 14 knots, while small fishing boats are much slower, less than 10 knots (data from www.marinetraffic.com). Finally, by the end of 2014 some news items reported about migrant smuggling using cargo or merchant ships (from 30 m to 70 m), not as mother ships but as ships used for the whole crossing (www.palermo.repubblica.it, 20/12/2014; www.repubblica.it, 20/12/2014).

Figure 1.7 – Mother ships (source: www.marina.difesa.it, 10/11/2013 for the photo on the left; www.marina.difesa.it, 3/10/2014 for the photo on the right).

Figure 1.8 – The mother ship is towing the migrants' ship that will be left drifting (source: www.marina.difesa.it, 10/11/2013).

A Particular illegal immigration begun to appear in 2014 towards the Ionian shore of Calabria, mainly on the way to Roccella Ionica and neighbouring towns. Some news items mentioned the use of sail boats of different size (approximately between 10 m and 20 m) where people are usually squashed in the holds to avoid authorities control, as sail boats are generally touristic vessels. However, sometimes these boats are too crowded to contain all the migrants in the hold, therefore the immigrant traffickers also make use of deck (Figure 1.9) (www.gdf.gov.it, 19/03/2014; www.europaquotidiano.it, 19/03/2014; www.corriere.it, 10/04/2014; www.gazzettadelsud.it, 20/10/2014).

Figure 1.9 – Sail boats used by migrants to cross Mediterranean Sea towards Calabria (Source: www.gazzettadelsud.it, 20/10/2014)

A brief summary of the most common types of boats used by smugglers in the last two years, with some related information, is shown in Table 1.1.

Type of ship	**Length [m]**	**Number of people carried** (from sources)	**Speedrange [knots]**	**Source**
Rust-bucket Old African fishing boats	15-20	100-200	2-10*	www.marina.difesa.it www.lastampa.it
Fishing motorboats	25-30	200-250 (even 350)	2-10*	www.ilsecoloxix.it www.ilfattoquotidiano.it
Rubberdinghies	10-15	100	5-10**	www.marina.difesa.it
Big fishing motorboats or small cargo boats (Mother ships)	≥ 30	>200 (even 500)	10-15 (presumed)	www.gdf.gov.it www.ilsole24ore.com
Cargo or merchant ships (for the whole crossing)	30-70	≥ 500 200-800	10-20**	www.palermo.repubblica.it www.repubblica.it
Sailboats	10-20	Variable(> 40)	< 10 (presumed)	www.gdf.gov.it www.europaquotidiano.it www.corriere.it

* www.marinetraffic.com

** - Il traffico di migranti per mare verso l'Italia. Sviluppirecenti (2004-2008), Monzini P., 2008

Table 1.1 - Summary of the most common types of boats used by smugglers in the last two years, with related information (ship length, number of people carried, speed range and sources)

1.3THE LAST YEAR

A research by the International Organization for Migration (IOM) states that since 2000 close to 25,000 migrants have perished in the Mediterranean, making it the deadliest sea in the world [Brian T. and Laczko F., 2014]. The number of arrivals to southern Europe and, consequently, of dead and missing people in the Mediterranean sea, has enormously increased since 2013; and in 2015 it has more than doubled respect to the whole 2014. Figure 1.10 and Figure 1.11 shows some recent trends about sea arrivals to southern Europe.

In 2014 Italy experienced a dramatic increase in boat arrivals across the Mediterranean (170100 in total, three times the 2011 record), and at least 153600 people have arrived in Italy in 2015.

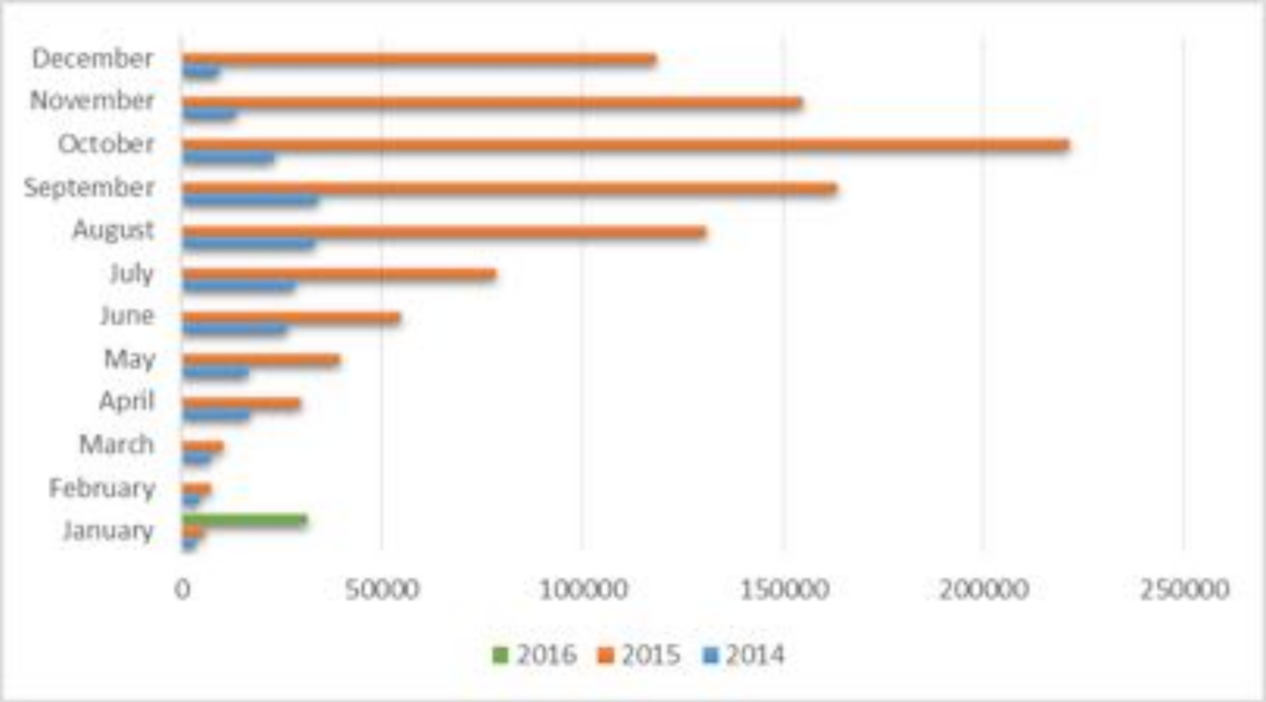


Figure 1.10 - Comparison of Mediterranean sea arrivals by month in 2014, 2015 and 2016; sea arrivals in 2015 are more than double respect to the whole 2014. Data are updated to 18th January 2016 (Source: UNHCR).

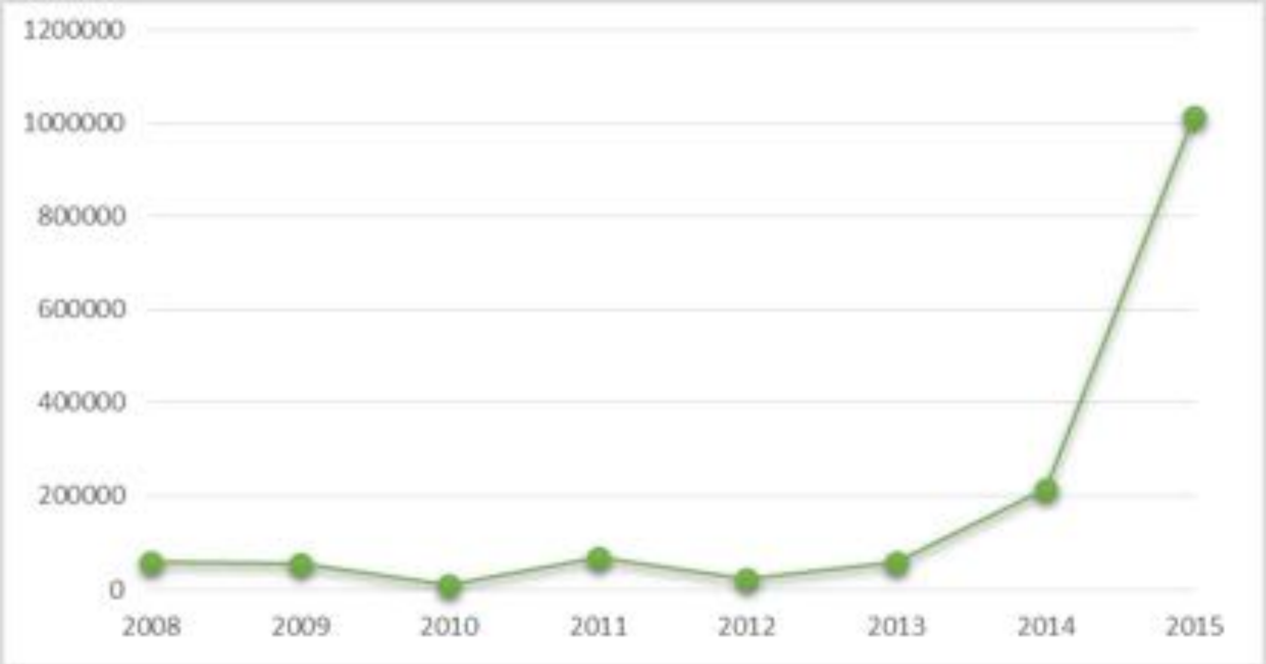


Figure 1.11 - Trend of sea arrivals to southern Europe between 2008 and 2015; since 2013 the number of Mediterranean sea arrivals has enormously increased (last update on 18th January 2016) (Source: UNHCR).

Egypt has become a more significant transit point in recent times, particularly in the case of Syrians, although Lybia continues to be the main departure point [Malakooti A. and Davin E., 2015]. An overview of the existent major routes in Mediterranean Sea is shown in Figure 1.12. In 2015, new routes towards Turkey and Greece are being exploited mainly by Middle-east people, with the result that from the beginning of 2015 Greece has experienced 887031 arrivals by sea of the 1046217 arrivals in the whole Mediterranean sea (Italy, Greece, Spain and Malta).

This tendency came out particularly in the last years, with the increasing number of Syrians migrants moving along the central Mediterranean route; as Syrians have greater economic means compared to sub-Saharans, they require for safer journeys with bigger boats for an increased price [Malakooti A. and Davin E., 2015].

Figure 1.12- Major routes in Central Mediterranean – Missing Migrants Project 2015 (source: www.missingmigrants.iom.int).

Currently, the surveillance system for migrants smuggling relies on ground-based radars, air (manned planes, helicopters and drones) and sea patrols and reports from nearby fishery vessels. However, these methods are someway limited, as they cannot see over the horizon, require good weather and daylight conditions and are subjects to constraints imposed by territorial waters. The amount of resources and time employed in these operations is considerable just to cover a small portion of the southern Mediterranean Sea. Space Shepherd proposes a novel approach to monitor, detect and track migrants' movements across Southern Mediterranean Sea; the idea is to exploit existing optical and radar satellites, which are operating for other purposes, including scientific satellites for remote sensing and commercial platforms. The use of satellites guarantees a global coverage over an extended area, thus overcoming the limits imposed by the horizon. All the collected data are integrated in a unique dedicated system, which allows to make maritime awareness activities more efficient and faster.

2 THE AIS SYSTEM

In order to implement maritime safety, security and sustainable development, several different instruments have been introduced to control and monitor the maritime traffic. The main goals of these systems are the prevention and reduction of incidents and risks for human life in the sea, for navigation and for the entire maritime environment [Russo, C., 2011]. In 1974 the *International Convention for the Safety of Life at Sea* (SOLAS)[3], imposed the member states to provide for the introduction of the *Vessel Traffic Service* (VTS), where it was legitimated by the traffic amount and the degree of risk, within the territorial waters[4] area (Figure 2.1). AVTS is a marine traffic monitoring system established by harbour or port authorities, similar to air traffic control for aircraft. Typical VTS systems uses radar, closed-circuits television (CCTV), VHF radiotelephony and automatic identification system to keep track of vessel movements and provide navigational safety in a limited geographical area.

Since 2002, the VTS is complemented by the *Automatic Identification System* (AIS), an automatic tracking system used on ships, made of a radio device operating in two channels in the maritime VHF band, which receives and transmits information with other nearby ships (*ship to ship*) and with ground based stations (*ship to shore*) for identifying and locating vessels. Originally conceived as a system aiming to avoid or limit collision risk between ships, it has developed into a maritime traffic monitoring equipment, and, thanks to the continuous update of the received and transmitted data, it revealed to be a fundamental instrument of the research and rescue activities in the sea.

---

[3] The*International Convention for the Safety of Life at Sea*(SOLAS) is an international maritime safety treaty. It ensures that ships flagged by signatory States comply with minimum safety standards in construction, equipment and operation. The SOLAS Convention in its successive forms is generally regarded as the most important of all international treaties concerning the safety of merchant ships. The first version of the treaty was passed in 1914 in response to the sinking of theRMS *Titanic*, while the most recent amendment dates from May 2011 (source: http://en.wikipedia.org/).

[4] Territorial waters limit, or aterritorial sea, as defined by the 1982*United Nations Convention on the Law of the Sea*,is a belt ofcoastalwaters extending at most 12nautical miles(22.2 km; 13.8 mi) from thebaseline(usually the mean low-water mark) of a coastal state. The territorial sea is regarded as the sovereign territory of the state, although foreign ships (both military and civilian) are allowedinnocent passagethrough it.
The other maritime zones are (source: http://en.wikipedia.org/):

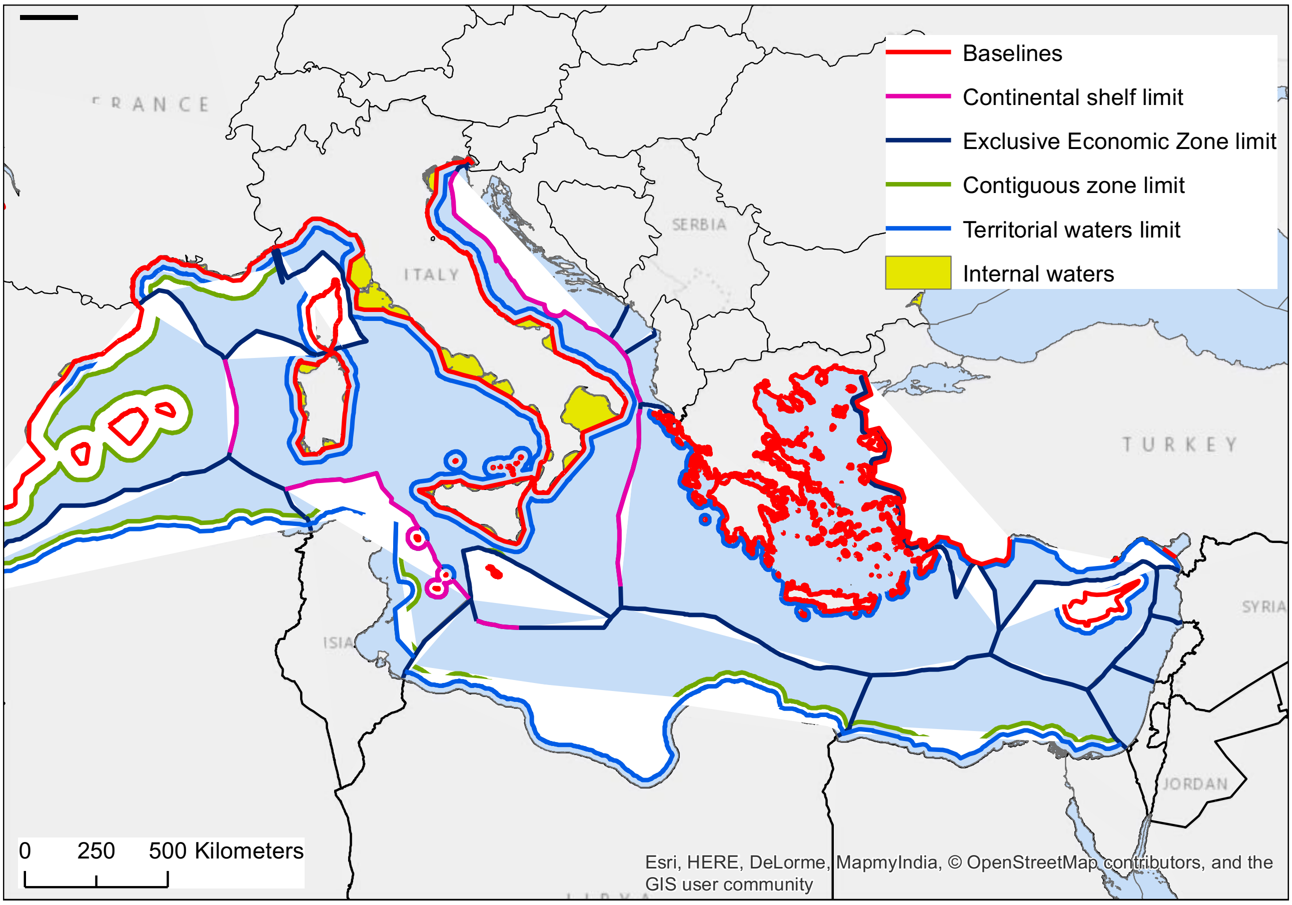
- Internal waters, waters landward of the baseline, over which the state has complete sovereignty, not even innocent passage is allowed. Lakes, rivers and all archipelagic waters within the outermost island are considered internal waters;
- TheContiguous zone, a band of water extending from the outer edge of the territorial sea to up to 24 nautical miles (44.4 km; 27.6 mi) from the baseline, within which a state can exert limited control for the purpose of preventing or punishing infringement of its regulations within its territory or territorial sea. This will typically be 12 nautical miles (22.2 km; 13.8 mi) wide, but could be more if a state has chosen to claim a territorial sea of less than 12 nautical miles, or less, if it would otherwise overlap another state’s contiguous zone. However, unlike the territorial sea, there is no standard rule for resolving such conflicts and the states in question must negotiate their own compromise;
- theExclusive economic zone, that extends from the outer limit of the territorial sea to a maximum of 200 nautical miles (370.4 km; 230.2 mi) from the territorial sea baseline, thus it includes the contiguous zone. Within this area, a coastal nation has control of all economic resources, including fishing, mining, oil exploration. However, it cannot prohibit passage above, on, or under the surface of the sea that is in compliance with the laws and regulations adopted by the coastal State;
- theContinental shelf, that extends out to the outer edge of thecontinental marginbut at least 200 nautical miles (370 km; 230 mi) from the baselines of the territorial sea. The outer limit of a country’s continental shelf shall not stretch beyond 350 nautical miles (650 km; 400 mi) of the baseline, or beyond 100 nautical miles (190 km; 120 mi) from the 2,500 metres (8,200 ft)isobath. A coastal nation has control of all resources on or under its continental shelf, living or not, but no control over any living organisms above the shelf that are beyond its exclusive economic zone. This gives it the right to conduct petroleum drilling works and lay submarine cables or pipelines in its continental shelf.

The requirements for AIS, outlined in the regulations of the SOLAS convention (IMO, 1974/1980), state that:

"AIS shall: 1. provide automatically to appropriately equipped shore stations, other ships and aircraft information, including the ship's identity, type, position, course, speed, navigational status and other safety-related information; 2. receive automatically such information from similarly fitted ships; 3. monitor and track ships; and 4. exchange data with shore-based facilities."

In addition, the *International Maritime Organization* (IMO) performance standards for AIS state:

"The AIS should be capable of providing to ships and to competent authorities, information from the ship, automatically and with the required accuracy and frequency, to facilitate accurate tracking [...]".



Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 2.1 – Maritime jurisdictions in the Mediterranean Sea (Exclusive Economic Zone 2014, Italian Baselines, Continental shelf, Contiguous Zone and Territorial Waters limits, Internal waters 2005, African Contiguous Zone and Territorial Waters limits 2006)

There exist two types of AIS systems:

- class A, an active system composed by a transmitter, used by all those ship constrained by legislation to transmit information;
- class B, a passive system composed by a receiver, used by small pleasure crafts and fishing ships, which could be interested in being aware of the surrounding maritime traffic, and it's not mandatory.

The Information exchanged between AIS devices can be grouped in static data (ship name and type, length, MMSI[5] and IMO numbers, load and type of cargo, etc.) and dynamic data (ship position, speed, heading, estimated time of arrival, departure harbour, next port of call, etc.), which are of particular interest to large-area ocean surveillance. Principal reporting intervals basing on the message type and on the ship dynamic conditions are shown in Table 2.1 and Table 2.2 [Eriksen, T., 2010].

Message type	**Description**	**Reporting interval**
Static	ship IMO number, call sign and name, length and beam, etc.	6 min
Dynamic	position, time, course over ground, speed over ground, heading, etc.	2 se to 3 min depending on dynamic conditions (see Table 2.2)
Voyage	destination, cargo type, waypoints, etc.	6 min

Table 2.1 – Class A shipborne mobile equipment message types

Shipdynamicconditions	**Reporting interval**
Ship at anchor or moored and not moving faster than 3 knots	3 min
Ship at anchor or moored and moving faster than 3 knots	10 s
Ship 0-14 knots	10 s
Ship 0-14 knots and changing course	3 1/3 s
Ship 14-23 knots	6 s
Ship 14-23 knots and changing course	2 s
Ship> 23 knots	2 s
Ship > 23 knots and changing course	2 s

Table 2.2 – Class A shipborne mobile equipment reporting intervals for dynamic messages

2.1 JURIDICAL BACKGROUND

The referential legislation is structured in different levels, from an international to a national one, with the resulting necessity to coordinate all the regulation having different origin [Russo, C., 2011].

The first mandate for the use of AIS equipment dates back to 2002, when the IMO SOLAS published an agreement which included a mandate requiring most vessels over 300GT on international voyages to fit a Class A type AIS transceiver; this operation affected approximately 100,000 vessels.

---

[5] A*Maritime Mobile Service Identity*(MMSI) is a nine digits number transmitted in digital form through aradio frequencychannel in order to uniquely identify ship stations, shipearth stations, coast stations, coast earth stations, and group calls (source: http://en.wikipedia.org/).

The juridical foundation of the AIS system is the *Montego Bay United Nations Convention* of 10 December 1982 on the Law of the Sea, which defined the rights and responsibilities of nations with respect to their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marinenatural resources. However, it was in 2004 that the SOLAS International Convention made the AIS system mandatory on specific ships according to dimension and tonnage criteria (vessels with a gross tonnage of 300 tons assigned to international travels, merchant ships with a tonnage of 500 tons which don't execute international travels, and passengers ships, independently from their dimensions).

In the European context, the directive 2002/59/CE, related to the creation of a common monitoring and informative system of naval traffic, made the AIS instruments mandatory on vessels with a gross tonnage higher than 300 tons, except for war ships, fishing ships[6] and pleasure crafts with a length lower than 45 meters.

In the Italian context, the legislative decree n. 196 of 19 August 2005 adopts the European Directive. Concerning the AIS system, this decree stated that its installation is mandatory for:

- passenger vessels, independently from their size, and all other vessels with a gross tonnage of 300 tons or more, built in 1st July 2002 and later, which dock in a harbour of a European Community member state;
- passenger vessels, independently from their size, and all other vessels with a gross tonnage of 300 tons or more built before 1st July 2002, which dock in a harbour of a European Community member state, by 1st July 2005.

After the publication of the directive 2009/17/CE, also in Italy the legislative decree of 2005 has been overcame by a new one, the legislative decree n. 18 of 16February 2011. It extended the AIS system installation commitment also to every fishing vessel longer than 15 meters and carrying any flag, operating in internal or territorial waters, or that unload in a national harbour. It furthermore asserted the compulsoriness for all fishing vessels to keep the AIS system working during navigation, unless the Captain considers its deactivation necessary for the ship security. Indeed, the AIS system should always be working, but can be disabled, prior annotation on the log book, if its continuous operation could threaten navigation security (for example in areas subjected to piracy). It should not be forgot that AIS is an "open" system and data can be exchanged among all vessels having suitable receiving instruments and can, eventually, be intercepted by unauthorized ground stations.

A new extension of the previous law was published in Italy, on 23rd July 2012 with a ministerial decree, stating that the AIS system was mandatory for passenger vessels, independently from their size, and all other ships with a gross tonnage higher than 300 tons operating or not on international routes and docking in a harbour of a European Community member state.

---

[6] The exception concerning fishing ships has been overcome by the European Parliament directive 2009/17/CE which, considering the high number of collision events that involved fishing ships, extended the use of AIS system also to all those fishing ships longer than 15 meters.

Concerning the exemptions from the commitment to install an AIS system, the European Directive states that member states can dispense from this obligation passenger vessels smaller than 15 meters, or with a gross tonnage lower than 300 ton, operating on national routes and all other vessel ships with a gross tonnage in a range of 300-500 tons operating exclusively in the internal waters of a member state and outside the routes normally used by vessels provided with an AIS system.

In Italy, passenger vessels with a gross tonnage lower than 150 ton, enabled to:

- National navigation limited to calm waters (during summer, day-time, with a good visibility) farther than a mile from the coast, within the Maritime District[7] limits;
- National navigation, within a mile from the coast, during day-time.

are dispensed from the installation of this system. In addition, the Italian law provides for a financial penalty in case of non-compliance of the rules.

A summary of three different (global, European and Italian) levels in legislation is reported in Table 2.3.

2.2 SAT-AIS

In 2004, the Norwegian Defence Research Establishment (FFI) undertook studies to evaluate if the AIS signals could be detected in Low Earth Orbit (LEO). Since then, the interest in space-based AIS reception has grown significantly, and both public and private sector organizations had established programs to study the issue and demonstrate such a capability in orbit. The first program of the FFI was a nano-satellite equipped with an AIS receiver into a near polar orbit to demonstrate space-based AIS reception [Eriksen, T.*et al.*, 2010]. This satellite, called AISSat-1, was successfully launched on 12th July 2010.

The satellite transmission made possible to overcome the local constraints related to the VHF range and provided global coverage/vision through a system known as "SatAIS". AIS signals sent from the land-based stations have a range of 40 nautical miles (75-110 km), while a satellite-based AIS system will increase this range to cover larger ocean areas, thus making it easier to monitor those areas which were difficult to monitor with the land-based AIS network [Hannevik, T.N., et al., 2010].

The advantages of SatAIS are clearly the following:

1. Complete global coverage and worldwide monitoring;
2. Vessel tracking from berth to berth;
3. Availability in areas without land-based means of vessel detection [Brusch, S. et al., 2022].

Moreover, SatAIS information can be easily correlated with additional information from other sources, such as radar, optical, and more SAR related tools, enabling the end-user to rapidly identify all types of vessel.

Later, on 8th July 2014 AISSat-2 was lunched and an AISSat-3 mission is programmed for July 2015.

---

[7] The Maritime District (Circondario Marittimo) is an administrative division of the Italian littoral zone; it is usually located in a minor harbour and it is ruled by the port authority.

<table>
<tr><th colspan="3">Duties</th></tr>
<tr><td rowspan="2">World</td><td>1982</td><td>IMO (<i>International Maritime Organization)</i>SOLAS (<i>International Convention for the Safety of Life at Sea)</i> required vessels over 300GT on international voyages to fit a Class A type AIS transceiver (this operation affected approximately 100000 vessels)</td></tr>
<tr><td>2004</td><td>SOLAS made the AIS system mandatory on vessels with a gross tonnage of 300 tons assigned to international travels, merchant ships with a tonnage of 500 tons which don't execute international travels, and passengers ships, independently from their dimensions</td></tr>
<tr><td rowspan="2">Europe</td><td>Directive 2002/59/CE</td><td>AIS instruments is mandatory on vessels with a gross tonnage higher than 300 tons, except for war ships, fishing ships and pleasure crafts with a length lower than 45 meters</td></tr>
<tr><td>Directive 2009/17/CE</td><td>Extended the use of AIS system also to all those fishing ships longer than 15 meters</td></tr>
<tr><td rowspan="3">Italy</td><td>Leg. Decree n. 196 of 19/08/2005</td><td>The AIS system is mandatory for:
- passenger vessels, independently from their size, and all other vessels with a gross tonnage of 300 tons or more, built in 1st July 2002 and later, which dock in a harbour of a European Community member state;
- passenger vessels, independently from their size, and all other vessels with a gross tonnage of 300 tons or more built before 1st July 2002, which dock in a harbour of a European Community member state, by 1st July 2005</td></tr>
<tr><td>Leg. Decree n. 18 of 16/02/2011</td><td>Extended the AIS system installation commitment also to every fishing vessel longer than 15 meters and carrying any flag, operating in internal or territorial waters, or that unload in a national harbour;
the AIS system should always be working during navigation, unless the Captain considers its deactivation necessary for the ship security</td></tr>
<tr><td>Min. Decree of 23/07/2012</td><td>The AIS system is mandatory for passenger vessels, independently from their size, and all other ships with a gross tonnage higher than 300 tons operating or not on international routes and docking in a harbour of a European Community member state</td></tr>
<tr><th colspan="3">Exemptions</th></tr>
<tr><td>Europe</td><td colspan="2">Passenger vessels smaller than 15 meters, or with a gross tonnage lower than 300 ton, operating on national routes and all other vessel ships with a gross tonnage in a range of 300-500 tons operating exclusively in the internal waters of a member state and outside the routes normally used by vessels provided with an AIS system.</td></tr>
<tr><td>Italy</td><td colspan="2">Passenger vessels with a gross tonnage lower than 150 ton, enabled to:
- national navigation limited to calm waters (during summer, day-time, with a good visibility) farther than a mile from the coast, within the Maritime District limits;
- national navigation, within a mile from the coast, during day-time.</td></tr>
</table>

Table 2.3 - Brief summary of the three different (global, european and italian) levels in legislation, concerning duties and exemptions.

3 OBSERVATIONS SCHEDULING

To date, the humanitarian emergency is faced with a surveillance system that relies on ground-based information, air/sea patrols, and fishery/commercial vessels reports. This approach has technical limitations that constrain the maximum acquisition range and reduce their effectiveness under night/adverse weather conditions. Patrols also have to respect the boundaries imposed by national water, thus limiting their area of operation and their visual (and instrumental) horizon is limited to (at best) tens of kilometers. Consequently, the monitoring of a limited sea area (the Strait of Sicily) involves a considerable amount of men and means.

Earth Observation Satellites have been successfully used in multiple scientific applications, ranging from environmental monitoring, to meteorology or map-making [Norris, 2008]. Over the last years, their performances (most notably the resolution per pixel and the delivery time) have been progressively improved, enabling many commercial and scientific satellites to effectively operate as reconnaissance satellite. Their applications, leaving aside dual-purpose military operators, include disaster monitoring, human right enforcement, border safety, and environment protection.

Monitoring immigrant flows across the Mediterranean Sea is another potential application for satellite surveillance. Satellites are not constrained by national boundaries and can operate even in adverse weather conditions. This comes at a price: satellites are not operated in real time and the gathered information can only be accessed with a delay. Furthermore the costs associated to their construction, launch, and operation make them high-value assets, limiting the number of deployed units. Satellite surveillance has the potential to cover large areas avoiding some (and in some cases all) of the limitations that affect conventional techniques [Policella, Oliveira and Benzi (2013)], If a method to plan in advance the acquisitions, according to the operative conditions is developed.

The idea is to use already existing satellites to remotely monitor the southern Mediterranean Sea, to detect and track migrant vessels, and to support the search-and-rescue operations. The ultimate aim is to report to the authorities the situational awareness in the Southern Mediterranean Sea. A pivotal point in the accomplishment of the aforementioned objectives is the capacity to schedule the satellite observations in order to maximize the covered area while minimizing the effort. When the event of interest is not localized over a specific spot, but is spread across a whole geographical region, the timing and spacing of the observation become important. The Mediterranean Sea is about 2.5 million km^2; even bounding the region of interest (for immigrants monitoring) to its Eastern Basin, the surface to be observed is still approximately 2200x750 km (1.65 million km^2). A satellite during a passage can cover only a minimum percent of this region: here the importance of scheduling the observations. Additional constraints are dictated by the delays both in commands upload and images download and process. Overall sea coverage is integrated with reconnaissance of definite locations, like known departure harbors or identified vessels under tracking.

