# Toward a Synergistic Framework for Human-Robot Coexistence and Collaboration (HRC$^2$)

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***Abstract*—This paper presents a proof of concept for a synergistic framework for human-robot coexistence and collaboration (HRC$^2$). By exploiting the loco-manipulation potential of our recently developed MObile Collaborative robotic Assistant (MOCA), we developed a novel framework that distinguishes and suitably reacts to coexisting and collaborative human partners. The framework avoids any collisions or physical contacts with coexisting partners while enabling ergonomic physical interactions with the collaborative-identified ones. The selection of the collaborative partners is achieved through body gestures.**

## I. Introduction

Versatile and easy-to-use collaborative robotic solutions, where human workers and robots share their skills, are becoming the new frontier in industrial Robotics [1]. The greatest advantage brought by collaborative robots lies in the opportunity to combine the accuracy, endurance and power of automation with the flexibility, expertise and cognitive abilities of humans [2]. Accordingly, an ever-growing number of studies is conducted to tackle the challenges for an efficient and fluent human-robot collaboration (HRC). Most of our previous work in this respect focused on the development of control strategies or feedback interfaces to improve the human counterpart's well-being and awareness while collaborating with a robot [3]. Consequently, to increase the potential of collaborative robot-based technologies in the workplace, we recently integrated the concept of mobility into the robot control framework, developing a new MObile Collaborative robotic Assistant (MOCA) to combine agile mobility with ergonomic interaction and co-manipulation [4]. The assumption of an empty and free working area was made in this work.

Nevertheless, preventing undesired collisions, handling unavoidable or unintentional physical contacts in a safe and robust way, and generating reactive motions are essential requirements for the robots to share a work space with their human counterparts [5]. Hence, one of the key forthcoming objectives of our work is to enable robot movements in realistic industrial environments, which may include fixed obstacles as well as human actors which, in turn, move unpredictably in the working area. The main requirements for such a system will be to recognize the coexisting elements as the *avoidable targets*, and the ones with collaboration needs as *interactive targets*.

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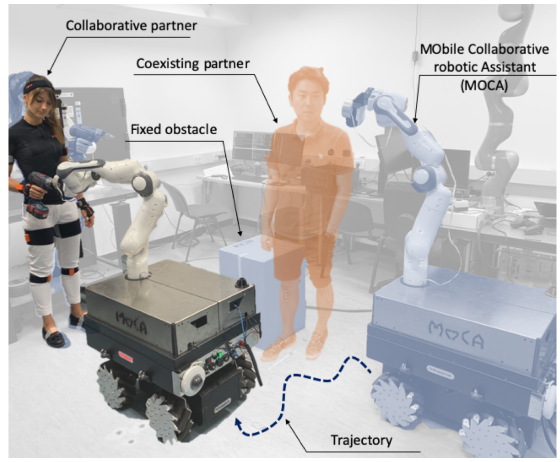



Fig. 1: The experimental setup.

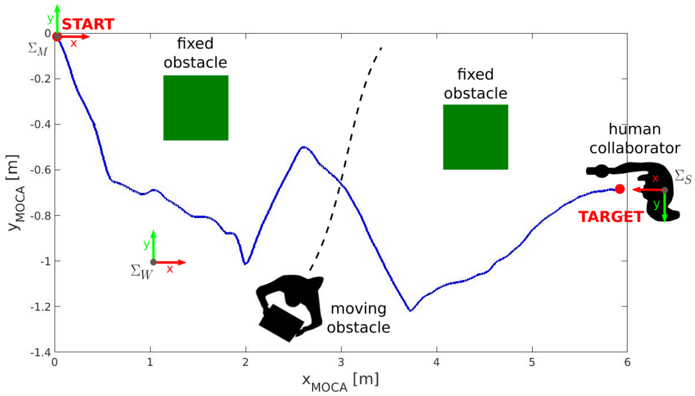
This paper presents the first attempt in this direction, with the aim to develop a synergistic framework for human-robot coexistence and collaboration (HRC$^2$). First, a navigation control strategy is implemented to make MOCA move in a laboratory-simulated working area, avoiding fixed and moving obstacles (including coexisting partners), and to reach the location of the human collaborative partner. Second, our HRC framework [3] is employed to enable an ergonomic, physical human-robot interaction in a co-manipulation task.

