Ontology-based surgical assistance system for instruments recognition

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***Abstract*—An ontology-based surgical assistance system was developed using ontology engineering, point cloud library and semantic technologies. An ontology, which provides knowledge base encoded with surgical instruments three dimensional model information as instances, was implemented. Colour-based region growing algorithm was used to segment the instruments and configured with the application. The final results were evaluated using the application interface, which allows to query on the ontology and to find an instrument's model that could be used for the instrument recognition and robotic assistance. We have segmented surgical instruments with approximately 64% accuracy and were able to integrate segmented models with the ontology. The results of model detection through ontology, for recognition, has sensitivity of 100%, specificity of 99.1% and accuracy 99.5%.**

Keywords—ontology, robotic surgery, object recognition, surgical assistance system

I. INTRODUCTION

Ontology, defined as in information science, is a formal contextualisation and characterisation of the types, properties, and inter-relationships of the entities which are factual or exist for a particular domain. Medical science is one of the fields where ontology has been used extensively, e.g. SNOMED-CT[a], for the actual implementation into information systems. However, surprisingly, ontology has not yet been widely implemented in the domain of robotic surgery where, we believe, contextual representation of surgical information has utmost importance for improving results of the surgical procedure. It may be possible that ontology based knowledge formalism enables surgical robot to get knowledge about the procedure and the surrounding environment to work along with surgeons. In our work, we tried to create environmental information grounded as instances of the concepts.

Previous research has been done using Description Logic (DL) to achieve knowledge formalisation for laparoscopic procedures such as cholecystectomy, and rule-based intra-operative context awareness [1] to recognise phases during the surgery. Katić et al. [2] have developed a computational model for laparoscopic surgeries, LapOntoSPM ontology, which is sharable, extensible and inter-operational with established knowledge representation for phase recognition with special importance to reusability. Conversely Neumuth et al. [3] have used information fusion methodology to detect, indentify and localise surgical instruments in the interventional suite. They have used radio-frequency identification (RFID) technology but the performance of the system was hindered by the metal surgical instruments influence on the RFID tags and so on. Most of the previous studies have been done on the detection of surgical phases through ontology, although detection of steps, anatomical parts and 3D surgical instrument's models were not investigated. Our work was focused on the modelling of the percutaneous surgical procedure called 'Thoracentesis', development of a robust algorithm for segmentation of the instruments and integration of surgical instrument's models with ontology for the instrument detection, for recognition, to provide assistance to surgeons. Pleural effusion is a debilitating condition, often associated with other diseases, in which, there is a build-up of fluids between lung tissue and chest cavity or pleural space. Common Symptoms of Pleural effusion can include pleuritic chest pain, coughing and dyspnoea [4]. Removal of fluid from the pleural cavity is performed by an invasive procedure called needle Thoracentesis, in which a needle is inserted into chest cavity and the fluid withdrawn using a syringe [5]. Procedure related complications are a major problem and can range from pain, dry cough, no fluid return or subcutaneous collection which affects at most 33% people, to life threatening complications such as pneumothorax, pulmonary oedema, unintentional puncture of spleen or liver and sheared off catheter in the pleural space and in some exceptional conditions winging of the scapula [5]. A reliable and repeatable aid to assist the clinician in performing needle Thoracentesis would therefore be of benefit and improve patient care.

II. MATERIAL AND METHODS

A Microsoft Kinect (Microsoft, WA, USA) was used to acquire dense point clouds with depth and colour information. In our work, the acquired point cloud was processed by Point Cloud Library (PCL)[b] in the Robotic Operating System (ROS)[c]. For the management of the surgical workflow and instrument detection, we designed and implemented the Thoracentesis ontology in RDF/XML(OWL), through Protégé[d]. For evaluation of implemented ontology, a software, using Java JFC/Swing [6] and Apache Jena API [7], was developed. To Query, reason and update the ontology, Jena API along with Graphical User Interface (GUI), provided by JFC/Swing, were implemented. It also gives opportunity to add or remove the newly detected instruments automatically. Each of them are explained briefly in the following sections. The particular scenario could be, when the procedure starts, the ontology along with Kinect tracker finds out the sequence of phases during the procedure and execute relevant steps in order to find the correct instrument. In the next stage, the detected model is forwarded for recognition and robotic assistance by providing instruments to the surgeons, and also decision support by GUI.