The Space Shepherd project's aim is to assess the effectiveness of a Sea monitoring system tailored to identify and track the vessels used by migrant's smugglers and based on existing scientific/commercial Earth Observation satellites. The fundamental concept is to exploit high and medium resolution imagery of the Mediterranean Sea and the North Africa shoreline to search for possible vessels; the achieved candidate ships are then compared with the real time database of the registered commercial, fishery and privately owned vessels, looking for unknown entries. The characteristics of the non-identified vessels are reported to the competent authorities and further analyzed and monitored using the other satellites. In fact, once that the position and the route of the vessel are known, it is possible to observe its progress by scheduling the acquisitions along its path.

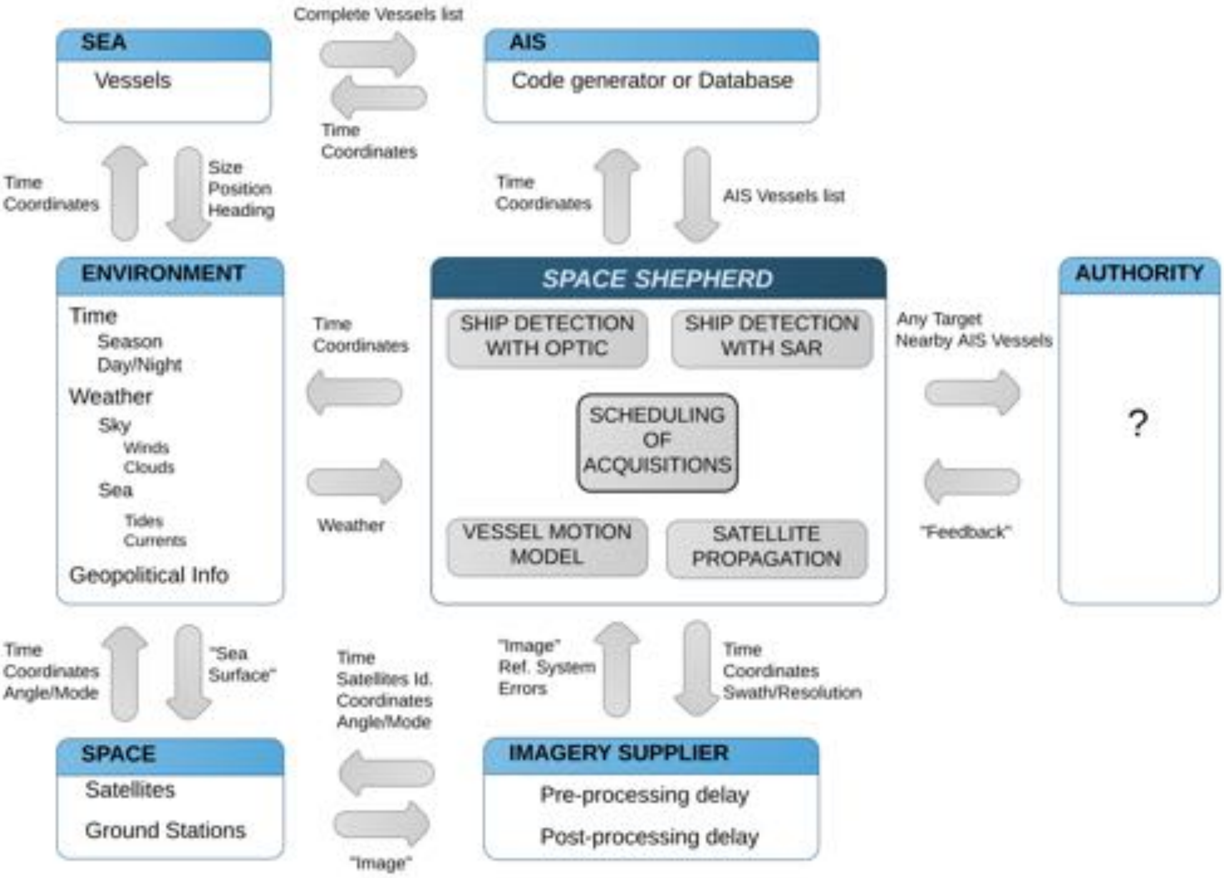


Figure 3-1: Simulator Framework.

One of the key points in order to accomplish the project objective is the development of a planning strategy to establish when and where the satellites should be operational. Several aspects have to be considered, ranging from vessels features to satellite orbits, sensors type and environmental conditions. The effectiveness of the surveillance has been addressed by creating a dedicated framework, whose structure is summarized in Figure 3-1 where the developed methodologies could have been tested; it can be broadly divided into two main classes of elements: the Space Shepherd software and a collection of modules whose aim is to reproduce the environment where Space Shepherd will operate. The concept is to replace the real world with artificial entities based on realistic features; these include known and unknown vessels, weather and sea conditions, authorities, satellites and the image provider companies.

The main task of the simulation is to test the project by realistically reproduce satellites should be operational. Several aspects have to be considered, ranging from vessels features to satellite orbits, sensors type and environmental conditions. The effectiveness of the surveillance has been addressed by creating a dedicated framework, whose structure is summarized in Figure 3-1 where the developed methodologies could have been tested; it can be broadly divided into two main classes of elements: the Space Shepherd software and a collection of modules whose aim is to reproduce the environment where Space Shepherd will operate. The concept is to replace the real world with artificial entities based on realistic features; these include known and unknown vessels, weather and sea conditions, authorities, satellites and the image provider companies.

The main task of the simulation is to test the project by realistically reproducing its foreseen operative conditions whether they are man-driven or not. The Space Shepherd software mimics the same features provided by the simulator but with a lesser degree of accuracy and with possible discrepancies and errors due to being designed with different aims: simulation modules reproduce the phenomena in order to behave the "real" world whereas their Space Shepherd counterparts model them. As an example, within the simulation framework position and motion of the vessels are known, but Space Shepherd has to estimate them using the available data/observations.

Thanks to satellites orbit propagation (thus their position function of time) is possible to evaluate both their capacity to communicate with the Ground Stations and to acquire images of specific areas. Consequently, coverage, revisit (two observations of the same vessel), cycle times (time to perform a command uplink, image acquisition and data downlink) and response times (average time to complete a cycle starting from a random time of the day) can be determined. Space Shepherd has been designed to work into different operative modes, each one with its own dedicated scheduling algorithms and tailored objectives.

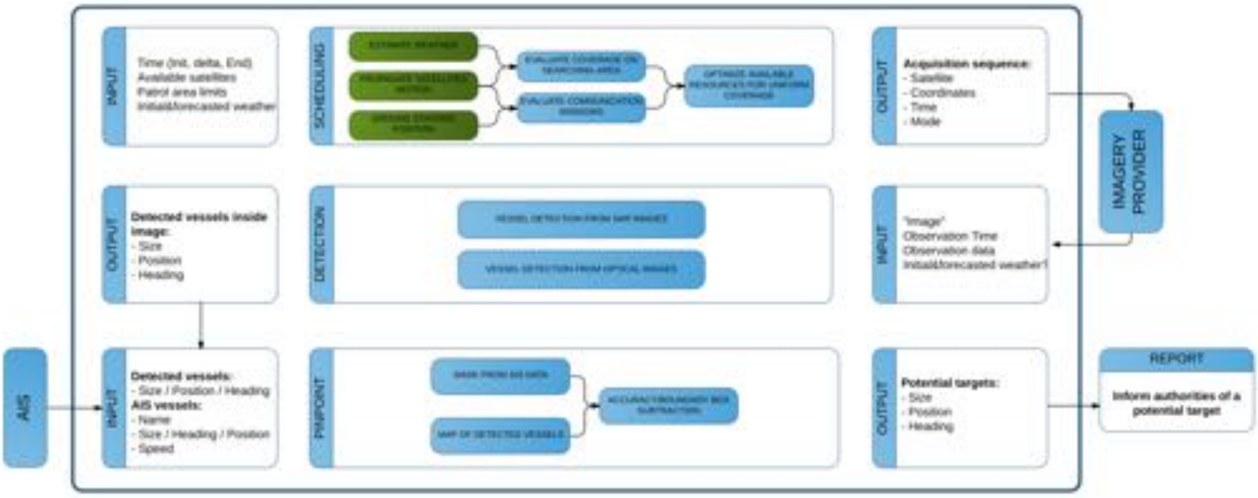


Figure 3-2: Monitoring procedure outline.

The rationale behind the distinction between monitoring (Figure 3-2) and tracking (Figure 3-3) arises from the analysis of the current activities performed by the law enforcement units and the evaluation of the different capacities of SAR and optical satellites. The former can operate (almost) regardless of the weather and light conditions whereas the latter, although subjected to environmental constrains (daylight, cloud-free sky), allow for higher resolutions. From the monitoring and tracking scheme can be observed that the scheduling is only a component of an extended procedure that also includes algorithms to process the images according to their source (SAR or optic) [Topputo et al. (2015-2)] and has interfaces with the "real" world (elements outside the blue frame are in fact part of the simulation framework). Both modes share the same general outline; a set of initial data defines the simulated scenario and is then elaborated to generate an acquisition plan that specifies used satellites, time, sensors mode and orientation.

The plan should then be passed over the companies or institutions that have the control over the required satellites and can provide the observation services. Images are then processed and the resulting ships are compared with the database. In the monitoring mode, no further iterations are needed; the candidate vessels are simply reported to the authorities, whereas during tracking operations, the updated information is used to adjust the original plan. Monitoring operations can be further divided into Sea and Ports monitoring; the former address the necessity to observe a specified region of the Sea providing the largest possible total coverage. The latter has been designed as a surveillance mean to spot vessels while still in port of close to the coast in known rally points. Due to the different objectives, the 2 monitoring operations have to be performed using different technologies; spot moving vessels in open waters could be done with medium resolution sensors (up to several meters, depending on the size of the vessels) but requires larger swaths to maximize the observed area.

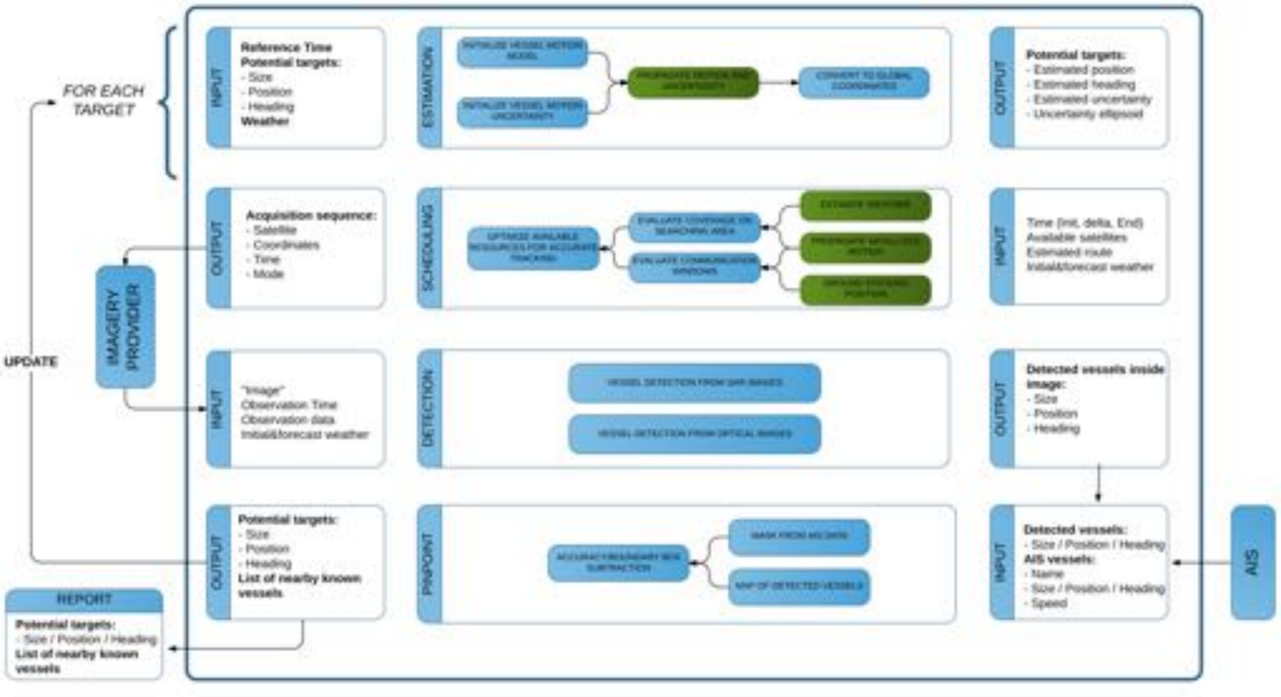


Figure 3-3: Tracking procedure outline.

On the contrary, the resolution has to be higher close to the coastline, where the presence of multiple vessels, rock-cliffs, breaking waves and man-made structures could alter the detection of the vessels; the drawback is the reduced geographical region covered with a single observation.

Tracking mode shares some of the requirements from the ports monitoring: it needs a resolution high enough to compare the observed vessels to confirm the match. However due to the limited extension covered by the sensor, the vessel position have to be estimated as accurately as possible, given the available information before the acquisitions are actually planned. Several scientific and dual use SAR-based satellites are currently operational. Each has specific performances and operative modes that could broadly be grouped into 3 main categories: spot (highest resolution, minimum covered area), strips (average resolution, average covered area, typically a rectangle oriented alongside the satellite projected velocity, up to 50-100 km in width and hundreds of km in length) and scan (lowest resolution, wider covered area). Remote sensing companies mainly rely on optical satellite to acquire high-quality, map-accurate, high-resolution imagery of the Earth surface; these sensors (essentially telescopes with digital cameras) can operate at much higher resolution than SAR sensors (down to .3 pixel/m) over smaller areas (<5x5 km).

	SAR	**Optic**
Italy	CSK 1 to 4	
Italy & France	CSK 1 to 4	Pleiades 1-A, 1-B, Spot 5 to 7
Copernicus	CSK 1 to 4, Sentinel-1A	Pleiades 1-A, 1-B, Spot 5 to 7
	RadarSat-2, TerraSAR-X	Deimos 2, Sentinel-2A

Table 3-1: Used satellites groups.

An a priori analysis of the currently operational Earth Monitoring satellites has been conducted to evaluate the number of (possibly) available assets, along with their performances and limitations (both technical and political). Different sets of satellites, summarized in table 3-1, have been introduced into a simulation framework (that also includes known and unknown vessels with realistic size and speed) and their capacity to locate, identify and track the vessels has been evaluated and compared. Sensors (type and performances) and satellites orbit are the main inputs used to assemble the observation scheduling problem. However, as in the real world, the performances of a satellite system are not just affected by its orbit and design; its ground segment determines how frequently commands can be sent and data downloaded, thus command center and communication links have been simulated and considered too [Vallado (2001)]. Finally weather and lighting conditions have been included.

3.1 PROBLEM FORMULATION

Maritime surveillance using satellites must face several main obstacles in order to candidate itself as an efficient monitoring technique. Spacecraft are not free to move as their orbits are predefined, thus the regions that they cover are known in advance and cannot be changed (without considerable efforts).

Furthermore, current sensors technology allows medium and high resolution imagery only from LEO satellites, typically placed on Sun-synchronous orbits, resulting in 1-2 passages per day over or in the proximity of a given target. Moreover, the area that they are able to acquire during a passage is a fraction of the nominal sensors range. Finally collected data have to be downloaded and processed; ground station visibility is the key aspect in determining how often the data can be received. A few, or poorly placed, stations could result in delays up to 24 hours. The combined effect of physical and technological constraints limits the effectiveness of a satellite as maritime surveillance platform unless it is integrated into a larger network that has both multiple satellites and ground stations around the globe. Still, increasing the number of the satellites is not enough unless their operations are coordinated in order to ensure a distributed coverage, thus avoiding multiple passages over the same area while leaving blind spots. Scientific and commercial satellites orbit are public and periodically maintained in order not to drift due to perturbations; orbital parameters can be propagated to evaluate with a reasonable degree of accuracy [Vallado, Crawford, Hujsak and Kelso (2006)] the position of the satellite at a given time. The information on the orbit combined with the sensor features allow to determine the boundary φ, λ of the quadrilateral $o = f(t; satellite; sensor)$ of the Earth surface observed during a passage. The N satellites passages within the geographical and temporal domain of interest define the set of observations O. Due to the inherent complexity and cost of orbital maneuvers, observation satellites are rarely ordered to modify their trajectories once they have reached the operative status. Acquisitions are performed when the target is visible by the sensors, thus allowing for the natural evolution of the satellite ground track to drift until the target is in sight.

Satellite orbit is not a control parameter, whereas orientation of the sensors and acquisition time can be changed by the control center. In order to maximize the efficiency of the system, an optimization algorithm has been used to find the combination of observations that, within assigned operative constraints depending on the surveillance mode, would have granted for the highest coverage, thus possibly avoiding unnecessary use of the satellites, multiple observations of the same area or missed high value targets.

3.2 MONITORING OF SEA

SAR-based satellites have the capacity to cover large stripes of sea on both sides of their flight direction within a minimum and maximum elevation, thus they have been preferred for this task [Curlander and McDonough (1991)]. The width of the swaths depends, from an operative point of view, on minimum size of the vessel of interest on. The resolution (and consequently the swath) have to be changed in order to have at least 4 pixels per boat [Topputo et al. (2015-1),]. Ship size has been considered an input, based on the available information regarding the vessels used by immigrants' smugglers. The regions of interest of Mediterranean Sea surface have been discretized into a map M with specific cost values $v = f(\varphi; \lambda)$ assigned to each tile (element) or group of tiles according to a priority concept, thus making a distinction between more interesting (due the available information on the immigration phenomena) and non-primary zones, Figure 3-5. The aim is to concentrate the satellites observations in well-defined areas; to this end, passages over more valuable zones have to be preferred. The size of the tiles is bounded to the width of the sensor stripes; a tradeoff between accuracy and computational times has been evaluated. The elements are squared and the length of the side is equal to ¼ of the width of the sensor swath. Within the limit of the observation o, each satellite is able to acquire a single swath (that represents a subset of the full elevation range) s and, in order to avoid complex commands and maneuvers, the minimum and maximum elevation of the sensor beam during the acquisition have been considered constant, see Figire 3-4. This is coherent with typical SAR operation modes, where beams are used to vary between specified ranges. This simplification also allow for a reduction of the possible solutions in the optimization problem, as the maximum width and the nominal sensor range determine the total number of possible stripes (z) within each observation o.

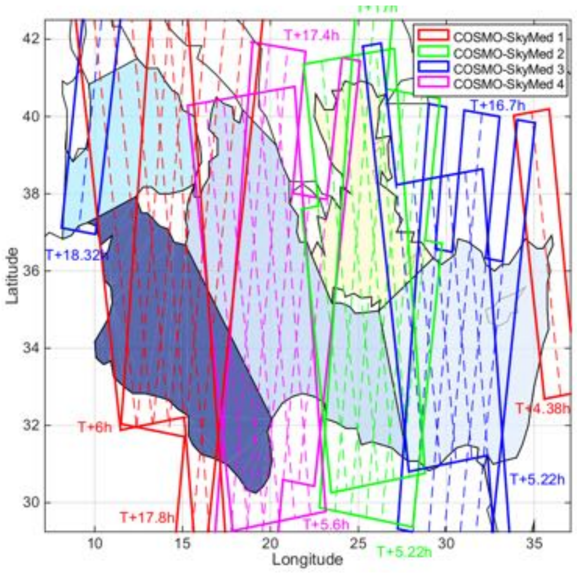


Figure 3-4: Monitoring, Mediterranean Areas and Swaths division. Dashed lines mark the internal division of the full sensor range into candidate swaths.

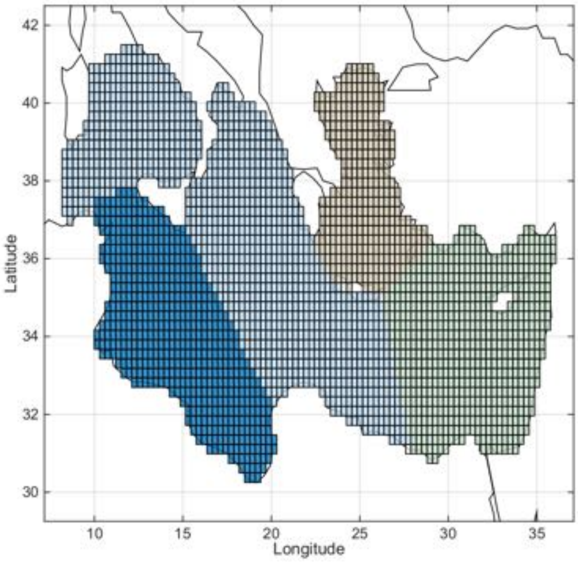


Figure 3-5: Map M; elements size is 25 km.

The subset of M within the sensor range during observation s is m and is composed of n tiles; $t_{i,j}$ is the denotation for the j-th tile of stripe i. The cost, or fitness, value associated to the tiles has been used to evaluate the fitness of a swath as the sum of the value of the covered tiles $f_i = \sum_{j=1}^{n} v(\varphi(t_{i,j}), \gamma(t_{i,j}))$.

The fitness value has not been normalized over n (total value has been used instead of the average) to favor long, continuous passages. Finally the fitness of all the satellite observations S can be evaluated as the sum of the value of all the passages with the fitness associated to multiple-observed tiles counted only once, that is equivalent to sum the fitness of all the observed tiles.

The search for the set of satellite observations S that maximize the total fitness is a combinatorial optimization problem (a problem in which the set of feasible solutions is discrete or can be reduced to discrete, and in which the goal is to find the best solution). Ggrid search is feasible but as the length of the reference timeframe increases, this approach is unpractical [Schrijver, A. (2003)]. In principle, any sort of search algorithm or meta-heuristic can be used to solve the problem. Among the possible solvers, genetic search algorithms (GA) have been adopted thanks to their straightforward implementation and adaptability. The drawback is that they are neither guaranteed to find an optimal solution, nor are they guaranteed to run in polynomial The optimization variable x is a boolean vector that determines whether or not a stripe is used; its size time [Steiglitz, C. H. (1998)] depends both on the number of observations (function of the length of the timeframe and the simulated satellites) and how tight are the swaths. For a single day simulation involving the 4 COSMO-SkyMeds searching for 30 m vessels, is around 40. The number of possible solution can be estimated through [D. Zwillinger, 2003] leading to approximately 800 millions of possible solutions.

The cost function to be minimized is the ratio between the total value of the mapped area and the evaluated fitness, $MinFun = \frac{\sum_M v}{F+1}$ where the +1 is to avoid to divide by 0 when a null solution is proposed.

3.3 MONITORING OF HARBORS

Ports and immigrants staging areas can be considered fixed, well defined targets where the higher resolution of optical sensors would be of great aid in the identification of the ships and their analysis. Pinpoint SAR modes could be used for the task, however due to the limited number of active radar satellites, those resources have been assumed as dedicated to sea monitoring. Optical satellites suffer from additional operative constrains; unlike SAR, they cannot operate without a source of light or clear sky. Planning the acquisitions of the optical satellites has been addressed evaluating the possible passages over the target including simulated weather forecast and visual conditions.

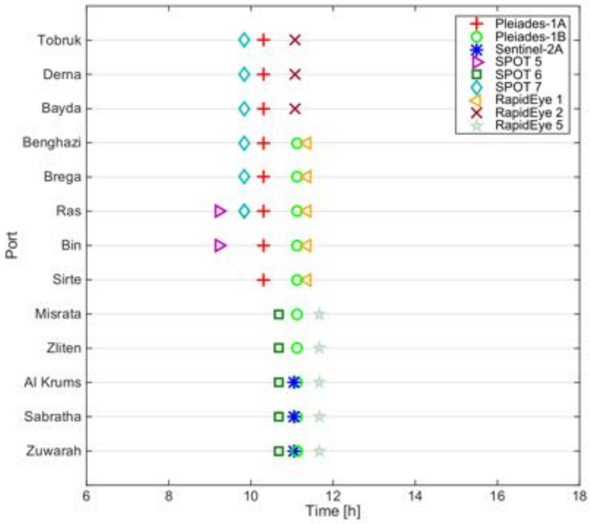


Figure 3-6: Targets visibility

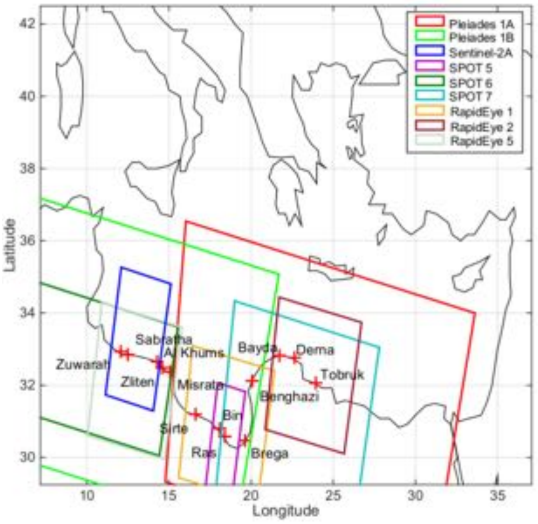


Figure 3-7: Optical satellites sensor range compared with candidate costal targets

Similarly to the SAR nominal-sensor-range/swath distinction, optical satellites can acquire a limited portion of their nominal envelope [J. B. Campbell (2002)](Figure 3-7). The nominally covered area usually contains more than one target, however in order to observe more than one spot per passage additional maneuvers would be necessary. This has been avoided imposing a one-target-per passage. The x vector establishes if a specific satellite-target couple is exploited, thus its size is $n = \sum_{i=1}^{n_{satellites}} p_i$ where p_i is the number of targets observed during the i-th passage of the satellite set. Ports and other locations have been associated to a numerical value p according to a priority list, evaluated according to a hypothetical (due to lack of bibliography) probability distribution of the smuggler vessels (normalized); the higher the value, the higher the chance to observe an unregistered vessel. The scheduling has been performed applying the GA to find the combination of observation that is associated to the highest score, evaluated as the sum of the value of the observed targets. In the determination of the total fitness of each proposed solution, multiple observations are discarded and only the first one is accounted for:

$$F_{ports} = \sum_{i=1}^{N} v(target_i)\,\delta_i \begin{cases} \delta_i = 1\; if\; target_i \neq\; target_j\, \forall j =\; \{1, \dots, i-1\} \\ \delta_i = 0\; otherwise \end{cases}$$

The actual function to be minimized is the inverse of the total fitness normalized over the number of observations.

3.4 TRACKING

Vessel tracking can be considered a dynamic version of the ports monitoring problem; optical satellites are used and each target has a fixed fitness value; the elements of a set T of targets are moving from known initial positions with a given (estimated) route and speed. The planner has to organize the observations in order to acquire the sea region where the vessels are expected to be according to the available data. The mean point of the probability distribution has been considered as the location to be observed. The main problem is the evaluation of the future position of the vessels, both due to limited and unpredictable accuracy of the initial conditions (the ship could have been observed with a binocular from commercial vessel, thus resulting in value indications or followed by a land radar, leading to an accurate estimation of its status) and to the human factor (low reliability of the vessels, arguable nautical experience of the smugglers). The latter aspects can hardly be modeled and considered whereas, in order to take into account at least the inaccuracies in the measurements, a simple 2D mathematical model of the ship motion has been used within the time-discrete, Extended Kalman Filter (EKF) algorithm [S. Thrun, W. B. (2003), Perez, T. I. (2009)].

From an operative prospective, the planner is the same used for the ports, the only difference is the estimation of the satellite-target relationships. Ship position is evaluated using the previous information and the EKF at the time of the satellite passage, thus determining the conditions of the possible observation (lighting, meteorological, perspective). An example of satellites-targets couplings for a test case has been provided in Figure 3-6. Figure 3-7 reports the different estimated positions for the same vessels due to different observation times; differences are mostly minimal as imaging satellites have similar orbit to exploit the best lighting conditions (see also Figure 3-6Figure 3-6, all the passages are concentrated in a 2 hours window), resulting in passages at around the same time. This, combined with the vessels low speed, results in similar propagated positions. Apart from the initial setup, the problem formulation used for the vessels tracking is identical to the harbor monitoring one.

Tracking have been subjected to post-processing that has not been used during the monitoring phase; due to partially unpredictable motion of the vessels, updated data are used to improve and redefine the route of the targets. Thanks to the updates evaluation of the ships position and route, their closest approaches with commercial vessels have been calculated. A simple geometric approach has been used; cargo and fishery vessels must have an AIS device that reports every few seconds their identification, position course and speed, thus their routes can be considered as known variables.

4 SHIP DETECTION

4.1 STATE OF THE ART OF SHIP DETECTION IN OPTICAL REMOTELY SENSED IMAGES

Since the beginning of the nineteenth century, ship detection has been a topic of interest, initially with the goal of collision avoidance. Recently, existing satellites for earth observation can provide access to global imagery with repeating coverage from few days to several weeks; under these conditions, the use of commercial satellites to monitor maritime activities become feasible [Mallas, P.A. and Graber, H.C., 2013]. Since the launch of ERS-1 in 1991 the problem of ship detection has been intensively studied, but, in most cases, the methods rely on Synthetic Aperture Radar (SAR) images [Greidanus, H. et al., 2004]. The well-known advantage of radar data is that they are much less influenced by atmospherical weather conditions than optical data and can be collected night and day. However, they are characterized by a high level of noise and are sensitive to sea surface state, thus producing clutter background, which tends to obscure smaller ships and create false alarm [Kourti, N. et al., 2005]. In SAR imagery also incidence angle, polarization and orientation of the ship respect to the sensor can play a role in vessel detection rates [Greidanus, H. et al., 2004]. All these factors summed up with lower spatial resolution, make SAR images visual interpretation difficult [Proia, N. and Page, V., 2010]. On the other and, Electro-Optical sensors have some shortcomings: clouds can obscure the field of view, sunlight is required to make observations and high-resolution optical systems have limited swaths. In contrast to detection, classification of ships in satellite radar imagery is much less developed [Greidanus, H., 2005]. Since optical imagery offer spectral information, they have better potential for identifying and classifying ships as they are more easily interpreted, and allows the detection of vessels made of low radar-scattering materials such as wood or fiberglass [Mallas, P.A. and Graber, H.C., 2013]. Moreover, current spatial resolutions permit the detection of very small targets [Proia, N. and Page, V., 2010], allowing for a more accurate dimension estimation [Bouma, H. et al., 2013], and the improved temporal resolution produced by the growth in the number of small optical satellite missions, enables frequent monitoring of the same areas [Kanjir U. et al., 2014]. However, factors such as different reflectivity of sea waves, complicated sea surfaces, weather, solar angle and imaging sensors, bring great variations in image intensity and contrast between foreground and background [Huang,G. et al., 2011]. Classical spatial threshold-based segmentation methods are suitable for the situations with smooth sea surface and high contrast between ship targets and sea background; furthermore, it is difficult to automatically select a suitable threshold when there exist illumination changes and bright and dark ship targets [Huang, G. et al., 2011].

Although little research has been conducted on the use of EO sensors for ship detection respect to radar data, it has become a topic of recent interest [Mallas, P.A. and Graber, H.C., 2013] and several methods have been presented in recent literature.

Existing ship detection techniques can be roughly divided into three categories: the first makes use of neural networks, the second is based on the analysis of the sea state even investigating spectral properties of features in the image, while the third is more concentrated on texture and geometrical features of the images.