## II. Method

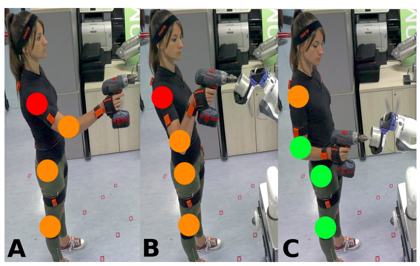
The proposed synergistic HRC$^2$ framework includes a navigation module and a collaboration module.

*Navigation Module*: The implemented navigation method is based on the "move_base" package of the Robot Operating System (ROS) [6] and it employs the ROS Global Planner along with the TEB (Timed-Elastic-Band) local planner [7]. This algorithm takes as input all the available data (the desired target pose, data from sensors and the odometry) and as output it provides the velocity commands for the robot. The mobile manipulator we use, MOCA, was developed in a previous work [8] and it is composed of a SUMMIT-XL STEEL platform (a holonomic mobile robot) and a Franka Emika arm. The system is initialized without a map, and to navigate in the unknown area it updates a cost map using the information from three sensors: two lasers (one in front and the other in the rear part of the mobile platform) and a RGB-D camera (in front).

*Collaboration module*: We recently developed a human-robot collaboration framework to improve human ergonomics by using a collaborative robot [9]. The method is based on the real-time estimation of the physical loading on the human co-worker's body joints induced by an external force (e.g. tools




(a) MOCA trajectory




(b) Human collaborative partner

Fig. 2: (a) MOCA trajectory in its reference frame ($\Sigma_M$) during the navigation phase. (b) Human collaborative partner in 3 time instants: calling the robot (A), starting HRC in a bad posture (B), adjusting posture through MOCA guidance (C).

or objects). This information is used for the on-line optimisation of the robot trajectories to assist the human partner in reaching more ergonomic body configurations, to mitigate potential risk of injuries or chronic pathologies. Accordingly, in the proposed HRC$^2$ framework, MOCA addresses human collaborative partner's ergonomics with the same strategy, after reaching the suitable location in the work space. A detailed explanation of the method, which cannot be reported here due to space limitations, can be found in [9].

## III. Experiments and Results

We present a preliminary experiment to illustrate the potential of the HRC$^2$ framework. The whole experimental procedure was approved by the ethics committee Azienda Sanitaria Locale Genovese (ASL) N.3 (Protocol IIT_HRII_001). The experimental setup is illustrated in Fig. 1. The actors involved were MOCA, a human subject moving unpredictably in space (coexisting partner) and a human subject, wearing a MVN Biomech suit (Xsens Tech) provided with seventeen interconnected inertial measurement unit (IMU) sensors to measure the whole-body motion (collaborative partner). A global reference frame $\Sigma_W$ was defined on the floor of the experiment room to localise the reference frame of each involved actor. Both MOCA and the MVN Biomech suit worn by the human subject were calibrated in order to set $\Sigma_W$ as their global reference frame. $\Sigma_S$ and $\Sigma_M$ were the local reference frames of the subject and MOCA, respectively.

The experimental procedure included two phases: the navigation phase and the Collaboration phase. In the navigation phase, MOCA had to navigate in the experimental room avoiding both the static obstacles and the human actor moving in the workplace, and distinguish the 'target' human, namely the collaborative partner, whose location is the goal of navigation. The operator, raising the arm to call MOCA, was depicted as the collaborative partner, and the rest of the people in the room as the coexisting ones. Then, in the Collaboration phase, the target human subject had to perform a collaborative task with MOCA, drilling an object held by the robotic arm.

As soon as the human subject was ready to perform the task, she raised slightly the arm holding the driller (see Fig. 2b, picture A), and the subject location in the work space was send to MOCA, which started approaching her. At the end of the navigation phase, MOCA stopped in front of the target human subject at a predefined distance and the Collaboration phase started. The subject started drilling the object in a bad body configuration (see Fig. 2b, picture B), the optimisation procedure to minimise the physical loading on the human joint was performed, and then the robotic arm moved and guided the human in the optimised body configuration (see Fig. 2b, picture C). In this way, the risk of injuries for human joint was reduced. In Fig. 2a the trajectory of MOCA throughout the working area is depicted. It can be noticed how MOCA was able to easily avoid the fixed obstacles as well as a human moving unpredictably close to it, and to reach the navigation goal with high accuracy.

## IV. Conclusion

This paper presented the first attempt to create a synergistic framework for human-robot coexistence and collaboration (HRC$^2$).

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