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The Marvin Project: an Omni-Directional Robot for Home Assistance

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***Abstract*—In the last decades, many researchers are investigating how robotic solutions may be adopted to address the increasing need for home and personal assistance aggravated by current global challenges, e.g. population ageing and pandemic emergency. In this direction, the researchers at Politecnico di Torino, together with the colleagues from Edison S.p.A., developed the Marvin project which aims at designing a useful mobile robot for the domestic environment. In this work, the main features of the Marvin prototype and a first qualitative experimental validation are presented.**

Keywords— assistive mobile robotics, artificial intelligence, autonomous robotics, vocal assistant, system design

I. Introduction

In recent years, the ageing of the population related to an unprecedented decrease in fertility and mortality rates in industrialized countries, together with the health emergency caused by Covid-19, are pushing research towards the development of autonomous robots, tailored on the purpose of assistance to weak or non-self-sufficient subjects [1]. Recently, Socially Assistive Robots (SAR) have been proposed as a possible solution for elderly care and monitoring in the domestic environment. According to Abdi et al. [2], various SAR already exist. Most of the attention has been focused on the human-machine interaction, realizing companion robots with humanoid [3] or pets-like architectures [4], specifically designed for dementia, aging, and loneliness problems [5]. Nevertheless, other studies proposed intelligent systems for monitoring tasks, such as heat strokes [6] and fall detection [7]. In this context the effort of the researchers at Politecnico di Torino met the commitment of Edison to assess the potential of service robotics in challenging human-machine interaction tasks. The most tangible output of this collaboration was the design and development of a mobile platform, then called Marvin, based on an open and modular approach both regarding HW and SW. Eventual future works will look to enhance the Marvin's social capabilities and to expand its features to address further challenging tasks like inspection and maintenance, so keep exploring the service robotics in all its facets.

The leading idea behind the Marvin prototype was that of designing a mobile robot to provide basic domestic assistance. For such task to be accomplished, the robot should be able to navigate in a cluttered and unknown environment, though confined spaces and over small obstacles that can lie on the ground, e.g. electric cables or carpets. Moreover, the robot must be provided with the capability to deal with the presence of big obstacles that cannot be overpassed. For the Marvin robot the following service functions have been identified: *user monitoring, night assistance, remote presence, and connectivity*. *User monitoring* concerns the capability of the robot to detect a potentially dangerous situation for the user and call for help. Since one of the most critical moments in the daily life of elders is the night-time bedroom-to-toilet journey, a specific function, *night assistance*, has been included to accompany the person to the desired destination inside the home, enlightening the path, while monitoring the user's movements. Finally, the robot should be able to help the assisted to access commonly used communication platforms (*remote presence, and connectivity*). For all these requirements to be fulfilled, a custom solution has been designed around the needs and characteristics of the user. In the following section, a brief description of designing process of Marvin is presented. For further information, the interested reader is addressed to the work [8].

II. Robot Design

During the last decades, robotics research has proposed advances in humanoid and pets-like robots that can deal with the great unpredictability that the robot may face, but at the cost of expensive, and complex balancing systems. To select the correct moving platform for the Marvin prototype, the application environment must be studied. This mobile robot is conceived for assistive domestic applications. For this reason, a low level of ground unevenness could be foreseen. It should

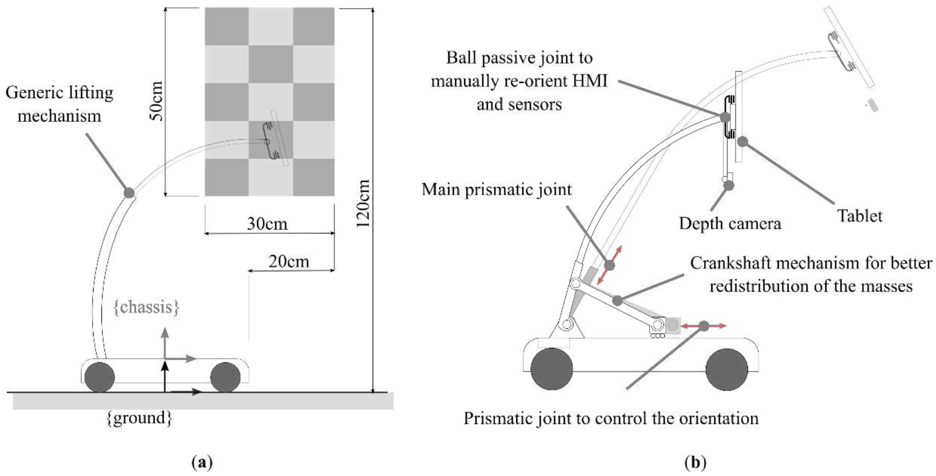

Fig. 1 Positioning device functional device: (**a**) workspace identified for the deployable mechanism, (**b**) functional representation of the proposed architecture.