Starting from their pre-works which describe genetic algorithms and neural networks [Corbane, C. et al., 2008a; Corbane, C. et al., 2008b], already defined by [Lure and Rau 1994], CorbaneC. et al. 2010 proposed a complete processing chain to detect small ships from 5-m resolution SPOT-5 panchromatic images. Targets are preliminarly detected by morphological filtering based on connected operators and automatic threshold, which allows to better distinguish ships from the background; a post-processing phase allows to eliminate false candidates through Wavelet analysis and Radon transform. Respect to neural networks, which generates a high number of false alarm in high sea clutter situations, this method achieve better detection performances with the price of high computational complexity [Tang, J. et al., 2015]. The same technique based on component tree is applied in [Saur, G. et al., 2012] over RapidEye multispectral images, but post-processing is done separately for each object; edge detection is performed through Canny algorithm followed by Hough transform to have indications if the object is a ship. Neural Networks technique is also used within ship detection methods in compressed domains (JPEG 2000 images) [Tang, J.et al., 2015]. Mathematical morphology is also used for ship detection in a QuickBird pachromatic image through Rank-Order Grayscale Hit-or-Miss transforms, which is able to reduce false alarms [Harvey, N.R. et al., 2010].

[Bouma, H.et al. 2013] proposed a method for segmentation of seafaring vessels in high resolution optical satellite images, based on foreground-background separation, ship-wake separation through statistical considerations. Dekker R. et al. [Dekker, R. et al., 2013] reported a ship detection method based on an algorithm which is usually applied to SAR imagery and which aims to discriminate between vessels and their background, the CFAR. In [Buck, H. et al., 2015] background is characterized as black (lower sea states) or gray texture (higher sea state) according to pixel intensity, and ship detection is performed in two different methods; a combination of threshold selection and Canny edge extraction for black background images, and a Fourier transform for gray background images. Proia N. and Pagé V. [Proia, N. and Pagè, V., 2010] proposed an automatic ship detection method to identify small targets based on Bayesian decision theory over 5-m resolution panchromatic SPOT-5 images. They assumed Gaussian distribution of the sea background density function and they detected ships by choosing the most likely result using Bayesian decision theory. Jubelin G. and Khenchaf A. [Jubelin, G. and Khenchaf, A., 2012] tested six known distributions to model sea clutter in panchromatic high resolution images acquired by different sensors (SPOT4, SPOT5, Formosat-2, Kompsat-2 having resolutions respectively of 10, 5, 2 and 1 m). The Kolmogorov-Smirnov test and the analysis of the sum of squared residuals provided by the least squares estimation proved the alpha-stable distribution to be the best model for sea clutter. Performances of ship detection methods, which take sea surface into consideration, are easily affected by the variation of illumination and sea surface conditions [Yang G. et al 2014]. Therefore, Guang Y. et al. 2011 proposed a ship detection method to reduce the influence of sea surface state, thus reducing the number of false alarms produced by waves. A sea state analysis is performed over real optical images (12-m and 10-m panchromatic images obtained from Google Earth, 5-m SPOT5 panchromatic images, 0.61-m QuickBird panchromatic images) and an appropriate detection algorithm is used to detect ships basing on the assumption that ships are anomalies on homogeneous sea surface. An improvement of this method has been retrieved by Yang G. et al 2014 over 5-m SPOT5 panchromatic images. Sea state is analyzedthrough an indexwhich describes sea homogeneity basing on pixel intensity; high values of this index corresponds to homogeneous areas, thus indicating a lower probability to find vessels. In non-homogeneous regions, a linear function combining pixel and region characteristics is employed to select ship candidates. A ship detection method based on the correlation of a pair of UAV images is proposed in [Kadyrov, A. et al., 2013]. During a short time, the sea wave pattern changes and hence the water area can not match with its previous state; on the contrary, a ship shape does not change much within this time interval. Ship detection is performed through a correlation technique based on a combination of focused orientation correlation and focused phase correlation, that is able to align geometrically mutually translated and distorted pairs of 2D images. Significant correlation values, entail the presence of a boat in the image.

Sea roughness is derived from standard deviation of the sea area in VHR optical data from GeoEye, WorldView-2, IKONOS and QuickBird sensors [Kanjir U.et al., 2014]; this value is needed in the vessel detection phase to define the size of the smoothing window over the NIR band. Candidate ship extraction is performed by removing pixel values of the smoothed NIR band with low reflection and by geometrically grouping the remaining pixels with higher reflections, which represent vessel candidates. ASTER VNIR images are used in [Partsinevelos, P. and Miliaresis, 2014] to detect vessels through a gray threshold, which defines the probability to detect a ship. Some methods are based on the observation that water absorption of the electromagnetic radiation increases with wavelength in the VNIR, so ships are generally bright targets; the majority of them make use of medium spatial resolution. Roskovensky J. K. [Roskovensky, J.K., 2012] computed a two-dimensional derivative field of the reflectance values on a pixel-by-pixel basis upon the NIR band reflectance values. Ship detection is performed through thresholds based on spectral properties of ships, ocean background and clutter (clouds, ocean waves and breaking waves) in the RGB, NIR, SWIR, MWIR and TIR bands of several Landsat7 images with different weather and sea conditions also in [Abileah, R., 2009]. A study over Landsat TM visible and infrared bands is performed to understand the relationship between the reflectance contrast and water turbidity, to analyze how water turbidity affected the capability of ship identification [Wu, G. et. al, 2009]. The only one ship detection method applied to low resolution images is reported in [Dorado-Muñoz, L.P. and Velez-Reyes, M., 2011] over MODIS images with high ship (cargo or oil tanker) traffic. Even if this method takes into account big ships, they are only present in 1-2 pixels of the images and often at the subpixel level. Therefore, an alternative approach for ship detection is by detecting contamination tracks left by ships in clouds, particularly visible in band 7 in the case of MODIS. An Orthogonal Subspace Projector (OSP) detector based on spectral mixing models is proposed for the detection of ships at a subpixel level.

The last category of techniques for ship detection is that one which is linked to texture and geometrical characteristics of the objects. Burgess [Burgess, D.W., 1993] introduced vessels detecting algorithm in SPOT Multispectral and Landsat TM, using masking, filtering and shape analysis techniques. Some works makes use of Local Binary Pattern Methods [Kumar, S.S. and Selvi, M.U., 2011][Song, Z., Sui, H. and Wang, Y., 2014], which are texture descriptors which allows to detect features. To classify the image these methods usually need a Support Vector Machine (SVM), supervised learning models with associated learning algorithms that analyze data and recognize patterns. LBP are extended with and Local Multiple Pattern methods [Huang, G. et al., 2011][Zhu, C. et al., 2010][Satyanarayana, M. and Aparna, G., 2012], which, in addition, preserve more structural information and are more suitable for image analysis. The method works on CBERS images with 20 meter resolution and SPOT image with resolutions 5 and 10 meters [Zhu, C.et al., 2010]. Graph-based techniques for ship detection are presented in [Antelo, J. et al., 2009] through an active contour-based algorithm, and in [Chen, F. et al., 2011] through a min-cut/max-flow algorithm. Bi et al. [2012] raised a visual search inspired computational model. In their approach, the salient candidates regions were first selected by a bottom-up mechanism and then real ships were validated by local feature descriptors and the support vector machine. In [Máttyus, G., 2013] ship detection is performed over WorldView-1 and WorldView-2 panchromatic images through a binary classifier which makes use of standard and simple features to distinguish between ships and background. An object based image analysis technique for ship detection is used in [Willhauck, G. et al., 2005], and provides a semi-automatic algorithm for ship detection within harbor areas in VHR satellite images. In [Shi, Z. et al., 2014] possible ships are preliminarily detected through a hyperspectral anomaly detector in a synthetic hyperspectral image defined from a panchromatic image. Then candidate targets are analyzed to detect their shape through the Histogram of Oriented Gradients (HOG), based on the idea that the appearance and shape of local object can be characterized rather well by the distribution of edge directions or gradients.

Pre-processing of images and post-processing of ship detection results are similar to the majority of the works found in literature. Pre-processing techniques can be grouped in sea/land segmentation or land mask to constrain the research only to sea [Bouma, H. et. a., 2013; Roskovensky, J.K., 2012; Xia,Y. et. al, 2014; Buck, H. et al., 2012, Arnold-Bos, A. et al., 2007], splitting of the image into small tiles to speed the process [Saur, G.et al., 2012][Partsinevelos, P. and Miliaresis, G., 2014][Song, Z., Sui, H. and Wang, Y., 2014], and border or contrast enhancement techniques to better identify targets [Corbane, C. et al, 2010][Zhu, C. et al., 2010][Rao, N.S. et al., 2005]. Post-processing techniques are mainly linked to false target elimination based on geometrical properties of ship targets: length to width ratio, perimeter to area ratio, compactness, convexity and eccentricity indexes are defined to set thresholds which allows to remove false target detections [Buck, H. et al., 2015][Liu, G. et al., 2014][Huang, G. et al., 2011][Zhu, C. et al., 2010][Saur, G. et al., 2012][Yang G. et al. 2011]. Another post-processing technique is based on the assumption that ships object can be distinguished by sea clutter as they are not isolated pixel [Corbane C., et al., 2008]. Some post-processing techniques are even a combination of the previous.

Ship speed is more easily derived from SAR imagery as it can be calculated from the wave number of the Kelvin wake through Fourier or Radon transforms. This is also applicable to optical data, even to estimate ship direction [Arnold-Bos, A.et al., 2007]. Ship speed can be also retrieved as a function of the displacement of ship position between two coregistered subsequent images [Rao, N.S. et al., 2005]. Finally, ship speed is retrieved from the wake wavelength measured over the cusp line formed by the interaction between divergent and transverse waves [Hallenborg, E.et al., 2013]. In [Partsinevelos, P. and Miliaresis, G.,2014] the direction of the ship is estimated through the displacement between the gravity cluster center and the minimum bounding rectangle center of the cluster, since the wake's trace could be thinner than the actual ship.

4.2 STATE OF THE ART OF SHIP DETECTION IN SAR REMOTELY SENSED IMAGES

Ship detection is one of the primary applications of interest for SAR (Synthetic Aperture Radar) imaging nowadays, as described for instance in the milestone review [Crisp, D.J., 2004] or in [Vachon, P.W., 2006]. Thanks to the fact that it is an active microwave sensor, SAR is ideally able to operate in all-weather conditions and at night, thus complementing imaging conditions of optical sensors. Moreover ships usually have at least some metallic parts, thus they usually produce a higher intensity than the surrounding environment in SAR images, appearing as bright spots. All these characteristics make SAR images particularly attractive for ship detection applications, especially when data are processed with adaptive threshold detection algorithms, as it will be explained in the following. Moreover, the trade-off between resolution and coverage that SAR offers [Brusch, S. et al., 2011] with different imaging modes (i.e., stripmap, spotlight or wide-swath) is also very useful for ship detection, since high resolution surveys over small areas or low resolution surveys over wide areas can be scheduled according to specific needs.

Many research groups have been working through turning ship detection with SAR into operational systems in the past years. Examples of these efforts are the Ocean Monitoring Workstation, the JRC system [Crisp, D.J., 2004], the Polar Epsilon project [Vachon, P.W. et al., 2014] and some others [Crisp, D.J., 2004]. Although issues still remain due to the complexity of imaging vessels with SAR and no universal system able to deal with all the possible conditions exists, all these cases provide effective examples of how SAR can be employed for maritime surveillance services tailored to specific scenarios of interest.

There are many techniques in literature that have been proposed over the years for ship detection. The most popular category is that of adaptive Constant False Alarm Rate detectors [Crisp, D.J., 2004], due to the simplicity of implementation and sound statistical approach. These algorithms basically search for bright pixels over a darker background in intensity SAR images. A local threshold is adaptively computed for each pixel of the scene from local sea clutter statistics, for which a statistical model is usually assumed. This threshold is used to assess whether the pixel under test belongs to a vessel or not. More complex approaches take into account also the statistics of the vessels [Crisp, D.J., 2004], even though this information is usually much harder to model than that of the sea clutter. Other approaches more sophisticated than CFAR rely on multi-channel information, such as polarimetric detectors [Yeremy, M.et al., 2001, Banda, F., et al., 2014]. With SAR polarimetry, electromagnetic descriptors can be computed in order to characterize different physical objects. In particular, a vessel usually exhibits a different polarimetric behavior with respect to sea clutter. Another multi-channel approach is along-track interferometry [Campbell, J.W.M. et al., 1997], which relies on the phase difference of a pair of complex SAR acquisitions displaced along-track, from which moving targets are identified and the velocity of the vessel is estimated. Multi-channel approaches provide indeed enhanced detection capabilities with respect to simpler CFAR approaches, but this comes at the cost of having a more complex/dedicated system [Crisp, D.J., 2004]. Another alternative approach is that offered by time-frequency processing of single-channel complex SAR data [Banda, F. et al., 2014; Hu, C., et al., 2013]. Lower resolution images corresponding to different portions of the SAR acquisition time can be synthesized from full resolution products through a windowed Fourier transform. These newly synthesized images can be used to assess particular properties of the target, such as its coherence during the acquisition time of the SAR, and thus used to detect vessels against the sea. However, also in this case, the processing is less straightforward than that required for a CFAR approach.

4.3 METHODS

4.3.1 Dataset

Satellite data

The data set used in this work comprises high-resolution images collected with five different sensors (i.e. WorldView-2, QuickBird-2, GeoEye-1, RapidEye and Formosat-2) and having different extensions. These images belong to the free sample data available in the satellite imagery catalogues and archives. All the dataset is characterized by different weather and sea conditions, and also include ships of different shape, size and speed. Being collected over different areas and in distinct dates, the set of optical images is characterized by different weather and sea conditions, so preprocessing steps are necessary before applying ship detection algorithms.

In addition to optical data, two SAR scenes (CSK01 and CSK02) acquired over the Hong Kong area in 07/01/2012 and 19/09/2012have been used in this project. The data processed are stripmap SAR data in Single Look Complex (SLC) Lv1 format from the COSMO-SkyMed system [Torre and Capece, 2011], operated by the Italian Space Agency (ASI). The imaged area corresponds to approximately 30 km x 30 km on ground, at an incidence angle of about 26° and a spatial resolution of approximately 3 m in azimuth and 1.3 m in slant range. The carrier frequency of the radar wave is 9.6 GHz (X band) corresponding to a wavelength of about 3 cm. Data were acquired in HH polarization. Only the intensity information has been used in the processing.

The main characteristics of the images used in this work are summarized in Table 4-1.

			Spatial resolution (pixel size) [m]		Available Spectral Bands
Sensor	**Acquisition Data**	**Location**	**Multispectral band**	**Panchromatic Band**	**[µm]**
WorldView-2	31/12/2010 03/04/2011	Xiapu (China) Sydney (Australia)	2	0.5	0.450 - 0.800 (PAN) 0.400 - 0.450 (C-B) 0.450 - 0.510 (B) 0.510 - 0.580 (G) 0.585 - 0.625 (Y) 0.630 - 0.690 (R) 0.705 - 0.745 (RE) 0.770 - 0.895 (NIR1) 0.860 - 1.040 (NIR2)
QuickBird-2	16/05/2001	Venice (Italy)	2.4	0.6	0.450 - 0.900 (PAN) 0.450 - 0.520 (B) 0.520 - 0.600 (G) 0.630 - 0.690 (R) 0.760 - 0.900 (NIR)
GeoEye-1	12/02/2009	Venice (Italy)	1.6	0.4	0.450 - 0.900 (PAN) 0.450 - 0.510 (B) 0.520 - 0.580 (G) 0.655 - 0.690 (R) 0.780 - 0.920 (NIR)
RapidEye	18/02/2011	Formentera (Spain)	5	2	0.440 - 0.510 (B) 0.520 - 0.590 (G) 0.630 - 0.685 (R) 0.690 - 0.730 (RE) 0.760 - 0.850 (NIR)
Formosat-2	15/12/2005	Barcellona (Spain)	8	2	0.450 - 0.90 (PAN) 0.450 - 0.520 (B) 0.520 - 0.600 (G) 0.630 - 0.690 (R) 0.760 - 0.900 (NIR)
COSMO-SkyMed	07/01/2012 19/09/2012	Hong Kong area	~3	n.d.	Intensity

Table4-1 –Satellite imagery used in this study.

AIS data

As previously stated, AIS allows to be aware of known ships main characteristics, position and route. In Space Shepherd context, it is a powerful instrument to distinguish known vessels from unknown, and maybe illegal, vessels [Ramona P. et al. 2014; Vespe M., et al., 2008;Wu F. et al., 2014]. Moreover, AIS data allowed us to validate the results of ship detection and spatial analysis. Thus, AIS data have been selected for time and locations corresponding to the available optical and radar images. Unfortunately, no AIS data was available for optical images of our dataset, but data were only available for the two COSMO-SkyMed data acquired over Hong Kong, China (Table 4-2), thus a validation with real data has been performed only for radar data.

	Image acquisition date and time	Number of AIS records	AIS data time resolution
CSK01	07-01-2012 10:18	169	5 minutes
CSK02	19-09-2012 10:16	77	5 minutes

Table 4-2 – Summary of available AIS data for COSMO-SkyMed images.

For each record AIS data contain vessel movement parameters as described in Table 4.3 and provided to users in a .csv file. An example of real AIS data for a COSMO-SkyMed image, provided by Astra Paging Ltd. (www.vesselfinder.com), is shown in Figure 4-1.

Parameter	Unit	Description
Date/Time	y-m-d h:m:s [UTC]	Time stamp of the last received position report
MMSI (Maritime Mobile Service Identity) number	-	Series of digits sent over a radio frequency channel in order to uniquely identify ship stations, ship earth stations, coast stations, coast earth stations, and group calls
Latitude and Longitude	Degrees [WGS84]	-
Course over ground	Degrees respect to the north [0° - 360°]	Intended direction of the ship's travel
Speed over ground	Knots	-
Heading	Degrees respect to the north [0° - 360°]	Direction the ship is currently navigating in obtained from the vessel's gyro compass
IMO (International Maritime Organization) number	-	Unique reference for ships and for registered ship owners and management companies
Name	-	Vessel'sname
Call sign	-	Unique alphanumeric identity that belongs to the vessel
AIS type	-	Unique alphanumeric identity that belongs to the vessel
A	Meters	Distance between AIS receiver and bow
B	Meters	Distance between AIS receiver and stern
C	Meters	Distance to port
D	Meters	Distance to starboard (i.e. Ship Width = C + D)
Draught	Meters	Depth of a vessel in the water, taken from the level of the waterline to the lowest point of the hull at the time of the position report
Destination	-	Port of call (as entered by the Master)
ETA	m-d h:m [UTC]	Estimated time of arrival (as entered by the Master)

Table 4-3 – Vessel movement parameters sent through the AIS message, with their unit and description.

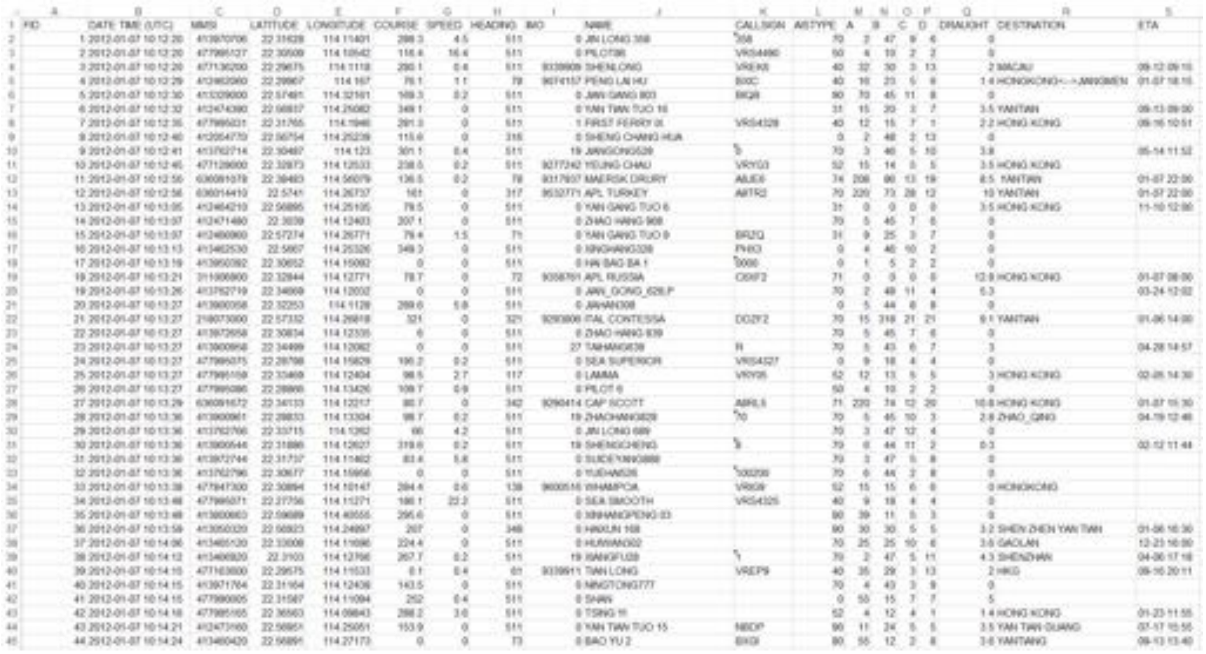


Figure 4-1 – Example of provided AIS data in .csv file

AIS positions have been first corrected to account for the boat-off-the-wake effect in SAR images [Crisp, D.J., 2004;Banda, F. et al., 2014]. This effect is so-called since whenever a wake can be observed in the SAR intensity image, the vessel may appear displaced from its wake in the sensor along-track direction due to a velocity component in the radar line-of-sight (LOS) direction (Figure 4-2). The equation that relates the shift dx in the along-track direction with the LOS velocity of the vessel V_{LOS} is:

$$\Delta x \cong -\frac{\mathrm{V_{LOS}}}{\mathrm{V_s}} R_0$$

where Vs is the sensor velocity and R_0 is the slant-range distance from the sensor to the vessel.

This correction has been done on the basis of AIS velocity records, scene acquisition geometry and sensor trajectory, in order to match AIS data with detected vessels and perform validation.

As AIS data have been collected two minutes before and two minutes after the SAR image acquisition time, the records are characterized by a time shift between the time of the last received ship position and the image acquisition time. The ship positions from AIS records have been used to calculate the positions at the acquisition time of the SAR products, by assuming that the ship heading and speed as reported by AIS have not changed within the temporal separation between AIS records an SAR data acquisition time. Such procedure is commonly called dead reckoning [Vachon, P.W. et al., 2007] and has been carried out since no multiple AIS records were available for interpolation.

Thus, each ship position has been brought (backward or forward) to the image acquisition time, considering the ship speed and heading given by AIS (course values have been considered for the correction when heading is not transmitted) and supposing the ship is moving with a uniform rectilinear motion.

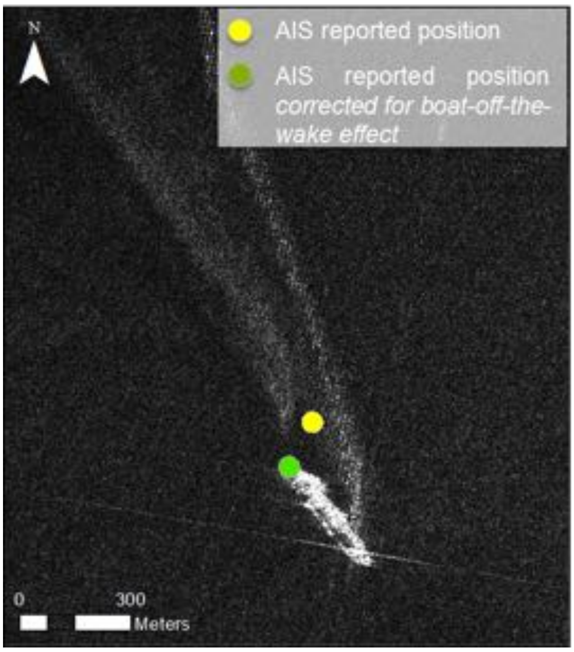


Figure 4-2 – AIS data correction for the boat-off-the-wake effect over a SAR image.

4.3.2 Ship detection in optical images

Since optical imagery offers spectral information, it has better potential for identifying and classifying ships and allows the detection of vessels made of low radar-scattering materials (wood or fiberglass).Environmental conditions can play a large role in the ability to observe a vessel. Winds and waves can create strong returns generating “false-alarms” in the observation of ships. Very high-resolution multispectral images can provide detailed information for even small ships and allow the estimation of their shape and route [Kanjir U., et al., 2014]. However, optical sensors have the same shortcomings as the human eye: clouds can obscure the field of view and sunlight is required to make observations. Examples of small and big vessels visible in high resolution multispectral and panchromatic images is shown in Figure 4-3.

The goal of the optical image processing is the ship detection and estimation of its size, heading and speed. A moving vessel is defined an object “ship” next to an object “wake”. The wakes produced by vessels are not exclusively correlated with their speed: many factors contribute to an individual wave wake pattern making a complete study very complex [Macfarlane, G.,Renilson, M. 1999]. Although it is not possible to calculate the vessel velocity, the following processing methodology tries to assign a ship speed range in relation with its size (through estimates defined in relation to the type of ships mainly used by migrant smugglers in the Mediterranean Sea).

The processing, outlined in Figure 4-4, can be divided in two main workflows:

1. Detection of moving vessels (ships and wakes) by means of Object Based Image Analysis (OBIA);

2. Estimation of vessels’ parameters by means of spatial analysis.

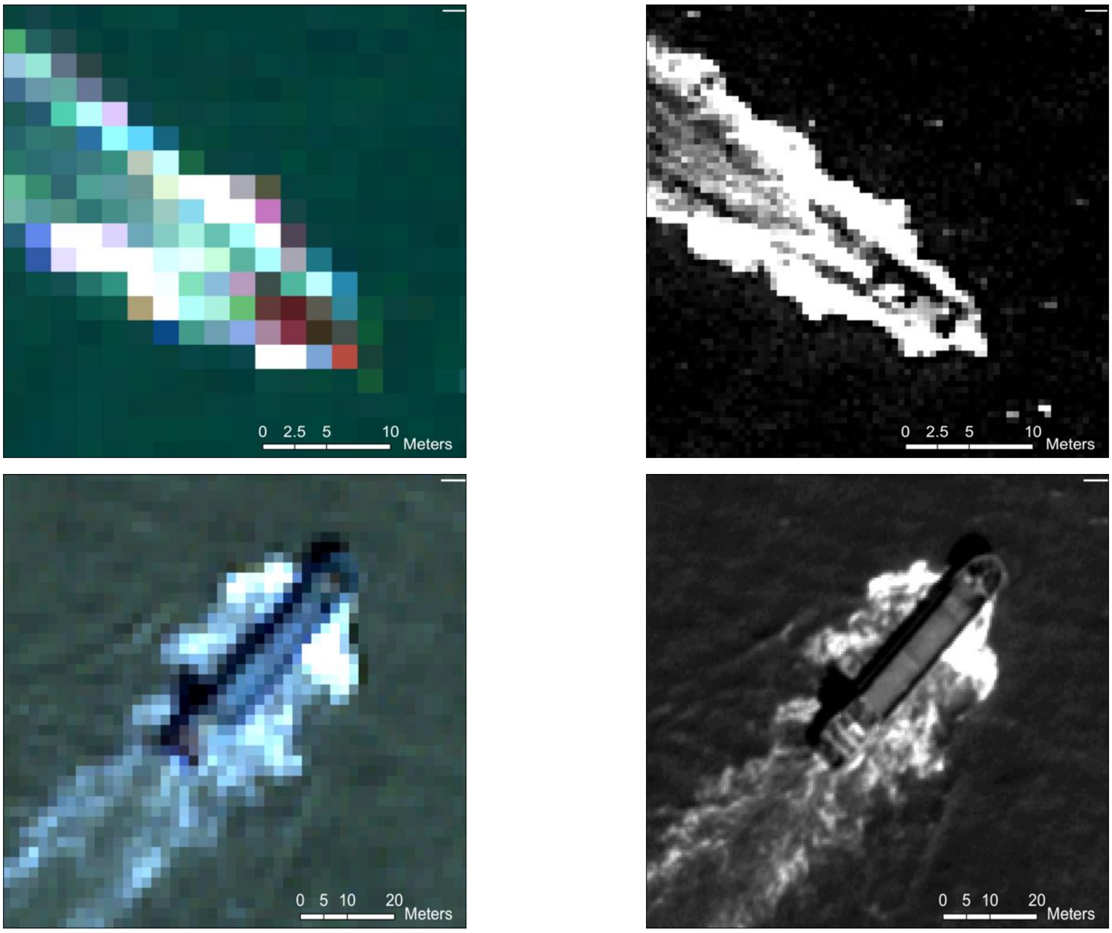


Figure 4-3 – Example of small (on the top) and big (on the bottom) ships in multispectral (on the left) and panchromatic (on the right) images.

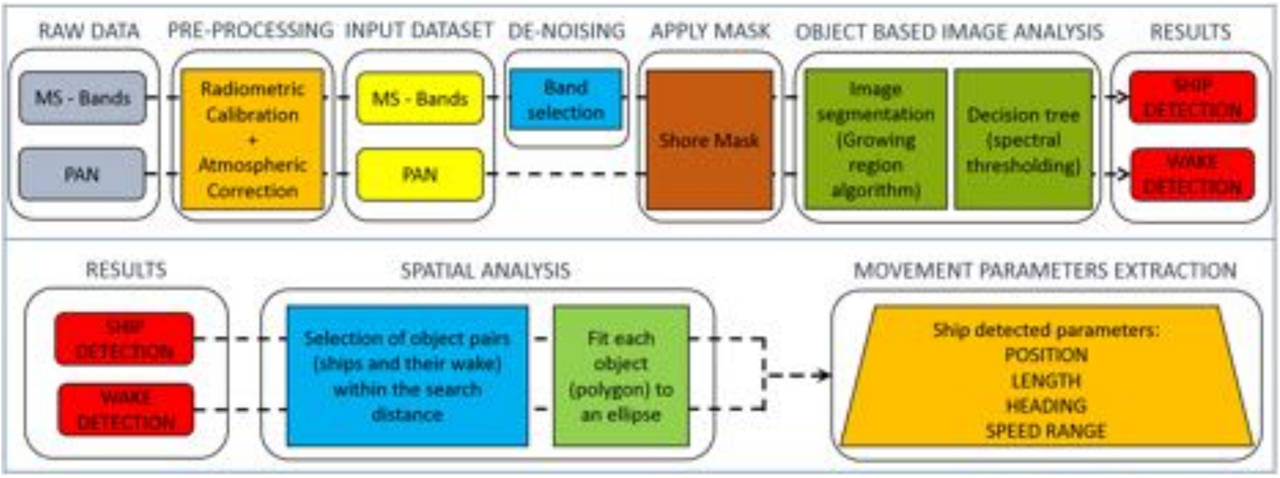


Figure 4-4 – Processing chain for moving vessel detection on optical images.

Ship's features are detected exploiting the multispectral data, making use of the spectral bands common to all the sensors here considered (blue, green, red, near infrared and panchromatic). Standard radiometric calibration and atmospheric correction are applied to all the images prior the processing. Data are manually land-masked for reducing the computing time by constraining the search only to the sea.

Concerning the ship detection phase, the multispectral bands are processed through a Minimum Noise Fraction (MNF) algorithmin order to select the most useful component by segregating noise in the data, so that ships are separated from the background, that is the sea and, thus, the ship's wake.