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a. http://www.nlm.nih.gov/research/umls/Snomed/snomed_main.html
b. http://pointclouds.org
c. http://www.ros.org/
d. http://protege.stanford.edu/

Ontology

Information about Thoracentesis was acquired from a journal article [8] and online resources, which were verified through HONCode[e] for health information authenticity. Procedure was analysed using approach similar to [9], where axioms are divided into triplets in the format of (instrument, step, anatomical site), specified for each surgical phase. For example, the withdrawal of large syringe (50 ml) from the area of insertion on inter-costal space is expressed as Closure (LargeSyringe ,WithdrawLargeSyringe, AreaOfInsertionIntercostal).
Information are also extracted from SNOMED-CT, especially anatomical parts, and merged with the developed ontology considering reusability. Part of the developed ontology is shown in Fig. 1. The instances of the instrument's models have been created in the ontology and configured in the application developed for detection.

Segmentation

The developed algorithm, for the segmentation of instruments using PCL libraries, includes the acquisition of depth registered points (for example, points with information of position, i.e. XYZ, and colour, i.e. RGB), then to approximate the region of interest, PassThrough filter is used to remove useless points such as walls. The real segmentation was done using colour based region growing method, which groups together points that check colour constraints. If the difference was less than a colour threshold specified, the relevant clusters were put as a same cluster. There are two post-processing steps in this algorithm. In the first one, neighbouring clusters with similar average colour are merged and second, clusters that are smaller than the minimum size are merged with their neighbours. Nearest neighbour search was employed to search internal structure (k-d tree) of the point cloud to identify potential point neighbours. Few segmented objects are shown in Fig. 3.

Application interface - NEAR Surgical Interface

The Graphical User Interface (GUI), as shown in Fig. 4., was developed using Java JFC/Swing and to handle the ontology, Apache Jena API was used to reason and query the ontology. Application contains sections for ontology, query (SPARQL language[f]) and results (Instrument point cloud information - points and model's centroid information, surgical phases, steps and anatomical parts). The software is configured, with local resources, through a key-value pair method [10].

Recognition synopsis

After user loads ontology for Thoracentesis in the application, the surgical workflow could do queries about the instrument's models, which are stored as local resources, during an instance of phase and step of the procedure when surgeon needs it. After searching the result, the instrument's model is forwarded to the recognition node implemented in ROS for the key-point matching between the model and the scene. The SHOT features are extracted for both of them and Geometric 3D Consistency Grouping algorithm is employed to find correspondences between a set of key-points. If model's correspondence is found in the scene, the centroid of the model is calculated. Based on the model's centroid information, pose of the instrument is returned, as an output of the algorithm, for further processing for the robots.

III. RESULTS

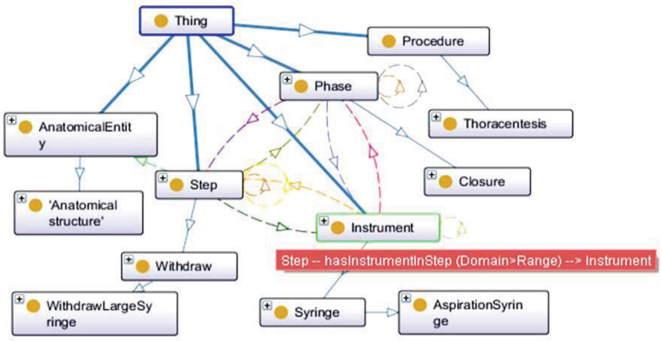

Fig. 1. The rectangles represent classes of the ontology, while blue edges represent hierarchies and other coloured edges represent the relationships between the classes

The ontology that we designed to make an example of the Thoracentesis workflow is reported in Fig .1. The procedure class for Thoracentesis is populated and it has relationships with steps, phases, surgical instruments and anatomical parts, which were specified through assertions. We collected a list of instruments that are used during the phases and steps of Thoracentesis procedure and populated the instrument class with instrument specific characteristics (e.g. instrument's dimension, its 3D model and so on)