be underlined that for every service robot to be successful, the cost-effectiveness as well as the mechatronic and software reliability are of paramount importance. Based on all these considerations a wheeled mobile base has been selected instead of the aforementioned walking architectures. Regarding the maneuverability of the platform, omnidirectional mobility is required to effectively perform the monitoring of the assisted while avoiding obstacles. This service function requires the ability to orient the sensors towards the user, thus the heading of the robot must be chosen independently from the linear velocity direction. General dimension requirements could be derived from the application environment. In fact, the robot will be adopted in the domestic environment, which is conceived for humans. Thus, a non-symmetrical base with a footprint like that of a person should be enough to guarantee navigation through the domestic environment, e.g. rectangular footprint with maximum dimensions of 500mm x 400mm. Considering these requirements and to speed up the prototyping phase, the commercial NEXUS 4WD platform has been chosen. This platform is provided with four mecanum wheels, to achieve omnidirectional motion, it is characterized by overall dimensions of 400mm x 360mm x 100mm, a limited mass (5.4 kg), and a passive roll joint between the front wheels and the rear wheels to deal with the presence of four contact points with the ground.

Other fundamental requirements can be derived from the necessity to facilitate the interaction between the robot and the user. For this reason, the robot should be able to lift and orient the tablet, which acts as connectivity and visualizing tool. As the application suggests, the tip of the mechanism should reach above common furniture to bring the user interface in a comfortable position. To perform this action, the robot can approach the furniture parking as close as possible to the goal position or it can partially go under the furniture if the cabinetry geometry allows it. Considering the high mobility of the base platform, a minimum set of two motions is needed to facilitate the interaction human-machine: the lifting motion and the forward displacement of the tablet. For the workspace definition of the positioning device, the following situations have been considered:

- *Dinner table*: under motion is possible, no longitudinal displacement from the platform border is required, working height approximately 90 - 100cm;
- *Home bed*: under motion is usually not possible, required longitudinal displacement from the platform border of approximately 20cm, working height approximately 80 - 90cm;
- *Standing person*: no longitudinal displacement from the platform border is required, working height approximately 120cm;
- *Seated person*: required longitudinal displacement from the platform border of approximately 10 - 20cm, working height approximately 90 - 100cm;
- *Person on wheelchair*: required longitudinal displacement from the platform border of approximately 10 - 20cm, working height approximately 80 - 90cm;

To keep the center of gravity low during motions, the conceived device should be able to be retracted during navigation. All these requirements result in the workspace presented in Fig. 1 (**a**). To keep the center of gravity as closer to the ground as possible, a crankshaft mechanism is used to tilt the main telescopic guide as represented in Fig. 1 (**b**). According to the workspace previously defined and considering the commercial platform Nexus 4WD height of 100mm and a longitudinal length of 300mm, the required linear stroke for the main prismatic joint and the required angular stroke for the tilting motion are respectively 350mm and 26°. Because no commercial solution was sufficient to fulfill all the requirements, a custom lightweight and compact solution has been designed and prototyped. The final Marvin prototype is represented in Fig. 2 (**a**), where all the main components are listed.

Autonomous navigation and human-robot interaction require good perception of the environment. For this reason, the robot must be provided with several sensors. Alongside classic devices like RGB cameras and Lidar sensors, the robot is provided with two state-of-the-art devices conceived for self-localization and depth estimation. For example, the Intel RealSense T265 Tracking Camera uses VIO technology to estimate the pose of the system with respect to the starting configuration. Moreover, the Intel RealSense D435i Depth Camera is used to acquire simultaneously depth and color images. To improve the robot perception, this depth camera is