Both ships and wakes are extracted through OBIA: the MNF component and the panchromatic band are the input data for the analysis. The Object-Based Image Analysis (OBIA) consists in two-step process: segmentation and classification. Segmentation aims at grouping adjacent image pixels into self-existent objects (or segments) with spectral and geometric similarities, so that textural and contextual/relational characteristics among objects can be exploited as well in target detection [Gianinetto, M.,Rusmini, M. et al. 2015]. Parameters selected for the segmentation phase are listed in Table 4-4. The accuracy of the classification results is highly dependent on the quality of the segmented objects [Auquilla, A.,Heremans, S. et al. 2014].

In order to make the process fully automated, simple and robust, a unique set of segmentation and classification parameters is defined for all the images, irrespective of the sensor used for their collection, which is necessary in situations as those Space Shepherd operates in. The classification of each multispectral and panchromatic dataset has been carried out through the threshold-based rule sets listed in Table 4-5 [Baatz, Schäpe 2000], where the parameters' values have been set using a trial and error method, taking into account both spectral and geometric properties. Results of segmentation and classification processes over multispectral and panchromatic images, which have allowed to detect respectively ships and wakes, are shown in Figures 4-5 and 4-6. Figure 4-7 shows the result of ship and wake detection on a wider area, thus after having applied segmentation and classification on both selected MNF band and panchromatic image.

Input layers	**PAN Band segmentation**	**MS Band (Selected) segmentation**
PAN Band	Yes	No
MNF component's values	No	Yes
Scale	400	10
Shape	0.1	0.1
Compactness	0.5	0.5

Table 4-4: Image segmentation parameters applied to the corresponding input layer.

Features	**PAN Band classification**	**MS Band (Selected) classification**
Reflectance	0.035 ÷ 0.650	-
MNF component's values	-	-23 ÷ 3
Area [pixel]	0 ÷ 21000	0 ÷ 2300
Length/Width	-	0.9 ÷ 8.9
Border Index	0 ÷ 7	-

Table 4-5: Features and values used for the image classification.

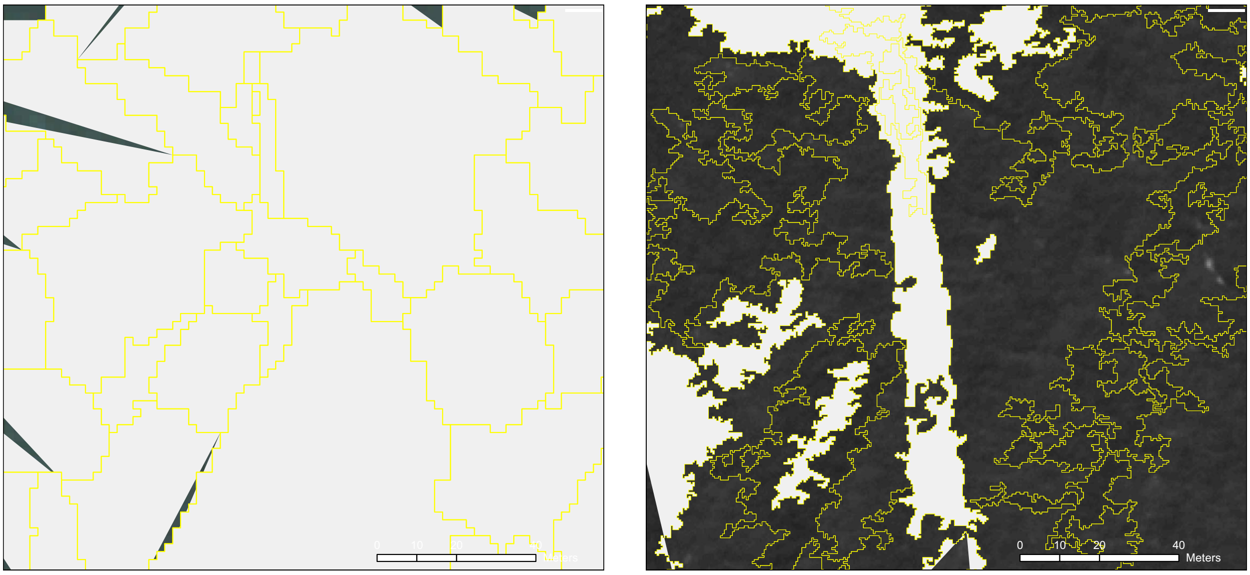


Figure 4-5 – Segmentation results for multispectral (on the left) and panchromatic (on the right) images to identify ships and wakes respectively.

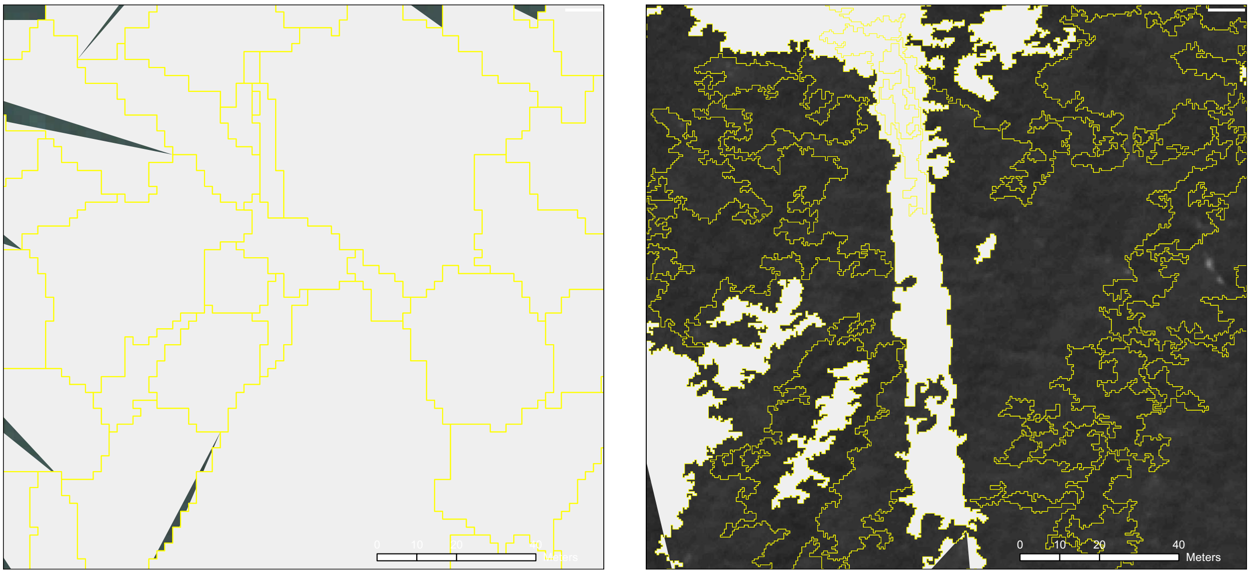


Figure 4-6 – Classification results for multispectral (on the left) and panchromatic (on the right) images to identify ships and wakes respectively.

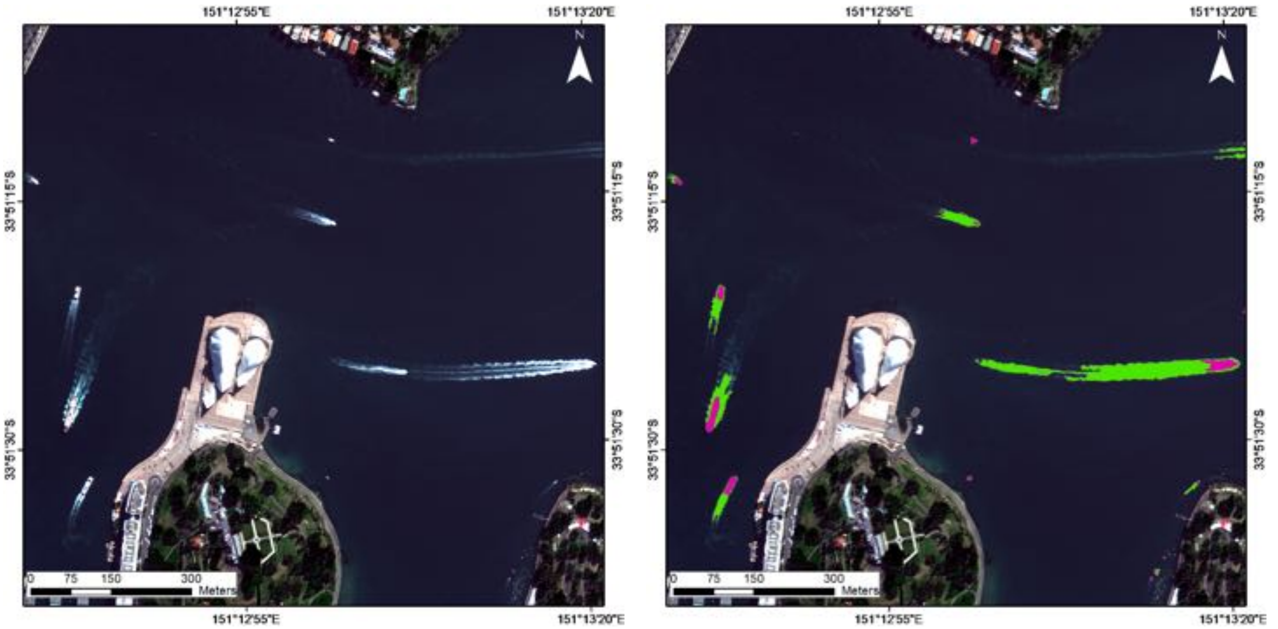


Figure 4-7 – On the left, example of a pan-sharpened WorldView-2 image (spatial resolution 0.5 m) collected over Sydney (Australia). The vessels in this subset have different size, but all compatible with those of the ships actually used by smugglers. On the right example of automatic image segmentation and classification superimposed on a pan-sharpened WorldView-2 image. Ships' object are in dark pink and wakes' object are in green.

Simulation with medium resolution imagery

High spatial resolution data guarantee high details and accuracy of the results. However their revisit time can be very small (e.g. 1.1 for WorldView-2, less than 3 days for GeoEye) and the swath widths are extremely narrow (less than 20 km), making them especially useful for small area studies. Medium resolution optical imagery can be useful for monitoring purposes, as it has a wider swath.Nevertheless, its coarser spatial resolution may not be optimal for the detection of small vessels. Consequently, a simulation was carried out for evaluating the potential benefits and limitations of including medium resolution multispectral data in the process.

Starting from the available high resolution imagery, 5-meters, 10-meters, 15-metersimages were generated (Figure 4-8) and the above processing chain was applied. An example of a 15-m spatial resolution optical image representing a wider area with some different vessels is shown in Figure 4-9. All the segmentation parameters were that used for the high-resolution images (Tables 4-4 and 4-5), except for scale which has been tuned according to the corresponding spatial resolution. With respect to classification, intensity and area were scaled to the spatial resolution of the simulated image, while length/width and border index did not change being ratios.

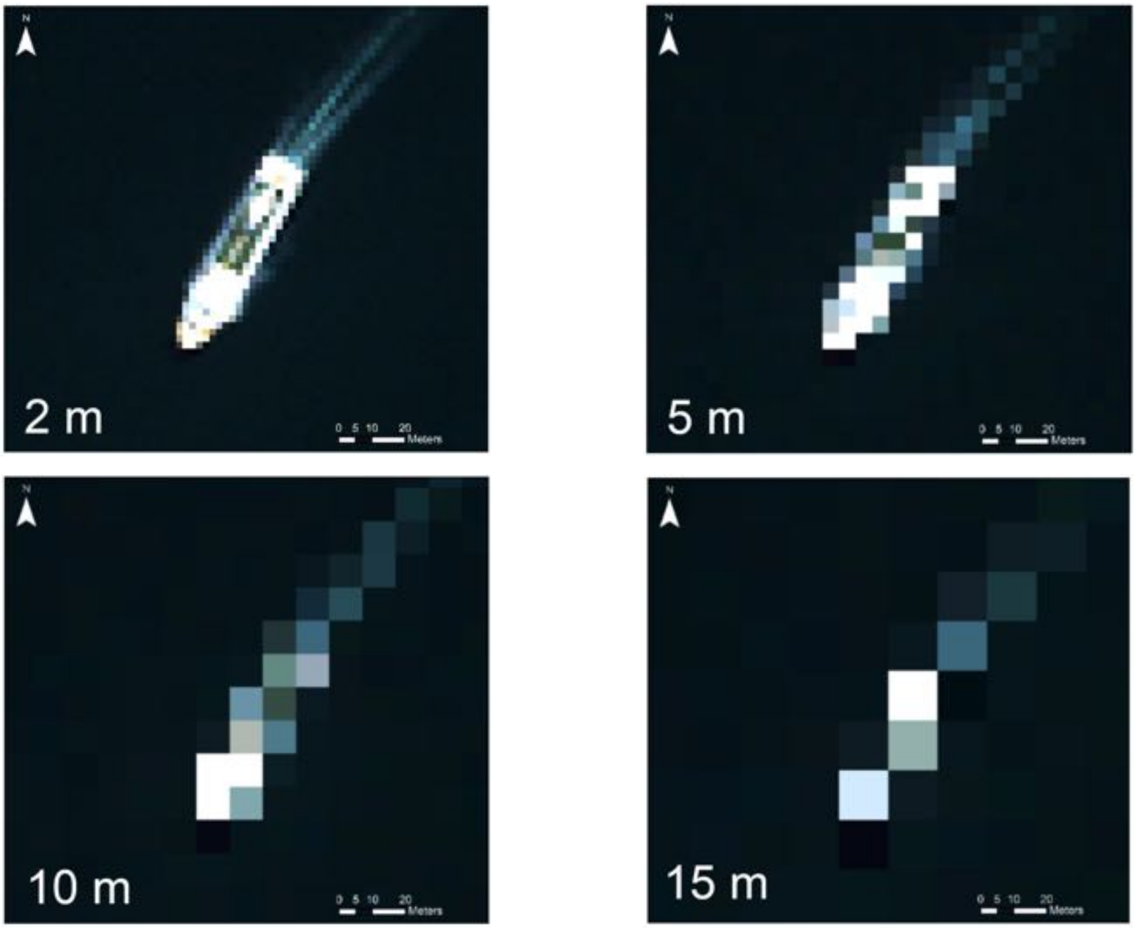


Figure 4.8 – Example of a 60 m long vessel in high spatial resolution (2 m) and simulated medium spatial resolution (5 m, 10 m and 15 m).

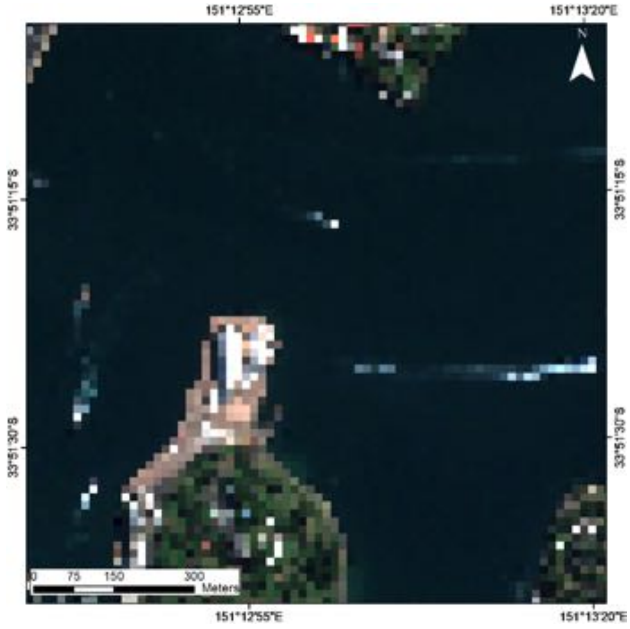


Figure 4-9 – Example of a simulated 15-meters WorldView-2 image collected over Sydney (Australia), generated from the available high resolution imagery (spatial resolution 2 m).

4.3.3 Ship detection in SAR images

Synthetic Aperture Radar (SAR) is a well-known technology for ship detection. Being an active microwave sensor, SAR is able to operate ideally in all-weather conditions and regardless of daylight. Moreover, ships usually have at least some metallic parts, and thus produce a much higher backscatter intensity than the surrounding environment in many conditions, appearing as bright spots in SAR images. The flexibility offered by SAR in terms of trade-off between resolution and coverage also makes SAR particularly attractive for ship detection applications: different operative scenarios are possible: Spotlight (Spatial resolution ~ 1-3 m), Stripmap (Spatial resolution ~3-6 m),Wide-swath (Spatial resolution ~15-20 m). Thus, very high resolution surveys for small areas (the operation mode called Spotlight) or low resolution and wide area coverage (wide swath ScanSAR or TOPS mode) can be scheduled according to specific needs. The above mentioned SAR characteristics turn out to be very useful for this project, considering the adaptability of the system required according to the different operative modes of Space Shepherd.

In this section a simple and robust methodology for ship detection using SAR data is described (Figure 4-10); the workflow is suitable to process even data acquired from various sensors, having different image characteristics (frequency, resolution, polarization, etc.). The proposed approach is mainly parallel to the one used for optical image processing. First, a mask to eliminate the shore and terrain pixels from the image is applied, in order to avoid producing unnecessary false alarms when processing the data with ship detection algorithm. This step is optional and should not be necessary in the ideal Space Shepherd detection scenario (open waters); however, it has been applied to our available data due to the presence of shore areas and islands in the scene.

The second step is the vessel detection. The approach chosen in this work is a simple adaptive threshold CFAR [Crisp, D.J., 2004]. This algorithm basically searches intensity SAR images for bright pixels with respect to the background, through the application of a 2D moving window all over the image. The pixel (or group of pixels) under test, which is called the cell under test (CUT), is surrounded by a guard area and by a background window. The pixels belonging to the background window only are used to locally estimate background statistics. The purpose of the guard window is to ensure that pixels belonging to the target do not bias background statistics estimation. A reasonable rule of thumb is often to choose the dimension of the guard window as large as the biggest target expected in the detection scenario. The windows are usually square, not knowing a-priori target orientation. The background window should be chosen as large as possible in order to have sufficient pixels to estimate sea statistics. At the same time the window should not be too large in order to not include nuisance pixels (e.g. nearby vessels, which is however an unlikely case in an open waters detection scenario). A threshold is determined according to the estimated background statistics in order to ensure a given probability of false alarm (PFA). The CUT is, then, tested against this threshold and detection is assessed if CUT intensity is greater than the threshold: namely, if the intensity of the CUT is greater, then the CUT is labeled as belonging to the vessel. For this reason, these algorithms are usually referred to also as Constant False Alarm Rate (CFAR) detectors. A modeling of the background, i.e. sea statistics is required to apply this methodology. Popular models for sea clutter are Gaussian, Rayleigh or K distribution (the latter is typically used to model textured clutter). A simple Gaussian modeling of the sea statistics has been chosen. Although Gaussian modeling is usually deemed not to be the most faithful choice to model sea clutter statistics (unless a sufficient averaging of pixels is previously performed [Crisp, D.J., 2004]), this choice has been retained here anyway, thanks to the fact that the resulting implementation is very efficient and fast. This is due to the closed form relation between the PFA and the testing threshold [Crisp, D.J., 2004], namely:

$$PFA = \frac{1}{2} - \frac{1}{2}\operatorname{erf}\left(\frac{t}{\sqrt{2}}\right)$$

Where t is the threshold and erf is the error function. The threshold t is then locally adapted on the basis of local sea clutter statistics [Crisp, D.J., 2004]:

$$CUT \gtrless \mu_b + \sigma_b t$$

Where μ_b and σ_b are local background mean and standard deviation respectively.

In order to detect small vessels in an open water scenario, the guard and background square windows have been set to a dimension of 20 and 50 pixels.

The choice of retaining a Gaussian clutter modeling is coupled with ad-hoc image post-processing, in order to properly remove false alarms (e.g. spurious points); majority filter[Padmaja et al., 2008] coupled with the application of the morphological operators of dilation and erosion have been applied. The results have been processed through an OBIA to cluster and extract ship objects as described in the previous section using specific ad hoc segmentation and classification parameters (Table 4-6).

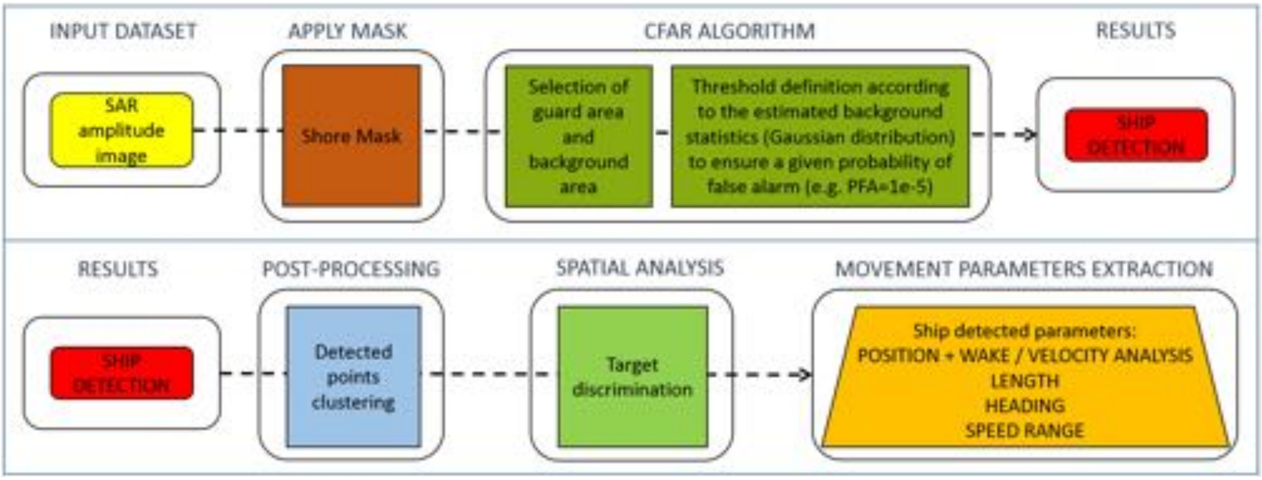


Figure 4-10 - Processing chain for moving vessel detection on SAR images.

Features	Segmentation	Classification
Scale	50	-
Shape	0.1	-
Compactness	0.5	-
Band value	-	1
Area [pixel]	-	0-350
Length/Width	-	0.9-6

Table 4-6: Features and values used for the segmentation and classification steps.

Small vessels simulation

Target ships for Space Shepherd project range from few meters to at most 70 meters. In the processed SAR dataset the detected ships with corresponding AIS validation available are mostly big-size vessels (i.e. typically of length >100 m) and most of these vessels are quite well isolated from nearby ships. Smaller ships are available in port areas near the coast, representing a difficult scenario for the detection with the previously methodology. Moreover, the matching between AIS data and detected ships is often difficult because of the occurrence of nearby vessels together with errors in the matching procedure [Vachon, P.W. et al., 2007]. In this way, smaller isolated vessels have been simulated starting from big-size vessels.

Full resolution SAR data have been low-pass filtered in order to generate three additional datasets, in which the resolution is worsened by a factor five, ten and twenty. As an example a ship of 400 meters length is composed by 140 pixels along the major axis at the full resolution SAR image; the same vessel is composed by 28 pixels in the first additional dataset, 14 pixels in the second and 7 pixels in the third, as a ship of 80, 40 and 20 meters length respectively at the full resolution (Figure 4-11).

The same methodology has been applied to the simulated images, scaling the dimensions of guard and background windows; also the segmentation and classifications features were the same used for the full resolution SAR images (Table 4-6), but the parameter values have been tuned basing on the new additional dataset targets.

It is worth remarking here that this simulation approach concerns only the geometric detection/estimation performance. The scattering properties of the simulated smaller vessels still remain that of big vessels imaged at a coarser resolution. In lack of real data, the simulation of vessel backscatter from smaller vessels, many of which are built with materials different from that of big vessels, would require a complex electromagnetic modeling with electromagnetic software. Such point however is beyond the scope of this paper.

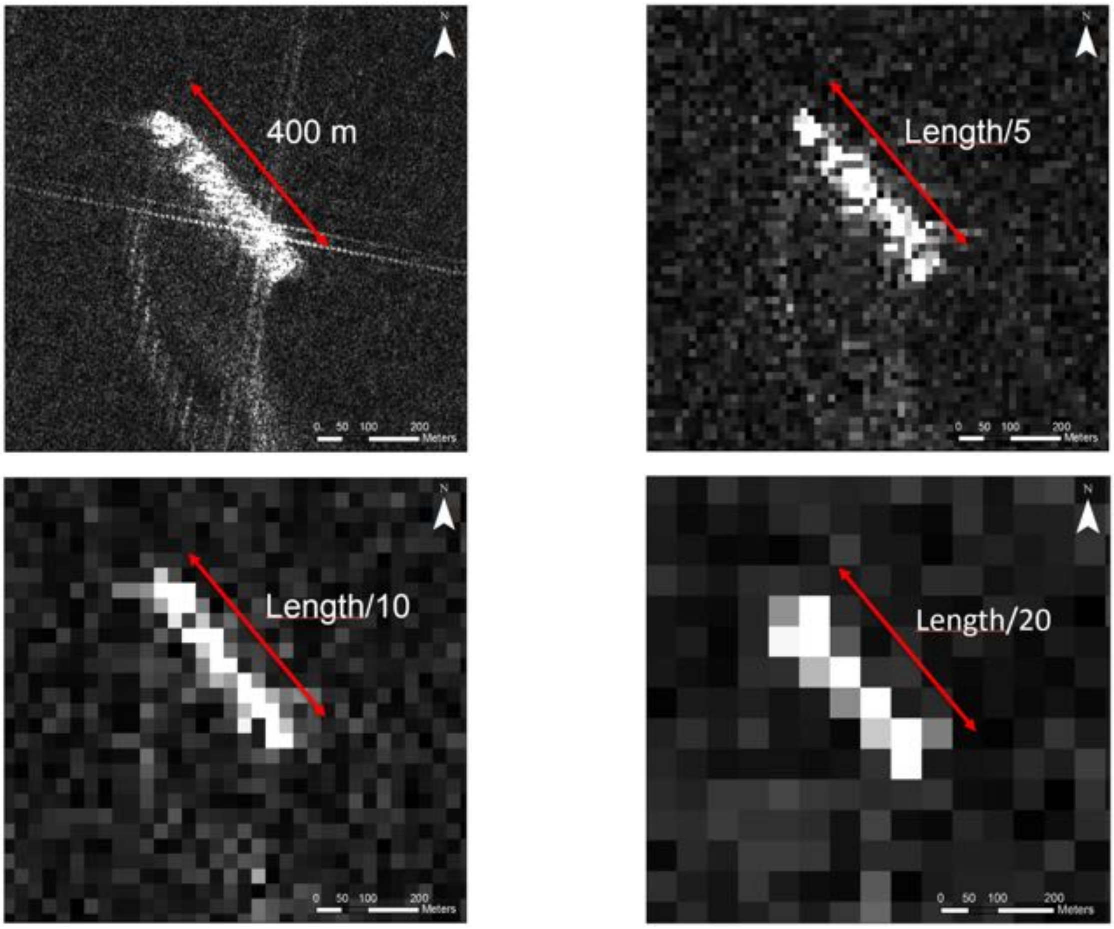


Figure 4.11–Low-pass filtering of full resolution SAR images to generate additional dataset worsened by factor 5, 10 and 20.

4.4 ESTIMATION OF ROUTE PARAMETERS

The aim of this section is to estimate the vessels' parameters (position, length, heading and speed range) by means of spatial analysis; thus, the vector files of vessel objects resulting from OBIA analysis for optical and radar data have been imported into a GIS environment (ArcMap 10.1).

In order to remove false targets, objects pairs (ships and their wake) are selected within a search distance. Each element of the moving vessel (ship and wake) is individually fitted to an ellipse and a rectangle of the smallest width (Figure 4-12), in order to extract movement parameters of the targets (Table 4-7).

Thus:

- the position of the vessel is estimated through the geographic coordinates of the centroid of the ship's ellipsoid;
- the length of the ship is estimated through the mean value of ship's ellipse major axis and the rectangle longer side, as the ellipse and the rectangle usually provide an underestimate and an overestimate of ship length, respectively;

- the heading of the vessel (clockwise respect to the North) is estimated from the orientation of the wake's ellipse for optical images. In SAR images wakes are not detected, so the route's parameters are estimated only from the ellipse heading;
- a speed range is finally assigned based on the vessel size (through estimates defined in relation to the type of ships mainly used by migrant smugglers in the Mediterranean Sea).

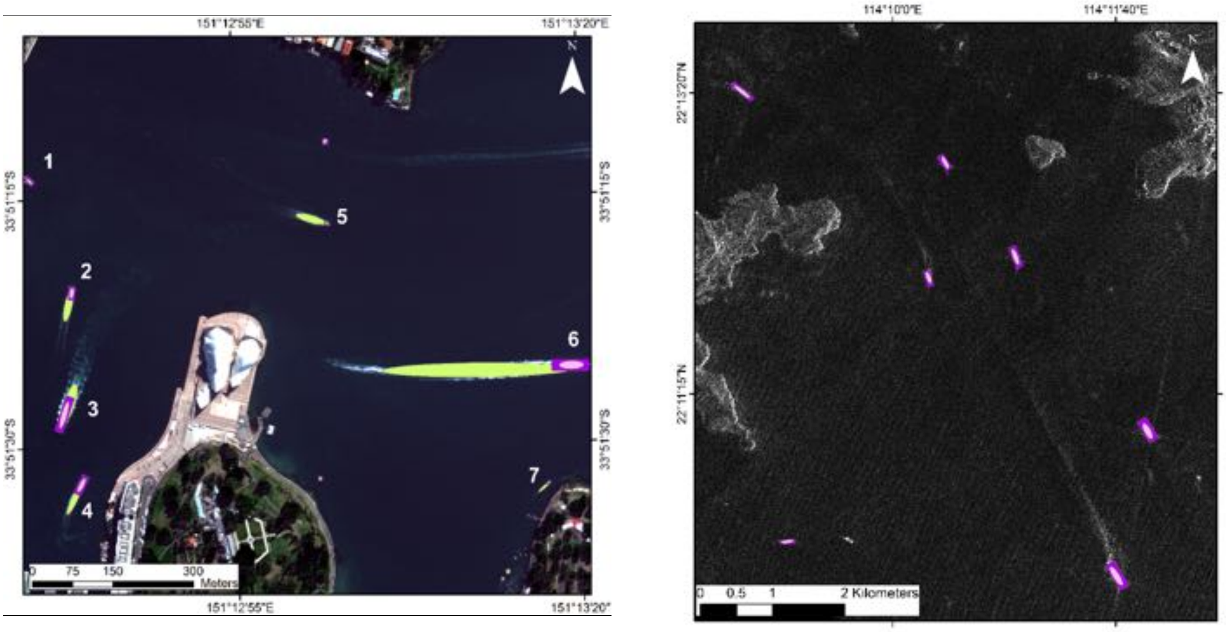


Figure 4-12 - Example of fitting the objects detected (ships and wakes) with ellipses and rectangles over an optical image (on the left) and a SAR image (on the right). Ships' ellipses are in light pink, ships' rectangles are in purple and wakes' ellipses are in light green. According to the processing chain, wakes are not detected in the SAR image.

ID	**Position of the ship centroid**		**Shiplength**	**Heading**	**SpeedRange**
	East	South	[m]	[Degrees]	[Knots]
1	151°12'40.470"	33°51'13.806"	13.80	120.74	5-10
2	151°12'43.401"	33°51'20.595"	19.72	12.42	2-10
3	151°12'42.695"	33°51'27.944"	51.92	198.48	10-20
4	151°12'43.854"	33°51'32.212"	28.84	25.84	2-10
5	151°13'2.0260"	33°51'16.649"	8.04	105.74	5-10
6	151°13'19.536"	33°51'25.450"	45.86	89.35	10-20
7	151°13'17.809"	33°51'32.526"	5.24	48.47	5-10

Table 4-7: Example of movement parameters calculated for of the vessels in Figure 4-12.