Experimental setup

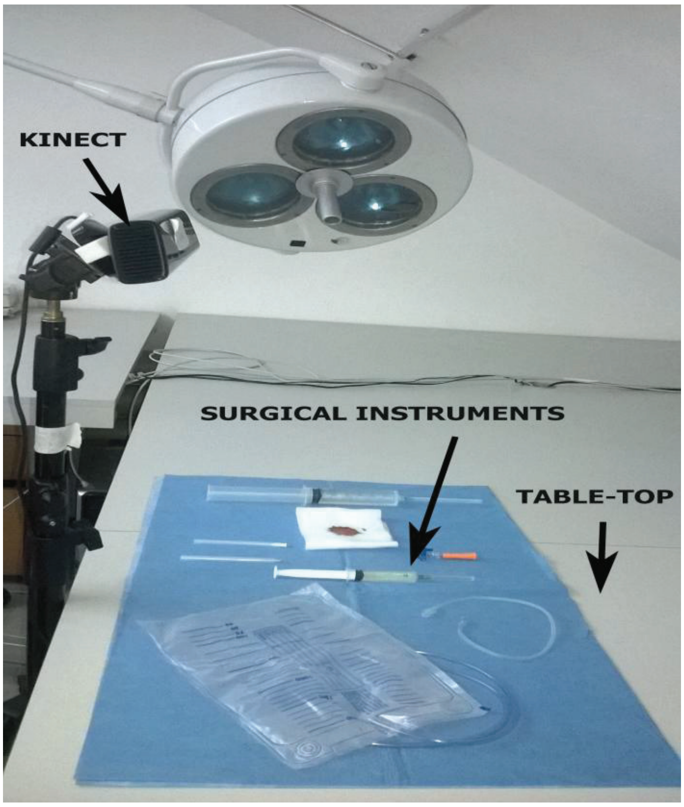

Fig. 2. Experimental setup showing Microsoft Kinect, table-top and the surgical instruments. The Kinect was setup approximately 50 cm away from the table-top. The figure showing the surgical instruments generally used for Thoracentesis procedure.

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e. https://www.healthonnet.org/HONcode/
f. http://www.w3.org/TR/rdf-sparql-query/

To segment, surgical instruments and materials (such as syringes and surgical-swab), we have repeated experiment for each instrument, in different poses, for 25 times and the algorithm was able to segment 50 ml syringe in different poses, that is used during the Penetration/Closure phase, from the background. However, the accuracy was found to be approximately 64%. The reasons for the limited accuracy are the limitation of the Kinect sensor and white opaque colour of the syringe.

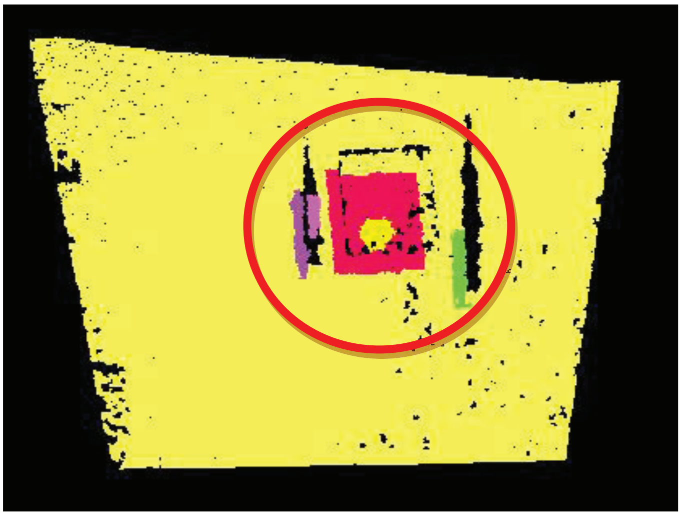

Fig. 3. Kinect acquisition of depth points. As can be seen in the highlighted circle, surgical-swab and a part of the syringes are segmented, also a table-top surface. The algorithm was able to detect instruments with different positions and orientations.