5 RESULTS

Regardless the type of data use for object extraction, a set of attributes is provided for each detected ship, as shown in Figure 5-1. As no AIS data was available for dates and location corresponding to optical data, the algorithm validation has been retrieved by manually measuring length and heading of visible ships. AIS data were instead available for the majority of the ships in SAR images, so it has been possible to compare the algorithm estimates to real information.

Position	E [m]	12°20'44"
	N [m]	45°25'56"
Length	[m]	7
Direction	Clockwise respect to the north	115°
Speed range	[knots]	(≤)5-10

Figure 5-1 – Final result of the detection: for each vessel (here identified through pink dots) a set of attributes (position, length, direction and speed range) is provided.

5.1 SHIP DETECTION IN OPTICAL IMAGES

5.1.1 Ship detection in high spatial resolution images

Figure 5-2 shows scatterplots of measured and estimated ship lengths and headings for high spatial resolution optical images (WorldView-2, GeoEye-1 and QuickBird-2).Results are referred to a sample of 50 ships represented in the three images. Overestimates of the rectangle length and underestimates of the ellipse respect to their mean value are shown by upper and lower error bars respectively. Big vessels are underestimated, while small vessels (length < 20 m) shows higher dispersion. Computed $R^2$are 0.8612 for lengths and 0.9946 for headings, which, are almost aligned over the 45° line.

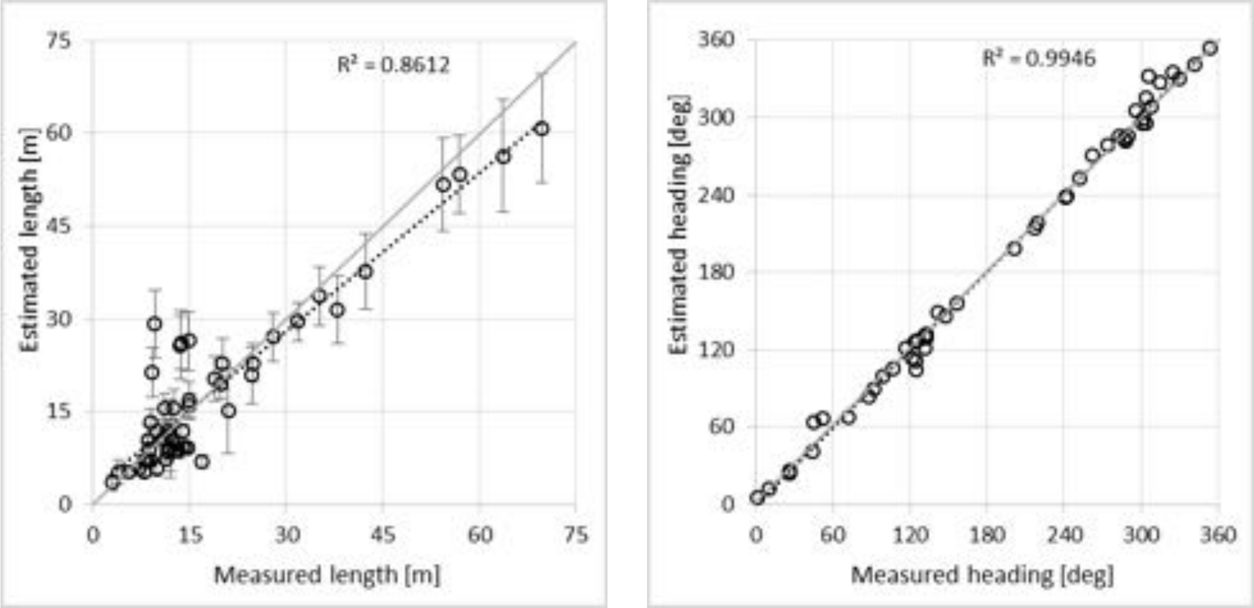


Figure 5-2 – Scatterplots of measured and estimated ship length (on the left) and heading (on the right) for high spatial resolution optical images (WorldView-2, GeoEye-1 and QuickBird-2). The grey line has a unity slope.

Then, available ships have been divided into three length classes (class 1: 0-15 m; class 2: 16-30 m; class 3: >31 m) and the percentage of correctly classified misclassified and not classified ships has been determined. "Correctly classified" means that estimated length falls into the same class of the measured length; "misclassified," means that estimated class is different from the measured class; "not classified" means that the ship has not been detected by the algorithm. In high spatial resolution images, no missed detection has been retrieved and almost 80% of class 1 and class 2 vessels and 100% of class 3 have been correctly detected (Figure 5-3). Less than 25% of class 1 and class 2 vessels have been misclassified; anyway, the presence of a vessel it is a reliable information for authorities.

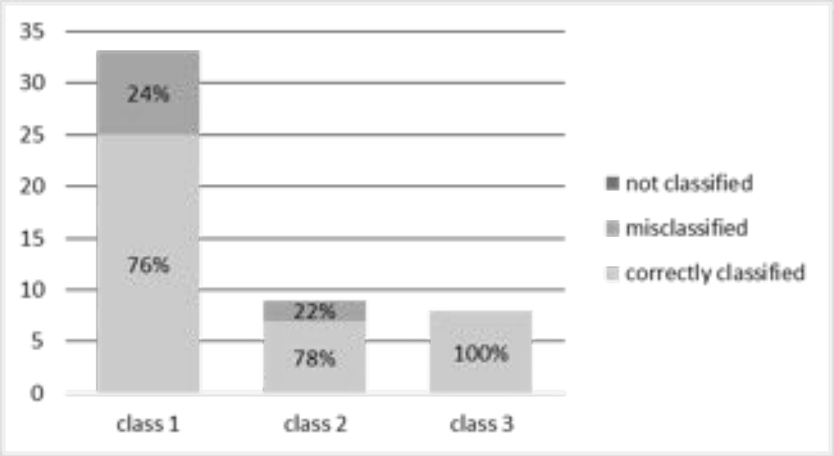


Figure 5-3 – Histogram showing percentage of correctly classified, misclassified and not classified vessels according to their length for three length classes (class 1: 0-15 m; class 2: 16-30 m; class 3: >31 m) in high spatial resolution optical images (WorldView-2, GeoEye-1 and QuickBird-2).

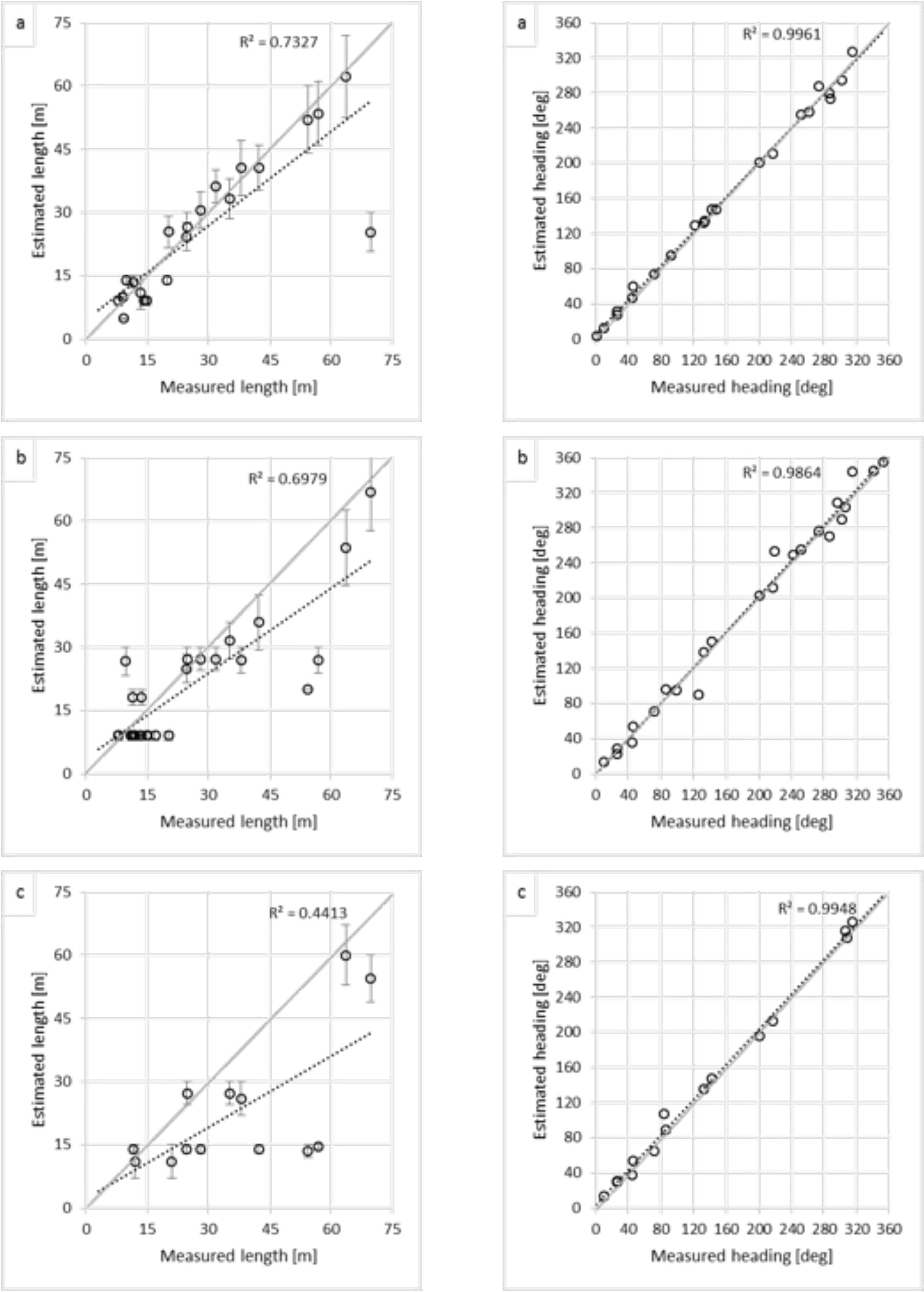


Figure 5-4 - Scatterplots of measured and estimated ship length (on the left) and heading (on the right) for medium spatial resolution optical images simulated at 5 m (a), 10 m (b) and 15 m (c). The grey line has a unity slope.

5.1.2 Ship detection in medium spatial resolution images

Results in simulated medium resolution imagery (5-meters, 10-meters and 15-meters) worsen when spatial resolution decreases; in particular, estimated length values are more dispersed (Figure 5-4) and the percentage of misclassified or not classified vessels increases in 10-m and 15-m images (Figure 5-5). On the other hand, headings keep on being accurately estimated (R^2 values are almost 0.99), since wakes define longer and easier to detect objects than ships. In addition, almost 60% of class 1 and class 2 vessels have been correctly detected in 10-m resolution images (Figure 5-5). This confirms the possibility to retrieve medium spatial resolution sensors, as ESA's Sentinel-2, to accurately and widely monitor vessels less than 30 m long, which are effectively used by smugglers in Mediterranean Sea.

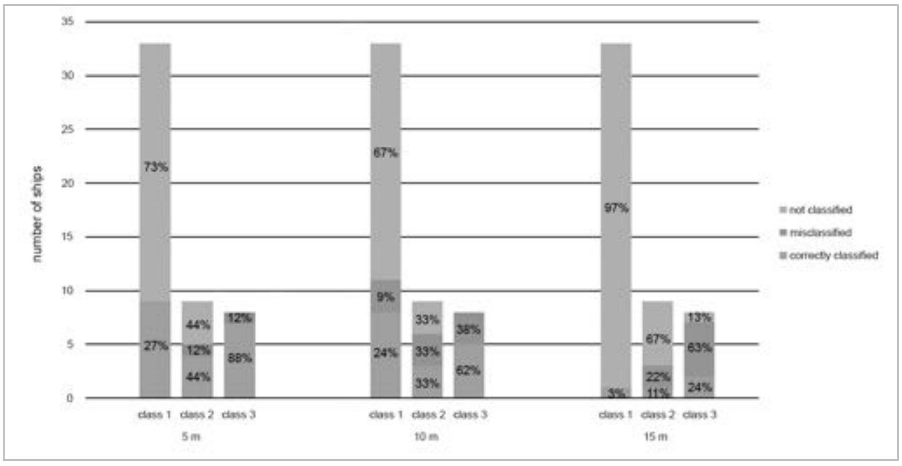


Figure 5-5 - Histogram showing percentage of correctly classified, misclassified and not classified vessels according to their length for three length classes (class 1: 0-15 m; class 2: 16-30 m; class 3: >31 m) in simulated medium spatial resolution optical images (5 m, 10 m and 15 m).

The dataset comprised two real medium resolution images acquired by RapidEye and Formosat-2 sensor (spatial resolution of 5 m and 8 m, respectively). Respect to high spatial resolution images, much less vessels were available in these images. Results for length estimate seem better respect to high resolution images (Figure 5-6), due to the presence of two huge vessels; when removing them, the accuracy in length estimate reaches 0.8414, which is comparable to the high resolution case. Vessels lower than 75 meters, thus belonging to all classes, are all overestimated (Figure 5-6). While in the 5-m simulated images estimated ships lengths are almost distributed around the 45° line, in the RapidEye image, which has the same spatial resolution, vessels length are all overestimated. Respect to the Formosat-2 image, the 10-m resolution simulated image shows a higher dispersion of estimates, with a prevalence in underestimates respect to overestimates. In the Formosat-2 image, ships smaller than 75 meters are slightly overestimated. Ships heading is always estimated with a very high accuracy (almost 1). While biggest ships have been correctly detected, vessels belonging to the first two classes have been completely misclassified (Figure 5-7). No missed detection came out for any of the three classes.

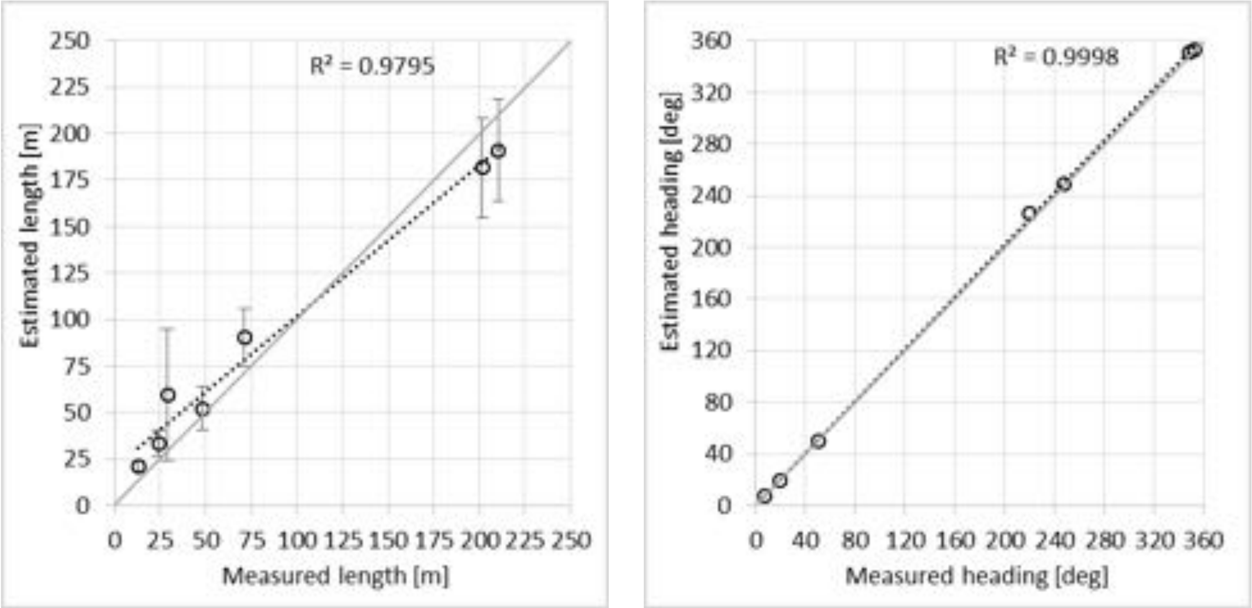


Figure 5-6 - Scatterplots of measured and estimated ship length (on the left) and heading (on the right) for medium spatial resolution optical images (RapidEye and Formosat-2). The grey line has a unityslope.

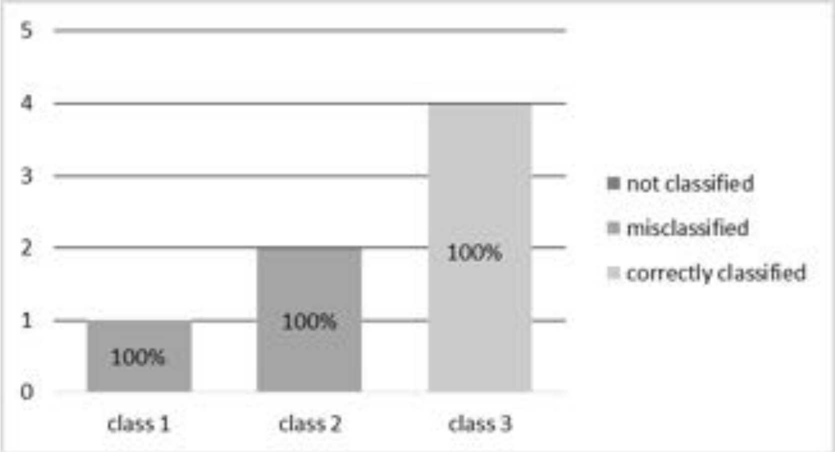


Figure 5-7 - Histogram showing percentage of correctly classified, misclassified and not classified vessels according to their length for three length classes (class 1: 0-15 m; class 2: 16-30 m; class 3: >31 m) in medium spatial resolution optical images (RapidEye and Formosat-2).

5.2 SHIP DETECTION IN SAR IMAGES

Different authors reports estimates of error for ship length declared by commercial AIS systems [Vachon P.W., 2007, Harati-Mokhtari A. et al., 2007]. Thus, available AIS data have been correlated to manual lengths (Figure 5-8); as results are reliable (R^2 = 0.9976), estimated length have been validated through AIS data. AIS and estimated lengths have been divided by 5, 10 and 20 according to the corresponding image resample factors. R^2 values for ships lengths range between 0.70 and 0.94, whereas those for heading estimates remains stable at approximately 0.99 (Figure 5-9). As in optical images, the percentage of misclassified and not classified vessels decreases while ship length increases (Figure 5-10). Almost 55% and 90% of class 1 and class 2 vessels respectively have been detected in available images, confirming the effectiveness of the described algorithm to detect small-medium (15-40 meters long) vessels.

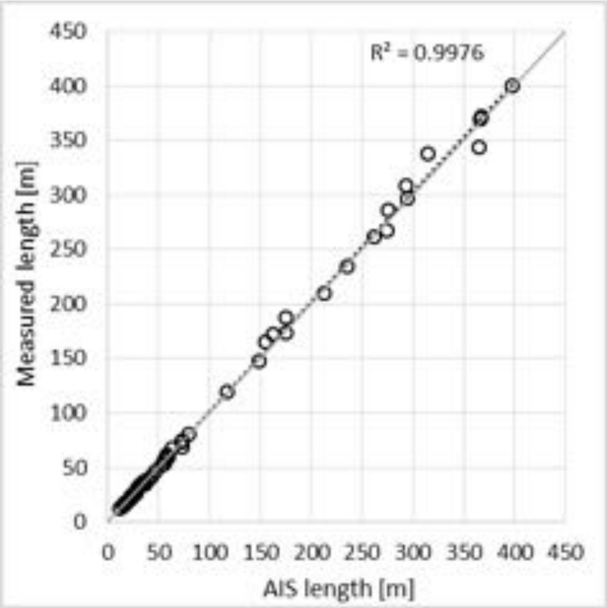
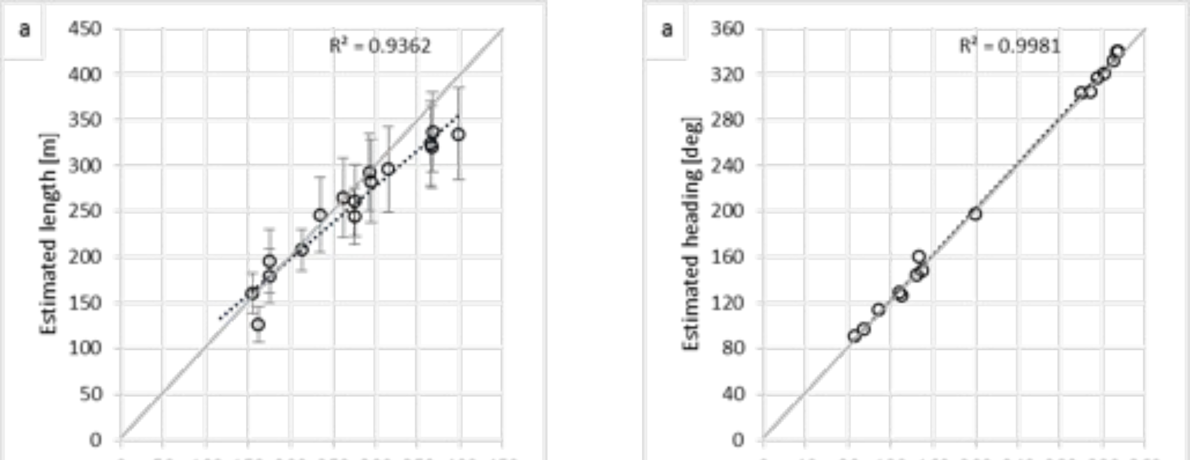


Figure 5.8 - Scatterplots of AIS and measured ship length in SAR images. The grey line has a unityslope.



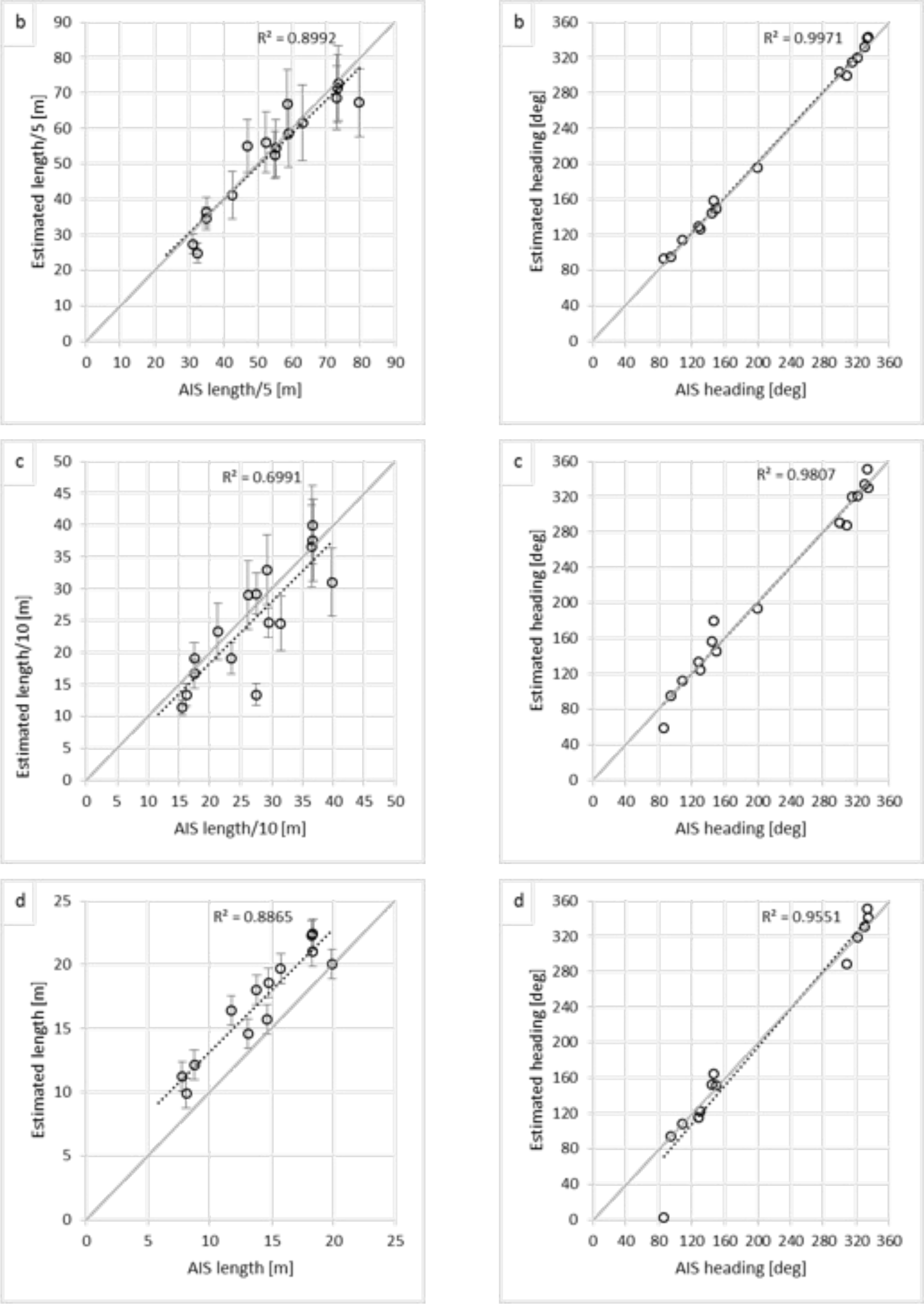


Figure 5-9 - Scatterplots of measured and estimated ship length (on the left) and heading (on the right) for SAR images at the full resolution of about 3 m (a), 15 m resolution (b), 30 m resolution (c) and 60 m resolution (d). The grey line has a unity slope.

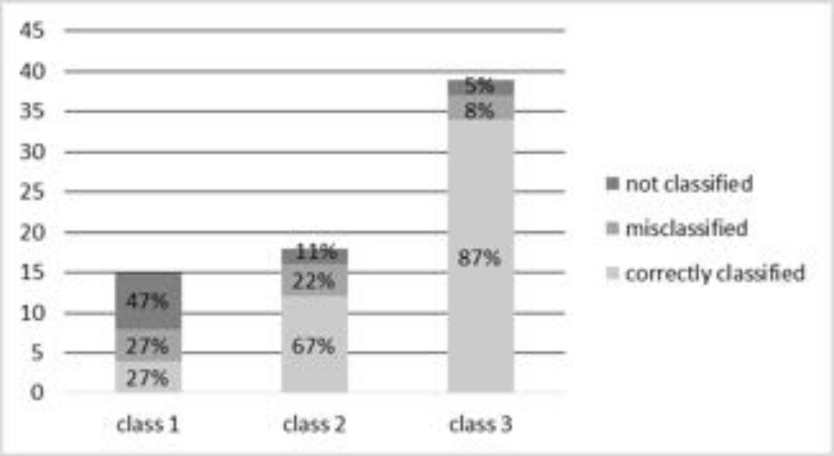


Figure 5-10 - Histogram showing percentage of correctly classified, misclassified and not classified vessels according to their length for three length classes (class 1: 0-15 m; class 2: 16-30 m; class 3: >31 m) in SAR images.

5.3 SATELLITE SCHEDULING

The planner and the simulation framework have been tested in the different operative modes. All the simulations involved a 24 hours scenario; the number of satellites and targets have been reported in Table 5-1. Realistic lighting conditions and derived constraints have been considered, whereas clear sky has been assumed. Satellites to ground stations contacts have been evaluated on the base of geometrical (line of sight and minimum angle above the horizon) considerations.

	Satellite Group	**Target**
Sea Monitoring	COSMO-SkyMed (CSK)	Southern Mediterranean
Ports Monitoring	Copernicus (Optic only)	13 Libyan Ports
Tracking	Copernicus (Optic only)	19 unknown vessels

Table5-1: Simulated Scenarios.

5.4 SEA MONITORING

A test problem has been created to evaluate the effectiveness of the proposed approach. The planning algorithm has been applied to the 4 COSMO-SkyMed satellites for a 1-day monitoring scenario involving 30 meters long unknown vessels. The 3 considered ground stations, for commands uplink and data download, are Fucino, Matera (both in Central Italy) and Neustrelitz (NE Germany).

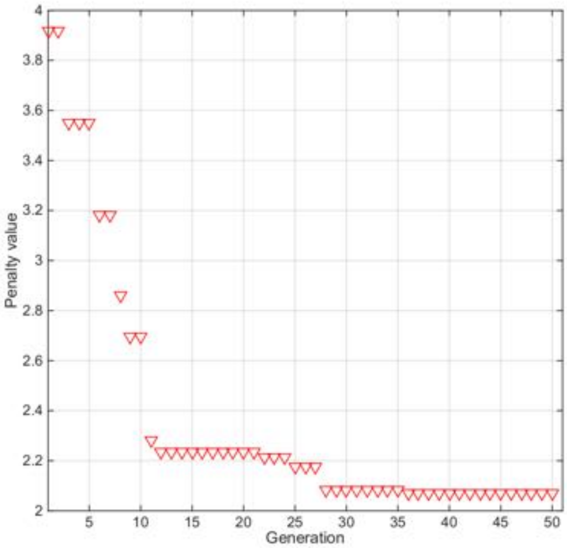


Figure5-11: Typical GA convergence.

	Coverage [%]	Fitness [-]
Min	41.75	1.9534
Mean	46.23	2.054
Max	49.43	2.2376
Std Dev	1.55	0.061

Table 5-2: Coverage and fitness range.

Considering both ascending and descending orbits, there are 10 passages that could be exploited; every passage stretches over nearly 600 km, whereas single swaths are less than 100 km wide. Figure 5-11 shows the convergence of the solution fitness. Tests have been conducted to estimate the accuracy and the consistency of the solver, by repeating the same scenario 100 times using different seeds to start the GA, see Table 5-2. In general, the solver does not converge to the best known solution; this is due to the GA parameters (population, number of generations and convergence tolerance) that, at this stage, have been chosen to enhance simulation speed over accuracy.

Another aspect that influences the convergence is the spatial resolution used to create M. More specifically low resolution maps could lead to inaccurate evaluations of the area to be covered, increasing the number of tiles marked as "overlapping" form swaths attributed to different satellites; that would result in inconsistencies in the total fitness evaluation.

Achieved coverage experiences significant variation among the proposed solutions; this is attributed to the GA fitness function that aims at maximize the weighted coverage, not just the total surface. A sample solution for the test problem has been reported in Figure 5-12. The swaths cover the 47.6% of the target area; there are overlapping between ascending (SE-NW oriented) and descending observations (NE-SW). The simulated scenario included 8 unknown vessels, 6 docked and 2 at sea at the beginning of the simulation; 2 of them have been observed, as well as several commercial vessels. Some vessels, as C61, appear repeated times in the figure; satellites passages are not simultaneous, resulting in possible multiple observation of the same vessel along its route. In order to maximize the swath, resulting SAR resolution (at best 3-4 pixels per vessel) is too coarse to investigate harbors.

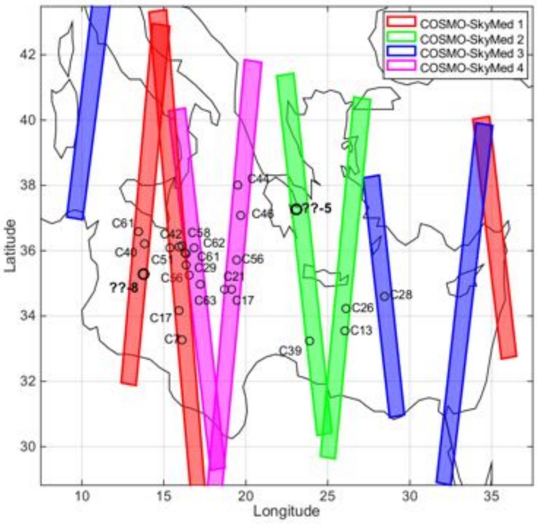


Figure 5-12: Monitoring, planned swaths and observed vessels.

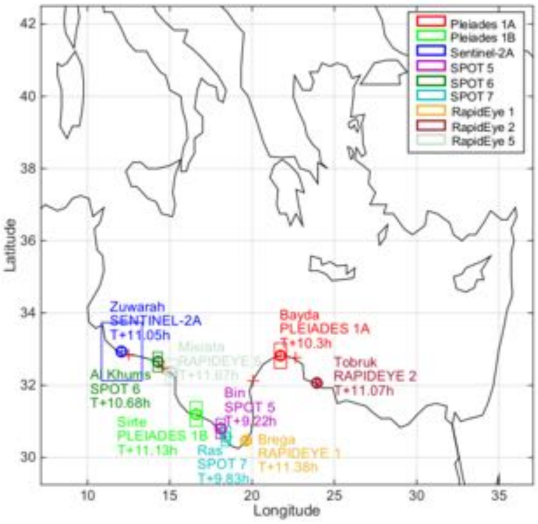


Figure 5-13: Scheduled ports observations.

5.5 HARBORS MONITORING

Planner capacities have been tested using a scenario involving 13 locations along the Libyan coast and a set of 11 imaging satellites; satellite-targets coupling and time of the observation have been documented in Table 5-3 (targets have been order along the coastline from left to right). Figure 5-11 illustrates the boundaries of the areas observed by the satellites with respect to the ground targets. 11 satellites have been considered, although only 9 could have been exploited. The eliminated passages have been discarded either because no targets have been within their sensors range or due to their download time, later than the scenario end-time, thus making them unable to deliver the information.

Satellite	Target Id	Time
Pleiades 1A	6 to 13	T+10.3h
Pleiades 1B	1 to 10	T+11.13h
Sentinel-2A	1 to 3	T+11.05h
SPOT 5	7, 8	T+9.22h
SPOT 6	1 to 5	T+10.68h
SPOT 7	8 to 13	T+9.83h
RapidEye 1	6 to 10	T+11.38h
RapidEye 2	11 to 13	T+11.07h
RapidEye 5	1 to 5	T+11.67h

Table 5-3: Satellites-Targets couplings.

Target Id	Value
1	.54
2	.08
3	.11
4	.01
5	.33
6	.04
7	.17
8	.18
9	.33
10	.12
11	.23
12	.01
13	.55

Table 5-4: Targets fitness value.

The passages are bounded in a 1.5 hours window, as all the satellites use similar orbits to ensure the best lighting conditions. The value of the targets has been summarized in Table 5-4. Simulation results are illustrated in Figure 5-13; the highest fitness ports, Tobruk (Id 13, value .55), Zuwarah (Id 1, value .54), Misrata and Brega (Id 5 and 9, value .33), Bayda (Id 11, value .23) Ras (Id 8, value .18) have been observed along with 2 less interesting targets. Squared areas in the Figure highlight the limits of the observed areas; as images are centered at the target coordinates, not only the sea, but also part of the surrounding lands are spotted for possible intels.

5.6 TRACKING

The tracking test case involved the observation of 19 target vessels. Initial positions and routes have been reported in **Error! Reference source not found.**Figure 5-14. Ships whose name starts with double question marks (??) were at sea at the beginning of the simulation, whereas names with structure "?-x-y" have been used to indicate the y-th vessel docked in port "x". Docked vessels departure time and route have been assumed as known; anchored ships have just been used as test, to evaluate the planner capacity to include targets that have a time-conditioned behavior; in a real situation the a priori knowledge of a smuggler's ship departure time is unlikely.

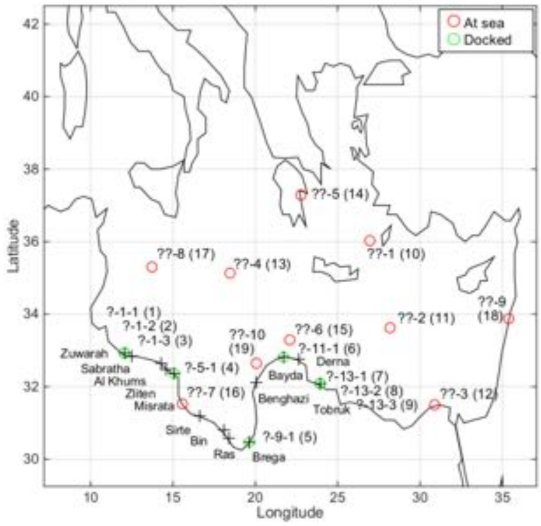


Figure 5-14: Tracked vessels initial position.

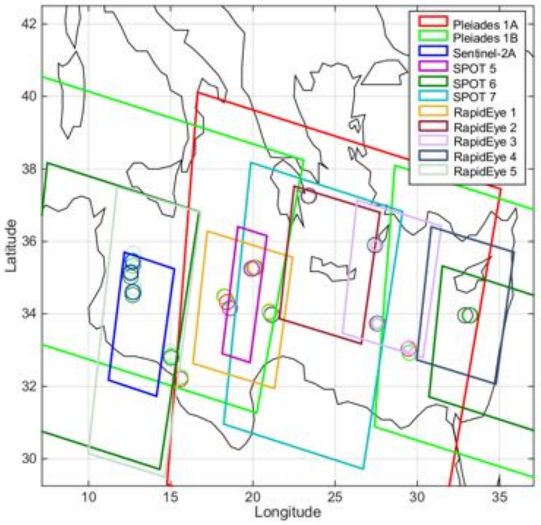


Figure 5-15: Satellites sensor range compared with vessels to be tracked.

The targets have the same fitness value. The simulation timeframe is the same used for the ports monitoring; due to the wider geographical distribution of the targets (over 20 degrees in longitude, whereas ports monitoring targets were concentrated in less than 10 degrees), some of the satellites are able to exploit 2 useful passages within one day, close to the eastern and western boundaries respectively. In this case multiple observations from the same satellite during the same day are allowed by the used planning rules, as they are performed during different passages. Both Pleiades 1B and SPOT 6 have 2 useful passages close to the outer boundaries of the region of interest, Figure 5-15 and, compared with the monitoring case, a larger number of satellites is able to acquire at least on target. The circles represent the estimated position of the vessels at the observation time (docked ships have been considered legitimate targets only after their departure).

Satellite	Target Id	Time
Pleiades 1A	10 to 16, 18, 19	T+10.3h
Pleiades-1B	12, 18	T+9.55h
	1 to 4, 13, 15, 16, 19	T+11.13h
Sentinel-2A	1 to 3	T+11.05h
SPOT 5	13, 19	T+9.22h
SPOT 6	18	T+9.03h
	1 to 4	T+10.68h
SPOT 7	10, 11, 13 to 15	T+9.83h
RapidEye 1	13, 15, 19	T+11.38h
RapidEye 2	14	T+11.05h
RapidEye 3	10 to 12	T+10.65h
RapidEye 4	18	T+10.32h
RapidEye 5	1 to 4	T+11.67h

Table 5-5: Satellites-Vessels couplings.

A resume of the vessels inside each satellite sensor range has been documented in Table 5-5; 13 observations are possible. Targets 5 to 9 have not been observed as they are docked during satellites passages; target 17 (??-8), whose starting position was close to the Italian Islands, has been able to reach the shore undetected. Planning results have been illustrated in Figure 5-16. The dashed lines represent the route from the initial position till the satellite observation. The continuous lines highlight the progressively growing extension of the propagated position uncertainty after the observation with a 2 hours interval. 12 out of 13 observations have been used; satellite RapidEye 4 had a single target, ??-9, that was also the unique valid target for SPOT 6 first passage (a few minutes earlier). As the target had been already acquired, RapidEye 4 passage has been skipped. Convergence (as for the port's monitoring case) is faster than the sea monitoring problem due to the smaller size of the problem and better "discretization" of the possible outcomes. Fitness is not derived by maps overlapping with possible rounding problems instead observations of specific targets is a strictly boolean condition, thus leading to non-ambiguous results. The combination of known vessels route (C-named) and estimated path (tracked targets) has been shown in Figure 5-17. The circles and triangles indicate the positions of the known and unknown vessels at time of the minimum distance.

Vessels route and speed have been considered constant in order to estimate the minimum crossing distance; due to environmental conditions and human factors, this is a reasonable approximation only for limited timeframes (a few hours). Possible crossings have been reported when the minimum distance is within 16 km, that is approximately the limit distance to spot an object that is 2 meters above the sea level (as a tug) from a 10 meters elevated deck.

Similarly to the ports monitoring, scheduled acquisitions are aimed on the target location, the estimated position in this case that, due to EKF working principle, is the most likely position given the available information. However, due to the uncertainties associated both to the observation and the previous states, the actual ship position is better represented by an ellipse, whose orientation and size depends on the reliability of the observations. Optical satellites common acquisition pattern returns images that have similar sides dimensions (nearly squared), thus they can observe the central region of the ellipse, but are ill-coupled with highly elongated ellipses.

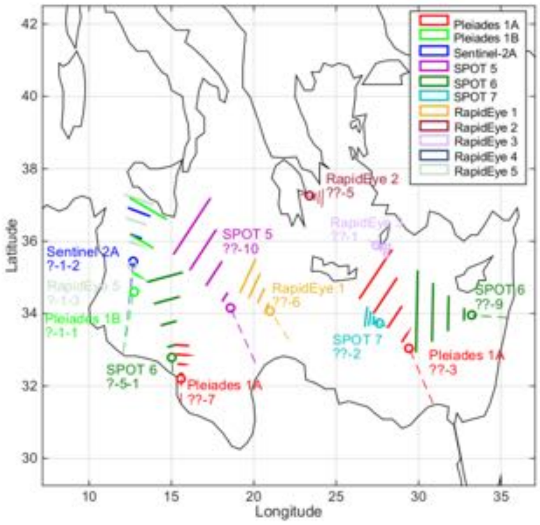


Figure 5-16: Vessels under tracking.

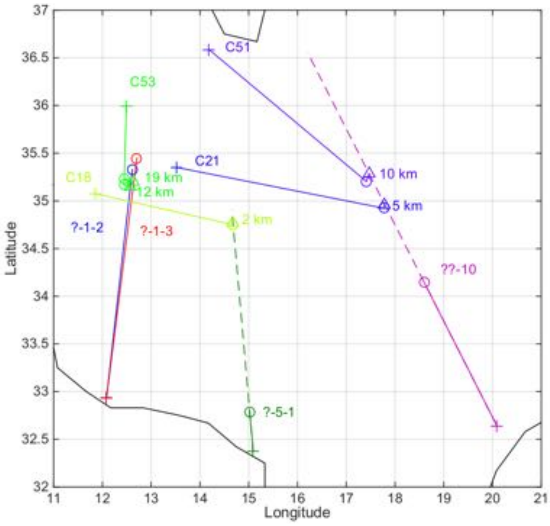


Figure 5-17: Closest approach estimations.

6 DISCUSSION

6.1 VESSEL DETECTION

Object based image analysis is not a common approach for ship detection in optical imagery. Just one study based on this kind of algorithm has been found in literature; Willhauck et al., 2005 described a ship detection approach within harbor areas in VHR satellite images. However, Space Shepherd operates in different conditions: targets are mainly small isolated vessels moving in an open sea, which, differently from port areas, can be characterizedby waves and high sea roughness that can easily generate false positives detection. This situation is even made more complicated by modification of sea state in the different images, which can, thus, change the number of false alarms. Through the object based analysis, the proposed approach can efficiently remove false positives in the classification phase, which makes use of geometric parameters typical of real ships.

In order to perform the three operative modes (Monitoring, Tracking and Search&Rescue), Space Shepherd infrastructure requires specific characteristics to the ship detection algorithm. First, as Mediterranean Sea is crossed everyday by thousands of different ships, a sufficient accuracy is needed in the identification of vessels position, heading and dimension, in order to correctly detect illegal vessels and separate them from legal ships. As stated in the previous section, positive results in the identification phase have been retrieved.

Then, the system works in maritime awareness situation, were time is an important factor to reach the objectives. Thus, simplicity and robustness are two important aspects that the automatic algorithm has to respect. In this way, the object oriented approach requires a moderate computational complexity and it makes use of only three parameters respectively for segmentation and classification and. In addition, respect to other algorithms described in literature, object-based approach is more adaptable to different environments, as the same process has been applied to images acquired by different sensors in various atmospheric and sea conditions and even characterized by different spatial resolution.

Moreover, images processed in Space Shepherd does not only rely on one acquisition technology, but, having complementary characteristics, both optical and radar data are necessary for a continuous activity. Optical imagery allows to detect vessels made of low-radar scattering material; however, sunlight is required for observation and clouds can obscure the field of view. On the contrary, SAR works better with metallic targets and it is able to acquire data also during the night and independently from meteorological conditions. Except for pre-processing operations and filtering techniques, the object oriented approach is valuable for both optical and radar data.

In SAR data, the object based analysis has been applied after performing the CFAR algorithm, which is one of the most frequently adopted procedures for ship detection, due to its simple statistical methodology. CFAR detects bright pixels over dark background, thus, in addition to ship targets, it also identifies sea clutter, which often characterizes SAR imagery. The object based algorithms allows to remove false positive detection over the image processed by CFAR. Traditionally, CFAR detectors rely on a K distribution for sea clutter model. Here we have chosen a Gaussian model combined to ad hoc post processing, due to its fast implementation, and retrieved results are encouraging. However, the described method has some shortcomings, too.

A lower detection accuracy is retrieved for both fast moving ships, as in optical images their bright wake can be easily confused with the ship itself, and very slow moving vessels, whose wake could not be visible.

To monitor vessel movements, ship speed is an important parameter to provide; actually, the algorithm is not able to accurately estimate ship speed, but only a speed range based on ship length is provided. While, speed estimate is not so common for optical images, ship speed estimate over SAR image has been intensively studied (though it is often not a straightforward task), and suggested techniques mainly rely on a Fourier transform. Thus, an integration of the proposed processing would include a ship speed estimate phase, through existing or ad-hoc algorithms.

Moreover, optical data results have not been validated with real AIS data, as they were not available for the correspondent timestamp, thus adding some uncertainty to final results.

Finally, testing the process on a real scenery, could help in tuning the algorithm on real sea and atmospheric characteristics of the Mediterranean Sea, thus, maybe, improving detection performances and reduce the number of false detections. This could be particularly important for ship detection over SAR images, where false alarms are mainly related to environmental conditions (winds and waves can create strong returns, making the ship difficult to distinguish from the background [P. A. Mallas and H. C. Graber, 2013]) which occur during the observation time. Various aspects which concern the radar system can have an influence on vessel detection rates; resolution, number of looks, incidence angle, polarization, and the orientation of the ship with respect to the radar play a role [Greidanus H., 2005]. In addition to possible high sea clutter background, azimuth ambiguity patterns (shifted in azimuth weak replicas of image features) can represent a significant problem to ship detection algorithms [Werle D., 1997].

As medium resolution simulations have provided positive results, the described algorithm has been applied to a real Sentinel-2 image acquired over Copenaghen. The characteristics of this satellite in terms of swath and revisit time, make it particularly useful for monitoring purposes. Only the four 10 meters resolution bands have been used in the processing (Table 6-1), being comparable to the bands of the previously used optical images. Being a testing phase, some parameters are different from those used for the simulated 10-m resolution image. Some detection results are shown in Figure 6-1.

Respect to the 10 meters simulated image, results for processing over the Sentinel-2 image have shown better results. The systematic length underestimate for ships longer than 30 m in the 10-m simulated image, disappears in the Sentinel-2 image; computed R^2 for ship length is 0.9195. The accuracy for heading estimates reaches 0.8104 (Figure 6-2) and increases to 0.9350 when removing two zero heading estimates, which belongs to small vessels having weak wakes.

			Spatial resolution (pixel size) [m]		Available Spectral Bands
Sensor	Acquisition Data	Location	Multispectral band	Panchromatic Band	[µm]
Sentinel-2	06/08/2015	Copenaghen (Denmark)	10	-	0.457 - 0.522 (B) 0.543 - 0.577 (G) 0.650 - 0.680 (R) 0.785 - 0.899 (NIR)
			20	-	0.697 - 0.712 (NIR-B5) 0.732 - 0.747 (NIR-B6) 0.773 - 0.793(NIR-B7) 0.855 - 0.875 (SWIR-B8a) 1.565 - 1.655(SWIR-B11) 2.100 - 2.280(SWIR-B12)
			60	-	0.433 - 0.453 (B) 0.935 - 0.955 (NIR) 1.360 - 1.390 (SWIR)

Table6-1 – Sentinel-2 image maincharacteristics

As shown in Figure 6-3, no missed detections have been retrieved; class 1 vessels have been quite completely misclassified, but, as stated in previous sections, this can be anyway a reliable information. Respect to class 2 and class 3, 88% and 100% of vessels respectively have been correctly detected, compared to 33% and 63% in the 10-m simulated resolution image.

Thus, applying the process to Sentinel-2 images, allows to detect vessels which can represent possible Space Shepherd targets, as the minimum length of the ships in the image is 20 m.

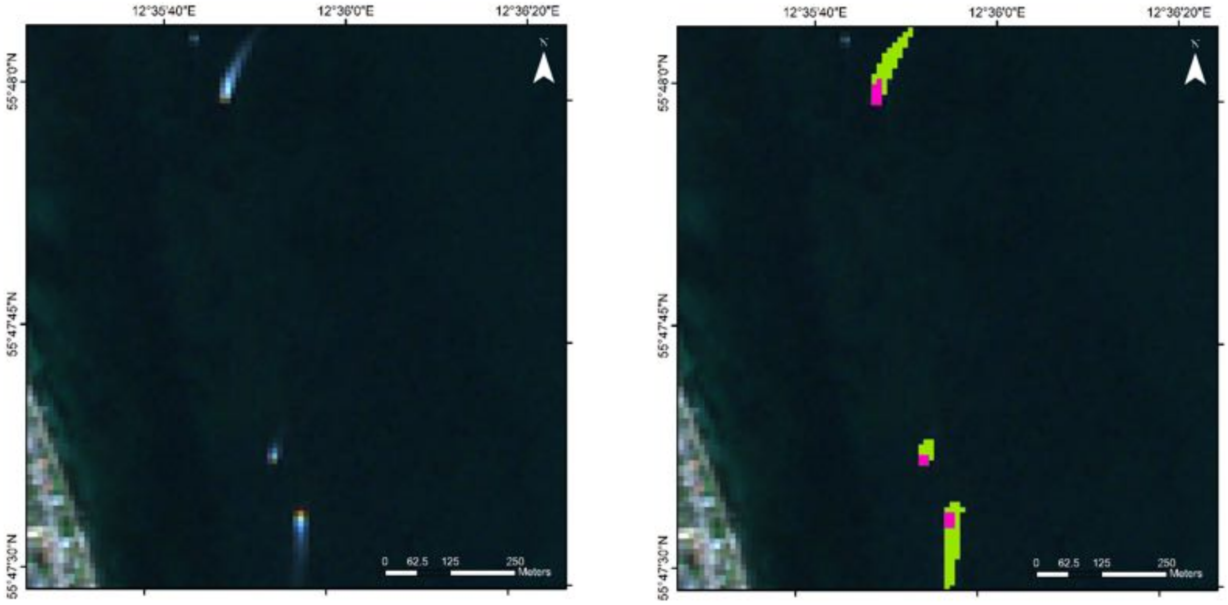


Figure 6-1 – Portion of a Sentinel-2 image acquired over Copenaghen (on the left) and the respective ship detection algorithm results (on the right). Vessels in this image have a length comprised between 20 and 30 meters.

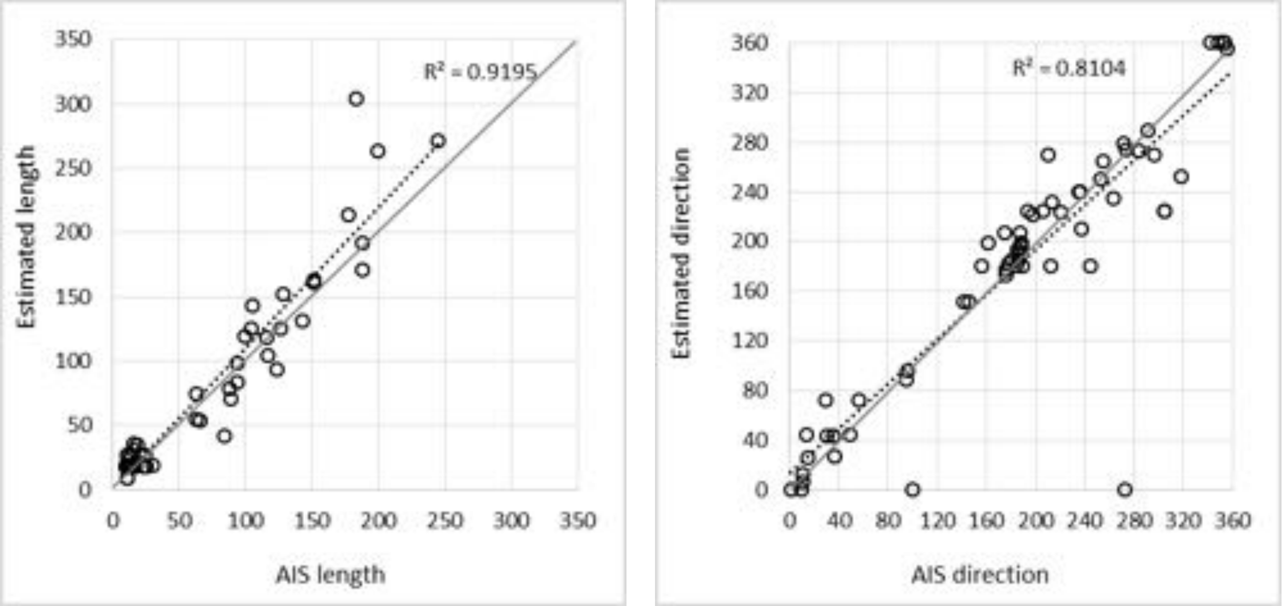


Figure 6-2 - Scatterplots of AIS and estimated ship length (on the left) and heading (on the right) for medium spatial resolution Sentinel-2 image. The grey line has a unity slope.

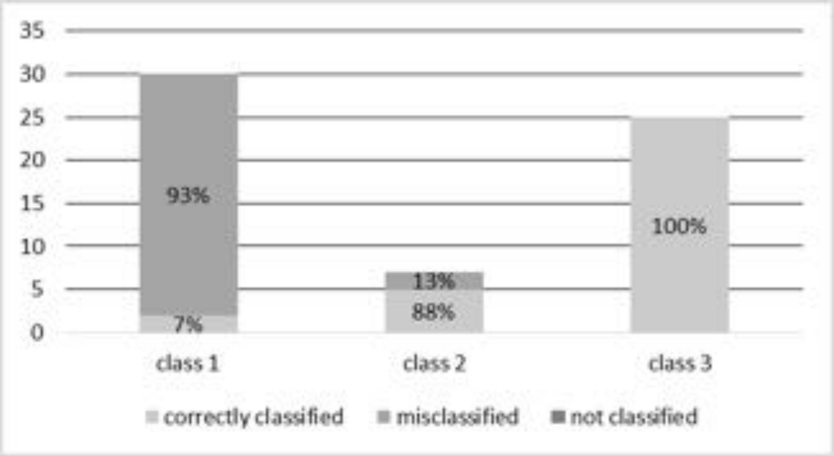


Figure 6-3 - Histogram showing percentage of correctly classified, misclassified and not classified vessels according to their length for three length classes (class 1: 0-15 m; class 2: 16-30 m; class 3: >31 m) in medium spatial resolution Sentinel-2 image.

6.2 OBSERVATIONS PLANNING

A study has been conducted to assess the feasibility of using existing space assets to monitor the migration flow in the Southern Mediterranean Sea. In order to quantify the performances of such an integrated system, a simulator has been developed. This is made of a core module that tries to extract information on vessels position, velocity, and heading through elaboration of optical and SAR images.

The results show the merit of our intuition, the system being efficient in terms of coverage gaps and cycle response times. The implemented planning algorithms, although created to address a simplified scheduling problem, have shown that the planning itself is not a major obstacle in the creation of a satellite monitoring system. The adopted strategy to solve the scheduling problems, although non optimal in terms of computation efforts, returns consistent results with running times of minutes or less depending on the complexity of the scenario.

The introduction and the comparison with more suitable algorithms will be investigated. The exploit of the satellites could be improved by allowing non-centered observations in order to acquire multiple, nearby targets, however this would also reduce the reliability of the tracking as the non-centered images have less probability to contain the real target position. The monitoring of the African ports efficiency would be limited as single-out migrants-related and normal fishery vessels would be extremely difficult; however, this monitoring application would prove valuable to spot non-official harbors close to smugglers rally points.

Sea monitoring main obstacle are the limited global coverage and the non-realtime capacity (that also affects the tracking); aiming for less than 20 meters long boats with the CSK constellation alone, the observed surface would be inferior than the 20% of the waters between South Italy and Libya. Depending on the geometry of the orbit and the ground station, the worst-case scenario could involve hours of delay before the images are downloaded.

Considering these constraints, a more comprehensive satellite, air/sea patrols and land-based radars system would be advisable, as it would improve the responsiveness close to the Italian coastline and would be able to use the satellites to explore the most remote areas. The basic scheduling strategy proposed could be extended to exclude the areas covered by the fixed radars and to evaluate dynamically the Sea surface including the movements of the patrols.

The system could, if implemented with adequate resources, allow the observation of regions that are beyond the range of fixed radar installations without the need for air or sea patrols, with limited costs due to exploitation of existent assets. However this also represents its main limitation: the combinations of differently build and operated satellites has performances (assuming equal number of satellites) that are inferior to a dedicated constellation (that would need several years of development and billions to finance it). International cooperation is a fundamental prerequisite in order to implement an efficient, satellite-based, sea surveillance system to support immigrants rescue operations.

ACKNOWLEDGEMENTS

This work has been supported by Politecnico di Milano through the Polisocial Award, Grant No. T5E4RIST00. The authors would like to acknowledge also the Italian Space Agency (ASI) and its “Centro Interpretazione Dati Osservazione della Terra” (ASI-CIDOT), the “Centro Militare di Studi Strategici” (CeMiSS), and Emergency for having endorsed the project.

REFERENCES

Smuggling of migrants into, through and from North Africa, United Nations Office on Drugs and Crime (UNODC), 2010.

Brian T. and Laczko F., (2014), Fatal Journeys. Tracking Lives Lost during Migration, International Organization for Migration.

Coluccello S. and Massey S., (2007), Out of Africa: The human trade between Lybia and Lampedusa, Trends Organ. Crim., 10:77-90.

Directive 2002/59/EC of the European parliament and of the council of 27 June 2002 establishing a community vessel traffic monitoring and information system and repealing council directive 93/75/EEC.

Directive 2009/17/EC of the European parliament and of the council of 23 April 2009 amending Directive 2002/59/EC establishing a community vessel traffic monitoring and information system.

Decreto Legislativo 19 agosto 2005, n. 196 - "Attuazione della direttiva 2002/59/CE relativa all'istituzione di un sistema comunitario di monitoraggio e di informazione sul traffico navale" (in G.U. n. 222 del 23 settembre 2005).

Decreto Legislativo 16 febbraio 2011, n. 18 - "Attuazione della direttiva 2009/17/CE concernente la modifica della direttiva 2002/59/CE relativa all'istituzione di un sistema comunitario di monitoraggio del traffico navale e di informazione" (in G.U. n. 58 dell'11 marzo 2011).

Decreto Ministeriale (Infrastrutture e trasporti) 23 luglio 2012 - Recepimento della direttiva 2011/15/UE della Commissione del 23 febbraio 2011 recante modifica della direttiva 2002/59/CE del Parlamento europeo e del Consiglio relativa all'istituzione di un sistema comunitario di monitoraggio del traffico navale e d'informazione (in G.U. n. 217 del 17 settembre 2012).

Eriksen T. et al., (2010), Tracking Ship Traffic with Space-Based AIS: Expereince Gained in First Months of Operations, Waterside Security Conference (WSS), 3-5 November 2010, Marina di Carrara.

Fargues P. and Bonfanti S., (2014), When the best option is a leaky boat: why migrants risk their lives crossing the Mediterranean and what Europe is doing about it, Migration Policy Centre, EUI.

Hannevik T. N. et al., (2010), Ship Detection using High Resolution Satellite Imagery and Space-Based AIS, Waterside Security Conference (WSS), 3-5 November 2010, Marina di Carrara.

IMO, 1974/1980, International convention for the Safety of Life at Sea (SOLAS), Chapter V "Safety of Navigation", Regulation 19.

Malakooti A. and Davin E., (2015), Migration Trends Across the Mediterranean: Connecting the Dots, International Organization for Migration.

Monzini P., Pastore F., Sciortino G., (2004), L'Italia promessa. Geopolitica e dinamiche organizzative del traffico di migranti verso l'Italia, CeSPIWorkingPapers, 9/2004.

Monzini P., (2008), Il traffico di migranti per mare verso l'Italia. Sviluppirecenti (2004-2008), CeSPI Working Papers 43/2008.

Monzini P., (2010), Smuggling of migrants into, through and from North Africa. A thematic review and annotated bibliography of recent publications, UNODC.

Ramona P. et al. (2014), Ship detection in SAR medium resolution imagery for mairtime surveillance: algorithm validation using AIS data, acts of the 35th Canadian Symposium of Remote Sensing (IGARSS), 13-18 July 2014, Québec, Canada.

Russo C., (2011), VTS, AIS e altri sistemi di monitoraggio del traffico marittimo, GIURETA Rivista di Diritto dell'Economia, dei Trasporti e dell'Ambiente, vol IX.

Sørensen N., (2006), Mediterranean Transit Migration, Danish Institute for International Studies (DIIS).

Vespe M., et al., (2008), Maritime multi-sensor data association based on geographic and navigational knowledge, RADAR Conference, 26-30 May 2008, Rome.

Wu F. et al., (2014), Vessel detection and analysis combining SAR imagery and AIS information, acts of the 35th Canadian Symposium of Remote Sensing (IGARSS), 13-18 July 2014, Québec, Canada.

Mallas, P.A. and Graber, H.C., 2013. Imaging ships from satellites. Oceanography, 26(2), pp. 150-155.

Greidanus, H., Clayton, P.J., Indregard, M., Staples, G., Suzuki, N., Vachon, P.W., Wackerman, C., Tennvassas, T., Mallorquí, J.J. and Kourti, N., 2004. Benchmarking operational SAR ship detection. IGARSS 2004, pp. 4215-4218.

Proia, N. and Pagé, V., 2010. Characterization of a bayesian ship detection method in optical satellite images. Geoscience and Remote Sensing Letters, IEEE, 7(2), pp. 226-230.

Bouma, H., Dekker, R.J., Schoemaker, R.M. and Mohamoud, A.A., 2013. Segmentation and wake removal of seafaring vessels in optical satellite images, SPIE Security Defence 2013, International Society for Optics and Photonics, pp. 88970B-88970B-11.

Kanjir, U., Marsetič, A., Pehani, P. And Oštir, K., 2014, An Automatic Procedure For Small Vessel Detection from Very-High Resolution Optical Imagery.

Corbane, C., Marre, F. and Petit, M., 2008a. Using SPOT-5 HRG data in panchromatic mode for operational detection of small ships in tropical area. Sensors, 8(5), pp. 2959-2973.