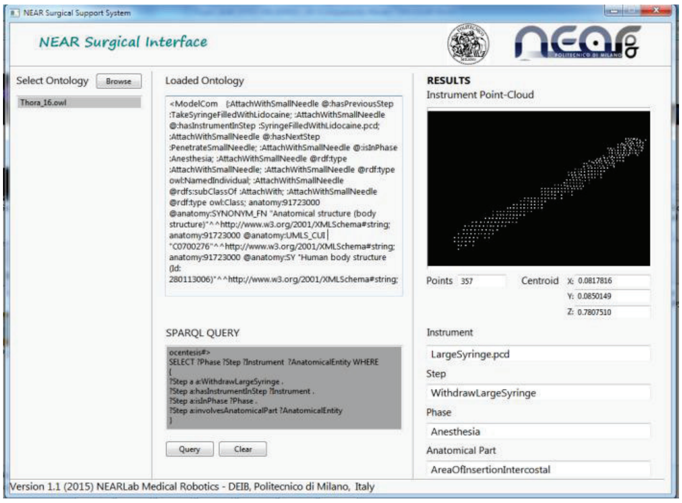

Fig. 4. NEAR Surgical Interface. The loaded ontology, SPARQL query and detected instrument, with information about cloud points and its centroid, is linked though instrument's instances as shown in the figure, which can be forwarded for recognition

As shown in Fig. 4. Ontology for Thoracentesis is uploaded in the application. After the ontology is loaded in the interface, user queries the ontology through SPARQL language. In the example above, it is requested, through query, to show information about the instrument, its point cloud model information and operation phase, all of which are requisite during the procedure step WithdrawLargeSyringe to provide assistance. As discussed before, segmented instrument's model is presented based on the instances created in the ontology (e.g. LargeSyringe.pcd). To evaluate the ontology, we iteratively checked it through 'pellet' reasoner, which is in-built plugin in Protégé, during the building process to minimise the inconsistencies in the ontology and through different queries during and after building the ontology with complete assertions. We have found out True Positives, False Positives, True Negatives and False Negatives, by asking positive and negative queries, with respect to the Thoracentesis procedure described in the literature to calculate statistical measurements. We run a total of 200 queries and we found sensitivity of 100%, with specificity 99.1% and accuracy 99.5% for ontology based decision support. The specificity and accuracy is high because we have used iterative and incremental development approach by constantly checking ontology and asserted procedural axioms iteratively through pellet reasoner and queries. If ontology was found to be inconsistent, then it was incrementally updated or adjusted.

IV. Conclusion and Future Work

We have presented a surgical assistance system which could provide surgeon decision support and get information about instrument's 3D model. For instance, system could provide intra-operative assistance to surgeon in selection of correct instruments that he/she requires during the surgery. An ontology describing Thoracentesis is implemented considering different phases, steps, instrument models and anatomical parts. Jena API has been implemented to reason over the ontology and to query to provide instrument at specific instance of time. We conclude that it is possible to make surgical assistance system which uses ontology as a main knowledge source for assistance to surgeons. While robotic surgery is mostly applied in the case of minimally invasive surgery, handling indirect sensor fusion by grounding it in the ontology would be helpful to extend the support to existing robotic surgical applications. In more realistic scenarios, when instruments are unorganised, 3D lidar or stereoscopic cameras and optical or magnetic trackers would be required for accurately locating and tracking all the instruments. If ontology is integrated with the data from the imaging sensors such as ultra-sonography or computed tomography, it could enhance ontology based intra-operative assistance, for example to detect accurate anatomical location (needle insertion region on the chest). Each surgical procedure has different steps, anatomical locations and a different set of instruments. It adds significant complexity and restrictions to ontological scalability. The possible solution to scale the ontology is by doing semantic mapping of metadata, such as instrument characteristics, which are represented for ontological classes. Metadata can be included in the ontology as annotation for the ontological classes. Consequently this common metadata could be used by different procedures to get information about similar instruments and thus removing architectural complexity to handle heterogeneous information. The approach similar to ROBOSHERLOCK [11] could also used where perception and interpretation of realistic scenes is formulated as an unstructured information management (UIM) problem. The framework supports task-specific queries about objects in the scene, combining different perception algorithms, support knowledge-enabled reasoning about objects and enable automatic and knowledge driven generation of processing pipelines. We also proposed a fuzzy extension to ontology to handle uncertainty, for instance, there is an uncertainty when the system need to decide which needle to choose to insert into some body structure although the different needle sizes and body structures are expressed in the ontology. Future work will also focus on wrapping different system components under common software framework such as ROSJAVA for real-time implementation, improvement of the segmentation and recognition algorithms, extending the ontology for the robotic implementations and grounding object affordances in the ontology.

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