Corbane, C., Pecoul, E., Demagistri, L. and Petit, M., 2008b. Fully automated procedure for ship detection using optical satellite imagery, Asia-Pacific Remote Sensing 2008, International Society for Optics and Photonics, pp. 71500R-71500R-13.

Corbane, C., Najman, L., Pecoul, E., Demagistri, L. and Petit, M., 2010. A complete processing chain for ship detection using optical satellite imagery. International Journal of Remote Sensing, 31(22), pp. 5837-5854.

Saur, G., Estable, S., Zielinski, K., Knabe, S., Teutsch, M. and Gabel, M., 2011. Detection and classification of man-made offshore objects in terrasar-x and rapideye imagery: Selected results of the demarine-deko project, OCEANS, 2011 IEEE-Spain 2011, IEEE, pp. 1-10.

Jubelin, G. and Khenchaf, A., 2012. A statistical model of sea clutter in panchromatic high resolution images, Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International 2012, IEEE, pp. 424-427.

Guang, Y., Qichao, L. and Feng, G., 2011. A Novel Ship Detection Method Based on Sea State Analysis from Optical Imagery, Image and Graphics (ICIG), 2011 Sixth International Conference on 2011, IEEE, pp. 466-471.

Yang, G., Li, B., Ji, S., Gao, F. and Xu, Q., 2014. Ship detection from optical satellite images based on sea surface analysis. Geoscience and Remote Sensing Letters, IEEE, 11(3), pp. 641-645.

Abileah, R., 2009. Surveying coastal ship traffic with LANDSAT, OCEANS 2009, MTS/IEEE Biloxi-Marine Technology for Our Future: Global and Local Challenges 2009, IEEE, pp. 1-6.

Roskovensky, J.K., 2012, Technique for ship/wake detection, United States Patent, Patent No: US 8,170,282 B1, May 1, 2012.

Greidanus, H., 2005. Assessing the operationality of ship detection from space, EURISY Symposium New space services for maritime users: The impact of satellite technology on maritime legislation 2005.

Kadyrov, A., Yu, H. and Liu, H., 2013. Ship detection and segmentation using image correlation, Systems, Man, and Cybernetics (SMC), 2013 IEEE International Conference on 2013, IEEE, pp. 3119-3126.

Kourti, N., Shepherd, I., Greidanus, H., Alvarez, M., Aresu, E., Bauna, T., Chesworth, J., Lemoine, G. and Schwartz, G., 2005. Integrating remote sensing in fisheries control. Fisheries Management and Ecology, 12(5), pp. 295-307.

Dorado-Muñoz, L.P. and Velez-Reyes, M., 2011. Ship detection in MODIS imagery, SPIE Defense, Security, and Sensing 2011, International Society for Optics and Photonics, pp. 80480U-80480U-9.

Wu, G., De Leeuw, J., Skidmore, A.K., Liu, Y. and Prins, H.H., 2009. Performance of Landsat TM in ship detection in turbid waters. International Journal of Applied Earth Observation and Geoinformation, 11(1), pp. 54-61.

Partsinevelos, P. and Miliaresis, G., Ship extraction and categorization from ASTER imagery, 2nd International Conference on Remote Sensing &Geoinformation of Environment, 7-10 April, 2014, Pafos, Cyprus.

Dekker, R., Bouma, H., Den Breejen, E., Van Den Broek, B., Hanckmann, P., Hogervorst, M., Mohamoud, A., Schoemaker, R., Sijs, J. and Tan, R., 2013. Maritime situation awareness capabilities from satellite and terrestrial sensor systems. Proc.Maritime Systems and Technologies MAST Europe.

Lure, F.Y. and Rau, Y., 1994. Detection of ship tracks in AVHRR cloud imagery with neural networks, Geoscience and Remote Sensing Symposium, 1994. IGARSS'94. Surface and Atmospheric Remote Sensing: Technologies, Data Analysis and Interpretation, International 1994, IEEE, pp. 1401-1403.

Willhauck, G., Caliz, J.J., Hoffmann, C., Lingenfelder, I. and Heynen, M., 2005. Object-oriented ship detection from VHR satellite images. SemanaGeomática.

Burgess, D.W., 1993. Automatic ship detection in satellite multispectral imagery. Photogrammetric Engineering and Remote Sensing, 59(2), pp. 229-237.

Huang, G., Wang, Y., Zhang, Y. and Tian, Y., 2011. Ship detection using texture statistics from optical satellite images, Digital Image Computing Techniques and Applications (DICTA), 2011 International Conference on 2011, IEEE, pp. 507-512.

Kumar, S.S. and Selvi, M.U., 2011. Sea object detection using colour and texture classification. Int.J.Computer Appl.in Engineering Sciences IJCAES, 1(1), pp. 59-63.

Song, Z., Sui, H. and Wang, Y., 2014. Automatic ship detection for optical satellite images based on visual attention model and LBP, Electronics, Computer and Applications, 2014 IEEE Workshop on 2014, IEEE, pp. 722-725.

Xia, Y., Wan, S., Jin, P. and Yue, L., 2014. A Novel Sea-Land Segmentation Algorithm Based on Local Binary Patterns for Ship Detection. International Journal of Signal Processing, Image Processing and Pattern Recognition, 7(3), pp. 237-246.

Zhu, C., Zhou, H., Wang, R. andGuo, J., 2010. A novel hierarchical method of ship detection from spaceborne optical image based on shape and texture features. Geoscience and Remote Sensing, IEEE Transactions on, 48(9), pp. 3446-3456.

Satyanarayana, M. and Aparna, G., 2012. A Method of Ship Detection FromSpaceborne Optical Image. International Journal of Advance Computer and Mathematical Sciences. ISSN 2230-9624. Vol 3, Issue 4, 2012, pp 535-540.

Máttyus, G., 2013. Near real-time automatic marine vessel detection on optical satellite images. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(1), pp. 233-237.

Antelo, J., Ambrosio, G., González, J. And Galindo, C., 2009. Ship detection and recognition in high-resolution satellite images, Geoscience and Remote Sensing Symposium, 2009 IEEE International, IGARSS 2009 2009, IEEE, pp. IV-514-IV-517.

Chen, F., Yu, W., Liu, X., Wang, K., Gong, L. and Lv, W., 2011. Graph-based ship extraction scheme for optical satellite image, Geoscience and Remote Sensing Symposium (IGARSS), 2011 IEEE International 2011, IEEE, pp. 491-494.

Bi, F., Zhu, B., Gao, L. and Bian, M., 2012. A visual search inspired computational model for ship detection in optical satellite images. Geoscience and Remote Sensing Letters, IEEE, 9(4), pp. 749-753.

Buck, H., Sharghi, E., Guilas, C., Schalcosky, B. and Stastny, J., 2012. Ship detection system and method from overhead images. United States Patent, Patent No: US 8,116,522 B1, Feb 14, 2012.

Shi, Z., Yu, X., Jiang, Z. and Li, B., 2014. Ship detection in high-resolution optical imagery based on anomaly detector and local shape feature. Geoscience and Remote Sensing, IEEE Transactions on, 52(8), pp. 4511-4523.

Harvey, N.R., Porter, R. and Theiler, J., 2010. Ship detection in satellite imagery using rank-order grayscale hit-or-miss transforms, SPIE Defense, Security, and Sensing 2010, International Society for Optics and Photonics, pp. 770102-770102-12.

Tang, J., Deng, C., Huang, G. and Zhao, B., 2015. Compressed-domain ship detection on spaceborne optical image using deep neural network and extreme learning machine. Geoscience and Remote Sensing, IEEE Transactions on, 53(3), pp. 1174-1185.

Liu, G., Zhang, Y., Zheng, X., Sun, X., Fu, K. and Wang, H., 2014. A new method on inshore ship detection in high-resolution satellite images using shape and context information. Geoscience and Remote Sensing Letters, IEEE, 11(3), pp. 617-621.

Arnold-Bos, A., Martin, A. and Khenchaf, A., 2007. Obtaining a ship's speed and direction from its Kelvin wake spectrum using stochastic matched filtering, Geoscience and Remote Sensing Symposium, 2007. IGARSS 2007. IEEE International 2007, IEEE, pp. 1106-1109.

Rao, N.S., Ali, M., Rao, M. and Ramana, I., 2005. Estimation of ship velocities from MODIS and OCM. Geoscience and Remote Sensing Letters, IEEE, 2(4), pp. 437-439.

Hallenborg, E., Buck, H. and Stephen Degrassie, J., 2013. System and method for inferring vessel speed from overhead images. United States Patent, Patent No: US 8,437,509 B1, May 7, 2013.

Crisp, D.J., 2004. The State–of–the–Art in Ship Detection in Synthetic Aperture Radar Imagery; Australian Government, Department of defence, 2004; p. 115.

Vachon P.W., "Ship detection in Synthetic Aperture Radar Imagery," in OceanSAR, 2006.

VachonP.W., KabatoffC., and Quinn R. “Operational ship detection in canada using radarsat”. In Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International, pages 998–1001, July 2014.

YeremyM., CampbellJ.W.M., MattarK., and Potter T. “Ocean surveillance with polarimetric SAR”. Canadian Journal of Remote Sensing, 27(4):328-344, 2001.

CampbellJ.W.M., GrayA. L., MattarK.E., ClarkeJ.H., and Van der KooijM.W.A. “Ocean surface feature detection with the CCRS along-track InSAR”. Canadian Journal of Remote Sensing, 23(l):24-37, 1997.

Banda, F.; Ferro-Famil, L.; Tebaldini, S., "Polarimetric time-frequency analysis of vessels in Spotlight SAR images," in Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International , vol., no., pp.1033-1036, 13-18 July 2014.

Hu, C.; Ferro-Famil, L.; Kuang, G. Ship Discrimination Using Polarimetric SAR Data and Coherent Time-Frequency Analysis. Remote Sens. 2013, 5, 6899-6920.

Torre A. and Capece P. “Cosmo-Skymed: The advanced SAR instrument” Proc. Int. Conf. Recent Adv. Space Technol., pp. 865-868, 2011.

Padmaja, T.M.; Krishna, P.R.; Bapi, R.S., "Majority filter-based minority prediction (MFMP): An approach for unbalanced datasets," in TENCON 2008 - 2008 IEEE Region 10 Conference , vol., no., pp.1-6, 19-21 Nov. 2008 (o rimpiazzare).

Brusch, S.; Lehner, S.; Fritz, T.; Soccorsi, M.; Soloviev, A.; van Schie, B., "Ship Surveillance With TerraSAR-X," in Geoscience and Remote Sensing, IEEE Transactions on , vol.49, no.3, pp.1092-1103, March 2011.

Vachon, P.W.; English, R.A.; Wolfe, J., "Ship signatures in synthetic aperture radar imagery," in Geoscience and Remote Sensing Symposium, 2007. IGARSS 2007. IEEE International , vol., no., pp.1393-1396, 23-28 July 2007

Auquilla, A., Heremans, S., Vanegas, P. and Van Orshoven, J., 2014. A Procedure for Semi-automatic Segmentation in OBIA Based on the Maximization of a Comparison Index. Computational Science and Its Applications–ICCSA 2014. Springer, pp. 360-375.

Baatz, M. and Schäpe, A., 2000. Multiresolution segmentation: an optimization approach for high quality multi-scale image segmentation. AngewandteGeographischeInformationsverarbeitung XII, pp. 12-23.

Gianinetto, M., Rusmini, M., Marchesi, A., Maianti, P., Frassy, F., Dalla Via, G., Dini, L. And Nodari, F.R., 2015. Integration of COSMO-SkyMed and GeoEye-1 Data with Object-Based Image Analysis. Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of, 8(5), pp. 2282-2293.

Macfarlane, G. and Renilson, M., 1999. Wave wake-a rational method for assessment, Proceeding of the international conference on coastal ships and inland waterways. Royal Institution of Naval Architects, London 1999, pp. 1-15.

Greidanus, H. (2008). Satellite Imaging for Maritime Surveillance of the European Seas. In Remote Sensing of the European Seas. Springer (Netherlands).

Perez, T. I. (2009). Kalman Filtering for Positioning and Heading Control of Ships and Offshore Rigs. IEEE Control Systems Magazine .

S. Thrun, W. B. (2003). Probabilistic Robotics. Boston: The MIT Press .

Schrijver, A. (2003). Combinatorial Optimization : Algorithms and Complexity. Berlin: Springer.

Steiglitz, C. H. (1998). Combinatorial Optimization: Polyhedra and Efficiency. Dover Publications.

Vallado, D. A. (2001). Fundamentals of Astrodynamics and Applications. Springer Science & Business Media.

Harati-Mokhtari A., (2007), Automatic Identification System (AIS): Data Reliability and Human Error Implications, The Journal of Navigation, 60:373-389.

Greidanus H. and Kourti N., A detailed comparison between radar and optical vessels signatures, Proc. IGARSS 2006, Denver, Colorado, 31 July- 4 August 2006.

MallasP. A. and GraberH. C., "Imaging ships from satellites," Oceanography, 26(2), pp. 150-155, 2013.

WerleD.Radarsat SAR azimuth ambiguity patterns - the ghost fleet of Halifax Harbour and implications for applications. In International Symposium, Geomatics in the Era of RADARSAT (GER'97), 1997. Ottawa, Canada, May 25-30.

P. Norris, (2008), "Spies in the Sky: Surveillance Satellites in War and Peace". Praxis Publishing.

N. Policella, H. Oliveira and E. Benzi (2013), "Planning Spacecraft Activities: An Automated Approach", In Proceedings of the International Conference on Automated Planning, ICAPS 2013.

D. A. Vallado, P. Crawford, R. Hujsak and T. S. Kelso (2006), "Revisiting Space-track Report #3", AIAA Astrodynamics Specialist Conference & Business Media, 2006.

J.C. Curlander and R.N. McDonough (1991), "Synthetic Aperture Radar", Wiley Interscience, New York.

D. Zwillinger, 2003, "CRC Standard Mathematical Tables and Formulae, 31st Edition", NY: CRC Press, p. 206.

J. B. Campbell (2002), "Introduction to Remote Sensing", The Guilford Press, New York.

Topputo et al. (2015-1), "Space Shepherd: Search and Rescue of Illegal Immigrants in the Mediterranean Sea through Satellite Imagery. 25th International Geoscience and Remote Sensing Symposium 2015 (IGARSS 2015), Milan (Italy), July 2015.

Topputo et al. (2015-2), “Space Shepherd: using space assets to monitor, track, and search-and-rescue illegal immigrants in the Mediterranean Sea”. International Astronautical Congress 2015 (IAC 2015), Jerusalem (Israel), October 2015.

Web sites

www.missingmigrants.iom.int

www.marinetraffic.com

www.unhcr.it

www.vesselfinder.com

www.wikipedia.com

http://database.eohandbook.com/

http://www.marineregions.org/

fortresseurope.blogspot.it

www.unhcr.org

www.iom.int

www.marina.difesa.it

www.gdf.gov.it

www.guardiacostiera.it

www.imap-migration.org

www.iso.org

www.massimosestini.it

www.lastampa.it

www.repubblica.it

www.ilgiornale.it

www.ilsecoloxix.it

www.ilmessaggero.it

www.internazionale.it

www.corriere.it

www.gazzettadelsud.it

www.forumnautico.it

www.europaquotidiano.it

Press review 2016

“Migranti, naufragio nell'Egeo: morti tre bambini”, 15/01/2016, http://www.repubblica.it/esteri/2016/01/15/news/migranti_naufragio-131317863/

“Migranti, 36 morti in Egeo. Vertice Ue su Schengen. Alfano: "Italia non sospenderà il trattato"”, 5/01/2016, http://www.repubblica.it/esteri/2016/01/05/news/migranti_naufragio_turchia-130641595/?ref=search

“Turchia: tre migranti morti nel naufragio di un barcone nell'Egeo”, 11/01/2016, http://video.repubblica.it/dossier/immigrati-2015/turchia-tre-migranti-morti-nel-naufragio-di-un-barcone-nell-egeo/224532/223793?ref=search

Press review 2015

“Cargo Ezadeen in porto in salvo. A bordo 360 profughi, 74 bambini”, 02/01/2015, http://www.repubblica.it/cronaca/2015/01/02/news/cargo_ezadeen_terminato_intervento_di_soccorso_dell_aeronautica-104161086/

“Immigrati: dopo i barconi è l’ora dei mercantili fantasma”, 04/01/2015, http://www.analisidifesa.it/2015/01/immigrati-dopo-i-barconi-e-lora-dei-mercantili-fantasma/

“Nave Libra soccorre 490 migranti a 60 miglia da Tripoli. Durante i soccorsi nasce un bimbo”, 16/01/2015, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20150116_libra_triton.aspx

“Migranti, in mille salvati in 24 ore nel Canale di Sicilia”, 17/01/2015, http://palermo.repubblica.it/cronaca/2015/01/17/news/a_porto_empedocle_arrivati_in_banchina_250_migranti-105127307/?ref=search

“Nuova tragedia nel Canale di Sicilia: venti migranti dispersi in mare”, 22/01/2015, http://palermo.repubblica.it/cronaca/2015/01/22/news/nuova_tragedia_nel_canale_di_sicilia_venti_migranti_dispersi_in_mare-105553010/?ref=search

“Immigrati, 3.500 sbarchi da inizio anno”, 29/01/2015, http://www.ilsole24ore.com/art/notizie/2015-01-29/immigrati-3500-sbarchi-inizio-anno-063758.shtml?uuid=ABpQFslC

“Lampedusa, ennesima tragedia in mare”, 09/02/2015, http://www.tgcom24.mediaset.it/2014/video/lampedusa-ennesima-tragedia-in-mare_2021841.shtml

“Lampedusa, 29 migranti morti assiderati. “Siamo tornati a prima di Mare Nostrum””, 09/02/2015, http://www.ilfattoquotidiano.it/2015/02/09/lampedusa-7-migranti-morti-15-gravissimi-erano-barcone-105-profughi/1409748/

“Strage al largo di Lampedusa, 29 migranti morti di freddo”, 09/02/2015, http://tg24.sky.it/tg24/cronaca/2015/02/09/lampedusa_migranti_barcone_vittime.html

“Lampedusa, i sopravvissuti: "Minacciati con le armi per salire a bordo"”, 09/02/2015, http://www.panorama.it/news/cronaca/lampedusa-migranti-morti/

“Lampedusa, la testimonianza: "Migranti costretti a partire sotto minaccia armi"”, 11/02/2015, http://video.repubblica.it/dossier/immigrati-2015/lampedusa-la-testimonianza-migranti-costretti-a-partire-sotto-minaccia-armi/191610/190555

“Naufragio Lampedusa, oltre 200 migranti morti. “Disperso gommone con altri 100″”, 11/02/2015, http://www.ilfattoquotidiano.it/2015/02/11/naufragio-lampedusa-morti-200-migranti-disperso-gommone-100/1414701/

“Immigrazione, superstiti del naufragio a Lampedusa: oltre 200 morti”, 11/02/2015, http://www.lastampa.it/2015/02/11/immigrazione-superstiti-del-naufragio-a-lampedusa-oltre-morti-Zg1ya21xQVhsh593pHKA3L/pagina.html

“Soccorsi davanti alla Libia 700 migranti Vaticano: stragi intollerabili, Triton inutile”, 14/02/2015, http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/02/14/soccorsi-davanti-alla-libia-700-migranti-vaticano-stragi-intollerabili-triton-inutile20.html?ref=search

“Soccorsi 2100 migranti su 12 imbarcazioni Motovedetta italiana minacciata con le armi”,15/02/2015, http://www.lastampa.it/2015/02/15/italia/cronache/migranti-barconi-localizzati-a-sud-di-lampedusa-nnSJSAJrElOpEJAB1deiNI/pagina.html

“Immigrazione, ancora sbarchi in Sicilia. A Lampedusa donne e bambini dalla Libia”, 16/02/2015, http://www.ilfattoquotidiano.it/2015/02/16/immigrazione-sbarchi-in-sicilia-lampedusa-donne-bambini-dalla-libia/1428654/

“Canale di Sicilia, si ribalta gommone di migranti: dieci vittime”, 04/03/2015, http://palermo.repubblica.it/cronaca/2015/03/04/news/canale_di_sicilia_dieci_migranti_morti_recuperati_da_nave_dattilo-108710165/?ref=HREA-1

“Naufragio di migranti, sono 50 i dispersi. Salvati altri 179 profughi”, 05/03/2015, http://palermo.repubblica.it/cronaca/2015/03/05/news/naufragio_di_migranti_sono_50_i_dispersi_fermati_due_scafisti-108812613/?ref=search

“Un milione di migranti pronti a invadere l'Italia”, 06/03/2015, http://www.ilgiornale.it/news/politica/milioni-migranti-pronti-invadere-litalia-1102327.html

“Allarme internazionale: un milione di immigrati dalla Libia verso l’Italia”, 07/03/2015, http://www.secoloditalia.it/2015/03/allarme-internazionale-milione-immigrati-dalla-libia-verso-litalia/

“Migranti, Unhcr: "Dall'inizio dell'anno 470 morti nel Mediterraneo"”, 12/03/2015, http://www.repubblica.it/solidarieta/immigrazione/2015/03/12/news/migranti_morti_mediterraneo-109376289/?ref=search

“Otto migranti annegati nel mar Egeo dopo l'affondamento di una barca”, 09/04/2015, http://www.repubblica.it/solidarieta/immigrazione/2015/04/09/news/naufragio_otto_migranti_annegati_dopo_l_affondamento_di_una_barca-111534983/?ref=search

“Migranti, barcone con 600 profughi eritrei lancia Sos”, 10/04/2015, http://palermo.repubblica.it/cronaca/2015/04/10/news/migranti_barcone_con_600_profughi_eritrei_lancia_sos-111618132/?ref=search

“Sbarcano migranti sulle coste del Salento, arrestati due scafisti albanesi”, 11/04/2015, http://bari.repubblica.it/cronaca/2015/04/11/news/sbarchi-111673100/

“Sbarchi, 1700 migranti tratti in salvo nel Canale di Sicilia”, 11/04/2015, http://tg24.sky.it/tg24/cronaca/2015/04/11/migranti_emergenza_sbarchi.html

“Sicilia, quasi mille i migranti soccorsi al largo delle coste libiche”, 11/04/2015, http://www.corriere.it/cronache/15_aprile_11/sicilia-quasi-mille-migranti-soccorsi-largo-coste-libiche-6e615926-e044-11e4-b0b6-cf60ff032a1c.shtml

“A Porto Empedocle 552 migranti soccorsi nel canale di Sicilia”, 12/04/2015, http://video.repubblica.it/edizione/palermo/a-porto-empedocle-552-migranti-soccorsi-nel-canale-di-sicilia/197518/196546

“Barcone capovolto al largo della Libia, recuperati 9 cadaveri”, 13/04/2015, http://palermo.repubblica.it/cronaca/2015/04/13/news/barcone_capovolto_al_largo_della_libia_recuperati_9_cadaveri-111820180/

“Riprendono le traversate della speranza, tremila migranti sulle coste siciliane”, 13/04/2015, http://palermo.repubblica.it/cronaca/2015/04/13/news/riprendono_le_traversate_della_speranza_tremila_migranti_in_arrivo_sulle_coste_siciliane-111884565/?ref=search#gallery-slider=111886906

“Traversate della speranza, a Palermo arrivati 1169 migranti”, 13/04/2015, http://palermo.repubblica.it/cronaca/2015/04/13/news/traversate_della_speranza_a_palermo_in_arrivo_1169_migranti-111887004/?ref=search

“Sicilia, soccorsi oltre 5mila migranti in tre giorni”, 13/04/2015, http://video.repubblica.it/edizione/palermo/sicilia-soccorsi-oltre-5mila-migranti-in-tre-giorni/197581/196609

“Affonda barcone al largo della Libia: almeno 9 morti”, 13/04/2015, http://tg24.sky.it/tg24/cronaca/2015/04/13/migranti_barcone_al_largo_della_libia_vittime.html

"Immigrati morti in mare, il Pd vuole il giorno del ricordo", 13/04/2015, http://www.ilgiornale.it/news/politica/immigrati-morti-mare-pd-vuole-giorno-ricordo-1115909.html

"Migranti: 1200 a Palermo, 700 a Rc. Superstiti: "400 vittime". Pozzallo, morto gettato agli squali", 14/04/2015, http://palermo.repubblica.it/cronaca/2015/04/14/news/migranti_1200_arrivati_a_palermo_pozzallo_morto_dato_in_pasto_a_squali-111898437/?ref=search

"Immigrazione, al via a Palermo sbarco di 480 migranti", 15/04/2015, http://video.repubblica.it/edizione/palermo/immigrazione-al-via-a-palermo-sbarco-di-480-migranti/197808/196837?ref=nrct-2

"Emergenza sbarchi: altri 400 migranti a Palermo, 230 a Messina. Centri d'accoglienza al collasso", 15/04/2015, http://palermo.repubblica.it/cronaca/2015/04/15/news/emergenza_sbarchi_altri_400_migranti_a_palermo_centri_d_accoglienza_al_collasso-111998190/

"Strage al largo della Libia: morti in mare tra 700 e 900 migranti, solo 28 superstiti. È la tragedia più grande di sempre", 19/04/2015, http://palermo.repubblica.it/cronaca/2015/04/19/news/almeni_700_migranti_morti_in_un_naufragio_a_nord_della_libia_solo_28_superstiti-112315076/?ref=search

"Migranti, 450 sbarcati ad Augusta e altri 200 a Pozzallo. Nuove accuse al comandante del naufragio", 22/04/2015, http://palermo.repubblica.it/cronaca/2015/04/22/news/migranti_altri_450_sbarcati_ad_augusta_tensione_in_un_centro_d_accoglienza_a_palermo-112566102/

"Sbarca a Salerno nave con 545 migranti", 22/04/2015, http://napoli.repubblica.it/cronaca/2015/04/22/news/sbarca_a_salerno_nave_con_545_migranti-112579301/

"Bloccati 64 migranti in Salento, 100 in 24 ore", 26/04/2015, http://bari.repubblica.it/cronaca/2015/04/26/news/bloccati_64_migranti_in_salento_100_in_24_ore-112875984/?ref=search

"Migranti, a Lampedusa 220 profughi salvati nella notte. Arrestati sei scafisti", 02/05/2015, http://palermo.repubblica.it/cronaca/2015/05/02/news/migranti_a_lampedusa_220_profughi_salvati_nella_notte_arrestati_sei_scafisti-113351021/?ref=search

"Migranti, ancora morti a largo Libia. Guardia costiera: salvate 3690 persone in un solo giorno", 03/05/2015, http://palermo.repubblica.it/cronaca/2015/05/03/news/guardia_costiera_3690_i_migranti_salvati_ieri-113420233/?ref=search

"Sbarchi senza fine, in Sicilia è emergenza. Bimba nasce su una nave militare, l'equipaggio la chiama Francesca Marina. Il ministro Alfano a Palermo e Catania", 04/05/2015, http://palermo.repubblica.it/cronaca/2015/05/04/news/sbarchi_senza_fine_in_sicilia_e_emergenza_bimba_nasce_su_una_nave_militare_il_ministro_alfano_a_palermo_e_catania-113484962/

"Migranti, nuova strage con 10 morti nel Canale di Sicilia. Seimila profughi soccorsi nel fine settimana", 04/05/2015, http://palermo.repubblica.it/cronaca/2015/05/04/news/migranti_nuova_strage_con_10_morti_nel_canale_di_sicilia_seimila_profughi_soccorsi_nel_fine_settimana-113475935/?ref=search

"Migranti, nuova strage nel Canale di Sicilia: "Almeno 40 morti". Si chiamerà Gift la neonata "battezzata" Marina, raffica di sbarchi in Sicilia", 05/05/2015, http://palermo.repubblica.it/cronaca/2015/05/05/news/migranti_primo_salvataggio_della_nave_dei_volontari_369_a_pozzallo-113561671/?ref=HRER1-1

"Trecento migranti soccorsi a 130 km dalla Calabria", 06/05/2015, http://www.repubblica.it/cronaca/2015/05/06/news/italia_all_onu_trecento_migranti_soccorsi_a_80_km_dalle_coste_-113639975/

"Nuovi sbarchi e salvataggi: a Messina 328 migranti, altri 500 soccorsi nel canale di Sicilia. Trenta siriani sbarcati in Salento", 06/05/2015, http://palermo.repubblica.it/cronaca/2015/05/06/news/nuovi_sbarchi_e_salvataggi_a_messina_328_migranti-113656286/?ref=HREC1-12

"Sono tutti salvi i 234 migranti recuperati al largo di Augusta", 28/05/2015, http://video.repubblica.it/dossier/immigrati-2015/sono-tutti-salvi-i-234-migranti-recuperati-al-largo-di-augusta/202339/201407?ref=HRBV-1

"Sicilia: sbarcano 454 migranti e 17 salme", 31/05/2015, http://video.repubblica.it/edizione/palermo/sicilia-sbarcano-454-migranti-e-17-salme/202666/201733

"Migranti su un gommone soccorsi dalla guardia costiera", 03/06/2015, http://video.repubblica.it/edizione/palermo/migranti-su-un-gommone-soccorsi-dalla-guardia-costiera/203002/202075

"Decine di barconi verso la Sicilia: 150 migranti intercettati da libici", 06/06/2015, http://video.repubblica.it/dossier/immigrati-2015/decine-di-barconi-verso-la-sicilia-150-migranti-intercettati-da-libici/203429/202501

"Migranti, Regno Unito: "Migliaia alla deriva su 14 barconi davanti alla Libia"", 06/06/2015, http://www.ilfattoquotidiano.it/2015/06/06/migranti-skynews-migliaia-alla-deriva-su-14-barconi-davanti-alla-libia/1753479/

"Duemila migranti in salvo nel Canale di Sicilia, altri tremila alla deriva: appello del ministro inglese", 06/06/2015, http://palermo.repubblica.it/cronaca/2015/06/06/news/duemila_migranti_in_salvo_nel_canale_di_sicilia_altri_barconi_alla_deriva_in_corso_il_salvataggio-116228473/

"Tra Palermo e Trapani sbarcati oltre 1400 migranti. In salvo 3500 profughi: ma un migliaio aspetta di essere soccorso", 07/06/2015, http://palermo.repubblica.it/cronaca/2015/06/07/news/immigrazione_-116287209/?ref=nrct-3

"Decine di barconi verso la Sicilia: 150 migranti intercettati da libici",07/06/2015, http://video.repubblica.it/dossier/immigrati-2015/decine-di-barconi-verso-la-sicilia-150-migranti-intercettati-da-libici/203429/202501?ref=vd-auto

"Soccorsi 1021 migranti nel Canale di Sicilia: sbarcati a Porto Empedocle e Lampedusa", 10/06/2015, http://palermo.repubblica.it/cronaca/2015/06/10/news/soccorsi_1021_migranti_nel_canale_di_sicilia_sbarcati_a_porto_empedocle_e_lampedusa-116560248/?ref=search

"Migranti, sulla nave che salva i profughi: "Noi finanzieri come in una guerra"", 11/06/2015, http://www.repubblica.it/cronaca/2015/06/11/news/sulla_nave_che_salva_i_profughi_noi_finanzieri_come_in_una_guerra_-116584998/?ref=HREC1-5

"Migranti, 2900 tratti in salvo nel Mediterraneo: 21 operazioni di soccorso", 29/06/2015, http://www.repubblica.it/cronaca/2015/06/29/news/migranti_2900_tratti_in_salvo_nel_mediterraneo_21_operazioni_di_soccorso-117904887/?ref=search

"Immigrazione, nei porti siciliani sbarcate oltre 1500 persone salvate in mare", 30/06/2015, http://palermo.repubblica.it/cronaca/2015/06/30/news/immigrazione_nei_porti_siciliani_sbarcate_oltre_1500_persone_salvate_in_mare-118016347/?ref=search

"Immigrazione: affonda gommone, recuperati 12 cadaveri", 09/07/2015, http://palermo.repubblica.it/cronaca/2015/07/09/news/immigrazione_affonda_gommone_recuperati_12_cadaveri-118741757/?ref=search

"Arrivata la nave con i profughi salvati e le 12 salme", 11/07/2015, http://palermo.repubblica.it/cronaca/2015/07/11/news/arrivata_la_nave_con_i_profughi_salvati_e_le_12_salme-118844052/?ref=HREC1-25

"Salento, sos per un veliero con 139 migranti: tutti in salvo, a bordo anche 40 bambini", 11/07/2015, http://bari.repubblica.it/cronaca/2015/07/11/news/salento_sos_per_un_veliero_con_139_migranti_tutti_in_salvo_a_bordo_anche_40_bambini-118867008/

“Un morto e tre neonati tra i 456 migranti arrivati a Cagliari”, 18/07/2015, http://www.repubblica.it/cronaca/2015/07/18/news/c_e_un_morto_tra_i_456_migranti_accolti_a_cagliari-119364260/?ref=search

“Mille migranti arrivati in Sicilia, 370 sbarcati a Palermo. Fiocco rosa sulla nave dei soccorsi”, 22/07/2015, http://palermo.repubblica.it/cronaca/2015/07/22/news/mille_migranti_in_arrivo_in_sicilia_370_sbarcati_a_palermo_fiocco_rosa_sulla_nave_dei_soccorsi-119578085/?ref=search

“Migranti, naufragio con decine di vittime al largo della Libia”, 23/07/2015, http://palermo.repubblica.it/cronaca/2015/07/23/news/migranti_naufragio_decine_vittime-119691444/?ref=HRER1-1

“Nave sbarcata a Messina con 450 migranti e 14 vittime. Altri 700 arrivati in Calabria”, 29/07/2015, http://www.lastampa.it/2015/07/29/italia/cronache/nave-sbarcata-a-messina-con-migranti-e-vittime-altri-attesi-in-calabria-foLzsamNsQcc2wvk81DBIN/pagina.html

“Circa 700 migranti arrivati a Reggio Calabria. Saranno tutti trasferiti fuori regione”, 29/07/2015, http://www.ilquotidianoweb.it/news/reggio-calabria/739428/Circa-700-migranti-arrivati-a-Reggio.html

“Migranti: sbarcano ad Augusta in 523, in arrivo altri 241 a Pozzallo”, 30/07/2015, http://palermo.repubblica.it/cronaca/2015/07/30/news/migranti_sbarcano_ad_augusta_in_523_in_arrivo_altri_241_a_pozzallo-120094636/?ref=search

“Migranti, salvate 780 persone: su un'imbarcazione recuperati 5 cadaveri”,01/08/2015, http://www.tgcom24.mediaset.it/mondo/migranti-salvate-780-persone-su-un-imbarcazione-recuperati-5-cadaveri_2125962-201502a.shtml

“Sbarco di 529 migranti domani a Palermo, a bordo anche 5 cadaveri”, 02/08/2015, http://palermo.gds.it/2015/08/02/sbarco-di-529-migranti-domani-a-palermo-a-bordo-anche-5-cadaveri_391008/

“Immigrazione: a Palermo nave con 529 persone. A bordo anche cinque cadaveri”, 03/08/2015, http://palermo.repubblica.it/cronaca/2015/08/03/news/immigrazione_a_palermo_nave_con_535_persone_e_cinque_cadaveri-120348063/?ref=search

“Immigrazione, Oim: "Oltre 2.000 morti nel Mediterraneo nel 2015"”, 04/08/2015, http://www.repubblica.it/cronaca/2015/08/04/news/immigrazione_oim_duemila_morti_nel_mediterraneo_nel_2015_-120397670/

“Barcone con a bordo 700 migranti si capovolge al largo della Libia, 25 cadaveri recuperati”, 05/08/2015, http://palermo.repubblica.it/cronaca/2015/08/05/news/barcone_carico_migranti_si_capovolge_al_largo_della_libia-120463749/

“Immigrazione, 1500 persone soccorse nel Canale di Sicilia”, 10/08/2015, http://palermo.repubblica.it/cronaca/2015/08/10/news/immigrazione_1500_persone_soccorse_nel_canale_di_sicilia-120764334/?ref=search

“Immigrazione: 50 dispersi al largo della Libia, salvate 119 persone”, 11/08/2015, http://palermo.repubblica.it/cronaca/2015/08/11/news/immigrazione_salvate_119_persone_in_350_sbarcati_a_messina-120813546/?ref=search

“Immigrazione: quasi 70 mila persone sbarcate in Sicilia quest'anno”, 12/08/2015, http://palermo.repubblica.it/cronaca/2015/08/12/news/immigrazione_quasi_70_mila_persone_sbarcate_in_sicilia_quest_anno-120881396/?ref=search

“Grecia, Oim: " 34.500 sbarchi nelle isole del Dodecaneso tra gennaio e luglio"”, 15/08/2015, http://www.repubblica.it/esteri/2015/08/15/news/kos-121014465/?ref=search

“Migranti, soccorso barcone al largo della Libia: almeno 40 vittime nella stiva”, 16/08/2015, http://palermo.repubblica.it/cronaca/2015/08/15/news/immigrazione_nave_marina_soccorre_barcone_con_300_a_bordo-121012695/?ref=search

“Migranti, a luglio 170mila arrivi nella Ue: triplicati rispetto al 2014”, 18/08/2015, http://www.repubblica.it/esteri/2015/08/18/news/migranti_a_luglio_170mila_arrivi_nella_ue_triplicati_rispetto_al_2014-121185401/?ref=search

“Catania, presi gli scafisti dei 49 morti: cinghiate a chi cercava di salvarsi. "Tra i migranti 116 marocchini, non profughi"”, 18/08/2015, http://palermo.repubblica.it/cronaca/2015/08/18/news/migranti_arrestati_gli_scafisti_del_barcone_con_49_morti-121163656/?ref=search

“Gommone con oltre 300 migranti soccorso nel Canale di Sicilia”, 19/08/2015, http://palermo.repubblica.it/cronaca/2015/08/19/news/gommone_con_300_migranti_soccorso_nel_canale_di_sicilia-121222444/?ref=search

“Gli immigrati sbarcano con lo yacht, arrestati due scafisti a Otranto”, 20/08/2015, http://bari.repubblica.it/cronaca/2015/08/20/news/scafisti-121288375/?ref=search

“Migranti, al porto di Palermo la nave con 359 persone”, 20/08/2015, http://palermo.repubblica.it/cronaca/2015/08/20/news/migranti_al_porto_di_palermo_la_nave_con_359_persone-121273871/?ref=search

“Immigrazione: la Marina salva 300 migranti su tre barconi in difficoltà”, 21/08/2015, http://palermo.repubblica.it/cronaca/2015/08/21/news/immigrazione_la_marina_salva_300_migranti_su_tre_barconi_in_dificolta_-121350358/?ref=search

"Tremila migranti su 22 barconi alla deriva nel Canale di Sicilia, quasi duemila in salvo", 22/08/2015, http://palermo.repubblica.it/cronaca/2015/08/22/news/migranti_sei_scafisti_arrestati_a_palermo-121394840/?ref=search

"Migranti, salvate 4.400 persone al largo della Libia. Scafisti arrestati a Messina", 23/08/2015, http://palermo.repubblica.it/cronaca/2015/08/23/news/migranti_la_guardia_costiera_salva_4_400_persone_complessivamente_le_operazioni_di_aiuto_sono_state_22-121461761/?ref=search

"Al porto di Palermo 548 migranti, i minori soli sono 45. Il comandante: "tragedia sfiorata"", 24/08/2015, http://palermo.repubblica.it/cronaca/2015/08/24/news/al_porto_di_palermo_548_migranti_130_minori_soli_il_prefetto_non_sappiamo_dove_accoglierli_-121532200/?ref=search

"Migranti, quindicenne somalo muore dopo le violenze subite in Libia", 25/08/2015, http://palermo.repubblica.it/cronaca/2015/08/25/news/migranti_quindicenne_somalo_muore_dopo_il_soccorso-121591933/?ref=search

"Migranti, 51 cadaveri su un barcone. Tremila salvati in un giorno", 26/08/2015, http://palermo.repubblica.it/cronaca/2015/08/26/news/migranti_a_catania_218_sbarcati_muore_un_sudanese_gli_scafisti_del_barcone_con_49_vittime_restano_in_carcere-121652250/?ref=search

"Migranti, nuova strage al largo della Libia. Bbc: "Almeno 100 vittime". A Palermo le salme dei 52 morti asfissiati", 27/08/2015, http://palermo.repubblica.it/cronaca/2015/08/27/news/a_palermo_i_51_migranti_morti_asfissiati-121704290/?ref=search

"Due naufragi al largo della Libia, individuati 200 corpi. Salvati cento migranti", 28/08/2015, http://palermo.repubblica.it/cronaca/2015/08/28/news/salvati_cento_migranti_su_un_gommone_in_calabria_sbarco_con_quattro_morti-121771104/?ref=HRER3-1

"Migranti: a Messina sbarcate 683 persone e due morti", 29/08/2015, http://palermo.repubblica.it/cronaca/2015/08/29/news/a_messina_sbarcati_683_migranti_e_due_morti-121825697/?ref=search

"Nuovo naufragio davanti alla Libia: almeno 37 morti. Conclusa l'autopsia sui 52 cadaveri al cimitero di Palermo: impossibile l'identificazione", 30/08/2015, http://palermo.repubblica.it/cronaca/2015/08/30/news/migranti_morti_nella_stiva_di_un_barcone_conclusa_l_autopsia_sui_cadaveri_impossibile_l_identificazione-121894129/?ref=search

"Emergenza migranti nel Mediterraneo, la mappa delle frontiere sotto pressione", 30/08/2015, http://www.repubblica.it/esteri/2015/08/28/news/emergenza_migranti_nel_mediterraneo_la_mappa_delle_frontiere_sotto_pressione-121787067/?ref=search

"Gommone con 118 migranti soccorso al largo della Libia", 31/08/2015, http://palermo.repubblica.it/cronaca/2015/08/31/news/gommone_con_118_migranti_soccorso_al_largo_della_libia-121942497/?ref=search

"Migranti: salvate circa mille persone, trovate morte quattro giovani donne", 01/09/2015, http://palermo.repubblica.it/cronaca/2015/09/01/news/tre_pentiti_fra_gli_scafisti_del_barcone_con_49_morti_nuovi_interrogatori_dei_pm-121992708/?ref=search

"Migranti: 138 sbarcati a Pozzallo, salvataggi di circa 800 persone", 02/09/2015, http://palermo.repubblica.it/cronaca/2015/09/02/news/migranti_138_sbarcati_a_pozzallo_in_corso_il_salvataggio_di_circa_800_persone-122060442/?ref=search

"Migranti: affonda gommone di fronte la Libia, un morto. Nasce un bimbo sulla motovedetta", 03/09/2015, http://palermo.repubblica.it/cronaca/2015/09/03/news/migranti_verso_messina_838_salvati_dalla_guardia_costiera-122127729/?ref=search

"Migranti: lo sbarco dei bambini, mai così tanti su un barcone. Fiocco azzurro sulla motovedetta", 04/09/2015, http://palermo.repubblica.it/cronaca/2015/09/04/news/migranti_fiocco_azzurro_in_motovedetta_a_trapani_409_profughi-122202826/?ref=search

"Migranti: a Pozzallo nave irlandese con 329 a bordo", 06/09/2015, http://palermo.repubblica.it/cronaca/2015/09/06/news/migranti_a_pozzallo_nave_irlandese_con_329_a_bordo-122314458/?ref=search

"Lampedusa, 20 dispersi nel Canale di Sicilia", 06/09/2015, http://palermo.repubblica.it/cronaca/2015/09/06/news/lampedusa_20_dispersi_nel_canale_di_sicilia-122347352/?ref=HREA-1

"Migranti dispersi nel Canale di Sicilia, ricerche in corso. Arrestato scafista che aveva portato il figlio di dieci anni", 07/09/2015, http://palermo.repubblica.it/cronaca/2015/09/07/news/migranti_dispersi_nel_canale_di_sicilia_ricerche_in_corso_arrestato_scafista_che_aveva_portato_il_figlio_di_dieci_anni-122369150/?ref=search

"Migranti: a Pozzallo sbarco di 140 persone", 12/09/2015, http://palermo.repubblica.it/cronaca/2015/09/12/news/migranti_a_pozzallo_sbarco_di_140_persone-122717594/?ref=search

"La Germania sospende Schengen. Naufragio in Grecia: 34 migranti morti, strage bambini", 13/09/2015, http://www.repubblica.it/esteri/2015/09/13/news/migranti_12mila_arrivi_ieri_a_monaco_nuovo_record_in_ungheria_4mila_in_24_ore-122779533/?ref=search#gallery-slider=122803828

“Migranti: salvate 284 persone, fra loro un neonato di cinque giorni”, 14/09/2015, http://palermo.repubblica.it/cronaca/2015/09/14/news/migranti_salvate_284_persone_fra_loro_un_neonato_di_cinque_giorni-122848146/?ref=search

“Migranti: a Messina in 280 sbarcano insieme ai croceristi”, 15/09/2015, http://palermo.repubblica.it/cronaca/2015/09/15/news/migranti_a_messina_in_280_sbarcano_insieme_ai_croceristi-122912154/?ref=search

“Migranti: salvati in 250, un morto. Strage di Lampedusa, chiesto un secolo di carcere per i sei scafisti”, 17/09/2015, http://palermo.repubblica.it/cronaca/2015/09/17/news/migranti_soccorsi_131_su_un_gommone_arrestati_due_scafisti_accusati_di_omicidio-123062884/?ref=search

“Migranti: 1.013 persone soccorse nel Canale di Sicilia”, 18/09/2015, http://palermo.repubblica.it/cronaca/2015/09/18/news/migranti_1_013_persone_soccorse_nel_canale_di_sicilia-123183918/?ref=search

“In salvo 4451 migranti soccorsi nel Canale di Sicilia, in 948 domani a Palermo”, 19/09/2015, http://palermo.repubblica.it/cronaca/2015/09/19/news/in_salvo_4451_migranti_soccorsi_nel_canale_di_sicilia-123232051/?ref=search

“Turchia, traghetto urta barcone di profughi: 13 vittime. Usa: "Accoglieremo 100mila rifugiati"”, 20/09/2015, http://www.repubblica.it/esteri/2015/09/20/news/migranti_affonda_gommone_in_grecia_26_dispersi_anche_bimbi-123276876/?ref=search

“Sbarchi, tra Sicilia e Calabria attesi oltre quattromila profughi”, 20/09/2015, http://palermo.repubblica.it/cronaca/2015/09/20/news/sbarchi_oggi_attesi_in_sicilia_quasi_duemila_migranti-123278523/?ref=search

“Migranti: a Messina sbarco di 271 persone”, 21/09/2015, http://palermo.repubblica.it/cronaca/2015/09/21/news/migranti_a_messina_sbarco_di_271_persone-123388248/?ref=search

“Migranti, barcone naufraga a largo di Bodrum: 17 morti”,27/09/2015, http://www.repubblica.it/esteri/2015/09/27/news/migranti_bodrum-123775922/?ref=search

“Pozzallo: sbarcati 77 migranti, tra loro due donne in gravidanza”, 27/09/2015, http://palermo.repubblica.it/cronaca/2015/09/27/news/pozzallo_sbarcati_77_migranti_tra_loro_due_donne_in_gravidanza-123778884/?ref=search

"Migranti: sbarchi a Messina e Pozzallo, 1151 soccorsi in mare", 29/09/2015, http://palermo.repubblica.it/cronaca/2015/09/29/news/migranti_sbarchi_a_messina_e_pozzallo_500_soccorsi_in_mare-123919803/?ref=search

"Migranti, naufragio a Lesbo: morti bambino di due anni e donna di 35", 30/09/2015, http://www.repubblica.it/esteri/2015/09/30/news/migranti_lesbo_naufragio-124000567/?ref=search

"Profughi, quasi 100 morti al largo della Libia",06/10/2015, http://www.repubblica.it/esteri/2015/10/06/news/profughi_strage_libia-124444814/?ref=search

"Egitto: affonda barcone diretto in Italia, 10 morti", 11/10/2015, http://www.repubblica.it/esteri/2015/10/11/news/egitto_affonda_barcone_diretto_italia_10_morti-124845571/?ref=HREC1-8

"Immigrati: continuano gli arrivi sull'isola di Lesbo",17/10/2015, http://video.repubblica.it/dossier/immigrati-2015/immigrati-continuano-gli-arrivi-sull-isola-di-lesbo/214992/214175?ref=search

"Migranti, Marina Militare: 562 soccorsi in 5 interventi",11/10/2015, http://video.repubblica.it/dossier/immigrati-2015/migranti-marina-militare-562-soccorsi-in-5-interventi/215023/214206?ref=search

"Oggi l'arrivo di 633 migranti sulla nave anche otto salme", 20/10/2015, http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/10/20/oggi-larrivo-di-633-migranti-sulla-nave-anche-otto-salmeBari06.html?ref=search

"Migranti, decine di cadaveri sulle spiagge della Libia", 24/10/2015, http://www.repubblica.it/esteri/2015/10/24/news/migranti_40_cadaveri_su_spiagge_libia-125830289/?ref=search

"Nuova tragedia sulle coste libiche affonda barcone decine di cadaveri",25/10/2015, http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/10/25/nuova-tragedia-sulle-coste-libiche-affonda-barcone-decine-di-cadaveri19.html?ref=search

"Migranti, due naufragi al largo di isole greche: almeno 22 morti", 30/10/2015, http://www.repubblica.it/esteri/2015/10/30/news/migranti_2_naufragi_al_largo_di_isole_greche_almeno_21_morti-126216179/?ref=search

"Grecia, nuova strage di migranti. Le immagini del naufragio a Lesbo", 30/10/2015, http://www.repubblica.it/esteri/2015/10/30/foto/grecia_migranti_salvataggio-126231605/1/?ref=search#1

"Strage di bimbi nel mar Egeo", 31/10/2015, http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/10/31/strage-di-bimbi-nel-mar-egeo21.html?ref=search

“Migranti, due naufragi nell'Egeo: 13 morti, anche quattro neonati”, 01/11/2015, http://www.repubblica.it/esteri/2015/11/01/news/migranti_naufragio_nell_egeo_undici_morti_anche_quattro_neonati-126385042/?ref=search

“E al largo dell'Egeo un'altra strage di bambini”,02/11/2015, http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/11/02/e-al-largo-dellegeo-unaltra-strage-di-bambini20.html?ref=search

“Turchia, 14 migranti muoiono annegati”, 11/11/2015, http://www.repubblica.it/esteri/2015/11/11/news/turchia_grecia_migranti_naufragio-127088920/?ref=search

“Dramma al largo della Turchia, muoiono 14 migranti”,11/11/2015, http://video.repubblica.it/dossier/immigrati-2015/dramma-al-largo-della-turchia-muoiono-14-migranti/218053/217249?ref=search

“Mille migranti sbarcati nell'Isola in un solo giorno”,15/11/2015, http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/11/15/mille-migranti-sbarcati-nellisola-in-un-solo-giornoPalermo02.html?ref=search

“Il fiume dei migranti va avanti: 5.000 al giorno”, 17/11/2015, http://www.ilgiornale.it/news/politica/fiume-dei-migranti-va-avanti-5000-giorno-1195107.html

“La barca dei migranti si inclina, il salvataggio drammatico nell'Egeo”,04/12/2015, http://video.repubblica.it/dossier/immigrati-2015/la-barca-dei-migranti-si-inclina-il-salvataggio-drammatico-nell-egeo/220879/220086?ref=search

“Emergenza migranti, la Guardia costiera: "Oggi salvate dal mare 1123 persone, 4649 negli ultimi tre giorni"”, 05/12/2015, http://www.repubblica.it/cronaca/2015/12/05/foto/migranti_la_guardia_costiera_oggi_salvate_dal_mare_1123_persone_4649_negli_ultimi_tre_giorni_-128877082/1/?ref=search#3

“Guardia Costiera: 9 operazioni e 1123 migranti in salvo al largo coste libiche”,06/12/2015, http://video.repubblica.it/cronaca/guardia-costiera-9-operazioni-e-1123-migranti-in-salvo-al-largo-coste-libiche/221153/220360?ref=search

“Mare sicuro, soccorsi oltre 700 migranti: le immagini del salvataggio”, 07/12/2015, http://www.repubblica.it/cronaca/2015/12/07/foto/immigrazione_soccorsi_oltre_700_migranti_immagini_salvataggio-128966630/1/?ref=search#1

“Mare sicuro, soccorsi oltre 700 migranti: le operazioni di salvataggio”, 07/12/2015, http://video.repubblica.it/dossier/immigrati-2015/mare-sicuro-soccorsi-oltre-700-migranti-le-operazioni-di-salvataggio/221201/220408?ref=search

“Migranti: naufragio al largo della Turchia, 6 bambini morti. Italia nel mirino Ue per impronte non prese”, 08/12/2015, http://www.repubblica.it/esteri/2015/12/08/news/migranti_naufragio_al_largo_della_turchia_6_bambini_morti-129024370/?ref=search

“Grecia, naufragio migranti: l'arrivo dei superstiti”, 09/12/2015, http://www.repubblica.it/esteri/2015/12/09/foto/grecia_naufragio_migranti_l_arrivo_dei_superstiti-129095903/1/?ref=search#1

“Grecia, affonda barcone: morti 11 migranti fra cui 5 bambini. Migrantes: "In un anno strage di 700 minori"”, 09/12/2015, http://www.repubblica.it/esteri/2015/12/09/news/migranti_naufragio_grecia-129080154/?ref=search

“Mille migranti sbarcati nell'Isola in un solo giorno”, 15/12/2015, http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/11/15/mille-migranti-sbarcati-nellisola-in-un-solo-giornoPalermo02.html?ref=search

“Migranti: altri 348 salvati dalla Guardia Costiera nelle ultime 24 ore”,16/12/2015, http://video.repubblica.it/dossier/immigrati-2015/migranti-altri-348-salvati-dalla-guardia-costiera-nelle-ultime-24-ore/222359/221590?ref=search

“Migranti, naufragi al largo Turchia: 8 morti, 5 sono bambini”, 18/12/2015, http://www.repubblica.it/esteri/2015/12/18/news/migranti_naufragio_al_largo_turchia_quattro_morti_due_sono_bambini-129758505/?ref=search

“Nuovo naufragio nel Mar Egeo: morti 18 migranti, 10 erano bambini”, 19/12/2015, http://www.repubblica.it/esteri/2015/12/19/news/nuovo_naufragio_mar_egeo_morti_18_migranti-129789185/?ref=search

“La strage infinita dell'Egeo dieci bambini morti nel barcone rovesciato”, 20/12/2015, http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/12/20/la-strage-infinita-dellegeo-dieci-bambini-morti-nel-barcone-rovesciato10.html?ref=search

“Libia: Marina Militare soccorre oltre 100 migranti”, 24/12/2015, http://video.repubblica.it/dossier/immigrati-2015/libia-marina-militare-soccorre-oltre-100-migranti/223181/222431?ref=search

“Migranti, barcone a picco nel Mar Egeo: 19 morti, sei sono bambini”, 24/12/2015, http://www.repubblica.it/cronaca/2015/12/24/news/migranti_egeo_naufragio_bambini-130096461/?ref=search

"Immigrati: più di 800 migranti salvati in mare in sette operazioni", 24/12/2015, http://video.repubblica.it/dossier/immigrati-2015/immigrati-piu-di-800-migranti-salvati-in-mare-in-sette-operazioni/223188/222438?ref=search

"Migranti: nuova ondata, i soccorsi della Guardia Costiera", 26/12/2015, http://video.repubblica.it/dossier/immigrati-2015/migranti-nuova-ondata-i-soccorsi-della-guardia-costiera/223262/222511?ref=search

"Natale, mille migranti salvati dalla Guardia Costiera",28/12/2015, http://video.repubblica.it/mondo-solidale/natale-mille-migranti-salvati-dalla-guardia-costiera/223414/222670?ref=search

"Migranti: sbarcate altre 931 persone al porto di Palermo",28/12/2015, http://video.repubblica.it/dossier/immigrati-2015/migranti-sbarcate-altre-931-persone-al-porto-di-palermo/223389/222645?ref=search

Press review 2014

"Mare Nostrum: prosegue l'arrivo di migranti sulle coste della Sicilia, la Marina Militare interviene in soccorso", 02/01/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20140102_sar2014.aspx

"La Marina salva i migranti di 4 barconi", 03/01/2014, http://www.lastampa.it/2014/01/03/italia/cronache/la-marina-salva-i-migranti-di-barconi-n8GErBnbnTXVf2QGssjRvK/pagina.html

"Catania, migranti a bordo di un barcone. Salvati in 175, sequestrata nave madre", 30/01/2014, http://www.lastampa.it/2014/01/30/italia/cronache/catania-migranti-a-bordo-di-un-barcone-salvati-in-sequestrata-la-nave-madre-sXNCCeL7XbFp1pmbeQCTkK/pagina.html

"Marina Militare: oltre 1000 migranti salvati dalle navi della Marina Militare a sud di Lampedusa", 17/02/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20140217_espero.aspx

"Mare Nostrum: nave Foscari soccorre 100 migranti durante la notte", 28/02/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20140228_foscari.aspx

"Mare Nostrum: le navi della Marina Militare soccorrono 219 migranti", 12/03/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20140312_marenostrum.aspx

"Nuovi sbarchi, soccorsi oltre duemila migranti in 48 ore", 19/03/2014, http://www.europaquotidiano.it/2014/03/19/nuovi-sbarchi-soccorsi-oltre-duemila-migranti-in-48-ore/

"Immigrazione clandestina – fermata barca a vela con oltre 40 immigrati irregolari", 19/03/2014, http://www.gdf.gov.it/gdf/it/stampa/ultime_notizie/info-1770721390.html

"Mare Nostrum: nave anfibia San Giorgio soccorre 128 migranti", 27/03/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20140327_sangiorgio.aspx

"Sbarchi in Sicilia e in Calabria, allerta del Viminale", 10/04/2014, http://www.corriere.it/cronache/14_aprile_10/sbarchi-sicilia-calabria-allerta-viminale-44715104-c081-11e3-95f0-42ace2f7a60f.shtml

"Naufragio di migranti, fermati due presunti scafisti", 14/05/2014, http://www.ilsecoloxix.it/p/italia/2014/05/14/ARjlOIG-naufragio_presunti_migranti.shtml

"Mare Nostrum: 1812 i migranti soccorsi dalle navi della Marina Militare", 15/06/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20140615_marenostrum.aspx

"Migranti, nave della marina soccorre barcone con 250 persone a bordo", 02/07/2014, http://www.ilfattoquotidiano.it/2014/07/02/migranti-nave-della-marina-soccorre-barcone-con-250-persone-a-bordo/1046911/

"Barcone con 350 migranti a Lampedusa, altri 100 lasciati dagli scafisti sulle spiagge di Ragusa", 15/07/2014, http://palermo.repubblica.it/cronaca/2014/07/07/news/barcone_con_350_attraccato_a_lampedusa-90897868/?ref=search

"Mare Nostrum: operazioni di soccorso e ancora un gommone semiaffondato", 21/07/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20140721_marenostrum.aspx

"Migranti, peschereccio si ribalta a largo di Lampedusa: 6 morti", 25/08/2014, http://www.ilfattoquotidiano.it/2014/08/25/migranti-peschereccio-si-ribalta-a-largo-di-lampedusa-6-morti/1098250/

"Attesi a Palermo 280 migranti salvati nel canale di Sicilia", 20/10/2014, http://palermo.repubblica.it/cronaca/2014/10/20/news/attesi_a_palermo_280_migranti_salvati_nel_canale_di_sicilia-98539744/?ref=search

"Ancora uno sbarco di migranti", 20/10/2014, http://www.gazzettadelsud.it/news//113132/Ancora-uno-sbarco--di-migranti.html

"Mare Nostrum: nave Fenice intercetta un peschereccio, trae in salvo 172 migranti e individua 13 scafisti", 23/10/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/MARENOSTRUM.aspx

"Operazione Mare Nostrum, determinante l'intervento del sommergibile Prini per il sequestro di un peschereccio e il fermo di 16 scafisti", 03/10/2014, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20141003_omnprini.aspx

"Soccorsi circa 600 migranti nelle ultime ore", 06/12/2014, http://www.internazionale.it/notizie/2014/12/06/soccorsi-circa-600-migranti-nelle-ultime-ore

"Soccorsi due gommoni con 210 immigrati a bordo", 15/12/2014, http://palermo.repubblica.it/cronaca/2014/12/15/news/soccorsi_due_gommoni_con_210_immigrati_a_bordo-102939059/?ref=search

"Soccorsi 800 migranti su cargo con pilota automatico inserito", 20/12/2014, http://palermo.repubblica.it/cronaca/2014/12/20/news/soccorsi_800_migranti_su_cargo_con_pilota_automatico_inserito-103389462/?ref=search

"Sicilia, mercantile affonda: in salvo 194 migranti", 20/12/2014, http://video.repubblica.it/cronaca/sicilia-mercantile-affonda-in-salvo-194-migranti/187216/186119

Press review 2013

"Portopalo, nuovo sbarco dalla Libia in 239 su una carretta di 15 metri", 8/06/2013, http://palermo.repubblica.it/cronaca/2013/06/08/news/capo_passero_e_lampedusa_in_275_sbarcano_dal_nordafrica-60687336/

"A Siracusa intercettato barcone con 125 migranti", 23/08/2013, http://www.ilgiornale.it/news/cronache/siracusa-intercettato-barcone-125-migranti-944895.html

"Immigrati, un nuovo sbarco a Siracusa:
in 140 sul barcone, anche bambini", 23/08/2013, http://www.ilmessaggero.it/PRIMOPIANO/CRONACA/immigrati_un_nuovo_sbarco_a_siracusa_in_140_sul_barcone_anche_bambini/notizie/318047.shtml

"Sequestrata nave madre con 199 clandestini a bordo", 12/09/2013, http://www.gdf.gov.it/gdf/it/stampa/ultime_notizie/info-167588487.html

"Sequestrata nave madre per il trasporto di immigrati clandestini", 15/10/2013, http://video.ilsole24ore.com/TMNews/2013/20131015_video_13201848/00014837-sequestrata-nave-madre-per-il-trasporto-di-immigrati-clandestini.php

"Mare Nostrum: due gommoni soccorsi da Nave Maestrale", 29/10/2013, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20131029_maestrale.aspx

"Operazione Mare Nostrum: prosegue l'impegno delle navi della Marina", 04/11/2013, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20131104_sar3novembre.aspx

"Operazione Mare Nostrum, soccorse due imbarcazioni al largo di Lampedusa", 8/12/2013, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20131208_eventosarimm.aspx

"Un altro gommone soccorso dalle unità della Marina Militare", 18/12/2013, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20131218_sar1712.aspx

"Mare Nostrum: Nave San Marco soccorre gommone a sud di Lampedusa", 19/12/2013, http://www.marina.difesa.it/conosciamoci/notizie/Pagine/20131219_sar_sanmarco.aspx

Press review 2012

"Immigrazione clandestina – Fermato peschereccio con 127 clandestini", 16/07/2012, http://www.gdf.gov.it/GdF/it/Stampa/Ultime_Notizie/Anno_2012/Luglio_2012/info1294935835.html

"Sbarchi, due barconi soccorsi al largo di Lampedusa", 18/08/2012, http://tg24.sky.it/tg24/cronaca/2012/08/18/immigrazione_migranti_barcone_soccorso_lampedusa.html