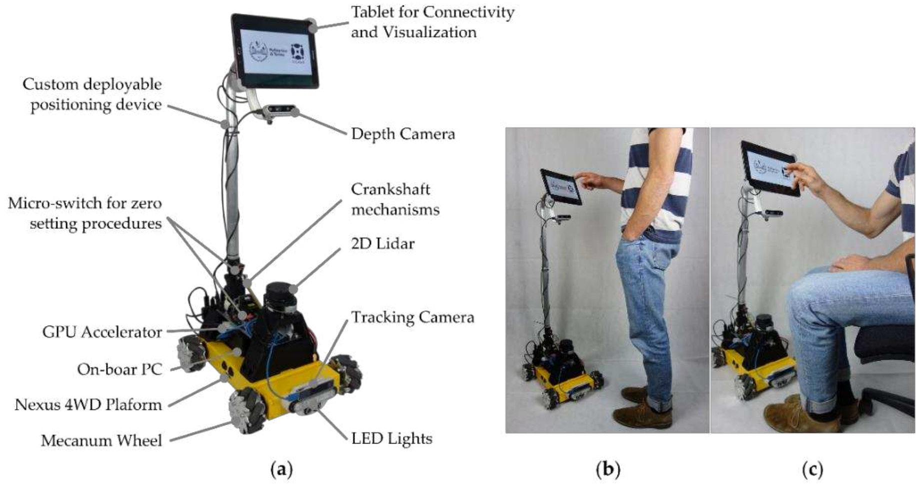

Fig. 2 Marvin prototype: (**a**) main components of the assistive robot, (**b**) deployed configuration for better-standing usage, tablet height = 1.1 m, tilting mechanism angle = 0°, (**c**) retracted and angled configuration for better-seated usage, tablet height = 0.80

mounted on the tip of the positioning device, thus the point of view of the robot can be adjusted according to the environment. Finally, a Jabra 710 panoramic microphone and speaker is used for vocal-based interactions, while a wireless gamepad may be adopted for manual controlled operations.

To address all the requirements, the robot must be able to autonomously navigate in an unknown environment, perform person following and monitoring, and must be capable of understanding vocal commands. All these features are highly demanding from a computational capability point of view. Therefore, an appropriate computing unit must be selected to achieve a good trade-off between high computational power and low energy consumption. For this reason, the Intel NUC11TNHv5 has been adopted. The planned motions for the robot are sent to a microcontroller unit (MCU), built around a Teensy 4.1 single board, through a serial bus. The MCU computes the inverse kinematics of the 4WD platform, to evaluate the required motors' speeds to achieve the desired motion, it performs PID-based closed loop controls on the motor's speed, it controls the motion of the two degrees of freedom positioning device, and it turns on and off the LED lights needed for the *night assistant* service function.

The person monitoring task is performed through a double-step computing pipeline. Firstly, the person-detection is obtained with PoseNet [33], a lightweight neural network able to detect humans in images and videos. A second simple convolutional neural network (CNN) is used to classify the pose of the person as standing, sitting, or laying. A custom-labeled dataset of images has been collected in a house environment to train the CNN for the pose classification. From the relevant body points predicted by PoseNet the dynamic goal for the person following task is evaluated. This goal pose is used by the motion planner to evaluate the twist velocity of the platform to achieve the person following task.

The principal user's communication interface is represented by an offline vocal assistant. A custom vocal assistant system, called PIC4Speech, has been created exploiting the combination of state-of-the-art Deep Neural Networks (DNN) for speech-to-text translation and a simple rule-based model for Natural Language Processing (NLP) derived from literature with the aim of minimizing the computational cost of the pipeline and preserving a flexible interaction. The retrained model achieved a test accuracy of 97% over the different classes on the 11005 test samples of the Speech Commands dataset. Because PIC4Speech works completely offline, it prevents Marvin from exposing the visual data of the domestic environment to internet-derived risks.

III. Experimental Test

A qualitative demonstration of the platform's capabilities had been conducted in the Domus Lab at the Officine Edison Milano during the presentation organized to validate the outcome of Marvin's prototyping process. The demo area simulates a real domestic environment made up of a kitchen, bedroom, living room, and bathroom (Fig. 3). In the setup phase, Marvin was guided in each of the different rooms and their relative positions were saved with respect to the starting point, where a docking station for recharging could eventually be placed. Moreover, a telephonic number was memorized for the emergency call task. From the starting point (Fig. 3 (**a**)), Marvin was asked to autonomously reach the bedroom, passing through the double-leaf door. Here, the user monitoring function was demonstrated, showing how Marvin was able to correctly classify the pose of the visualized person, standing, sitting on an armchair, or lying on a bed (Fig. 3 (**b**)). In addition, it was also demonstrated how, after a request from the user, the system was capable of connecting with the pre-configured telephone to call the emergency number. Then, the robot was asked to follow the user from the bedroom to the living room (Fig. 3 (**c**)). Later, the user activated the night assistance task by asking the rover to accompany him to the bathroom, causing the robot to turn on the onboard lights (Fig. 3 (**d**)). Finally, Marvin was asked to reach the kitchen and to adjust the inclination and height of the positioning device to adapt to the user, sitting on the chair, so that the mounted tablet could be more easily accessed and operated (Fig. 3 (**e**)).

During the demonstration, Marvin succeeded in the execution of the three proposed service functions. Thanks to its mobility and the elevated position of the camera, mounted

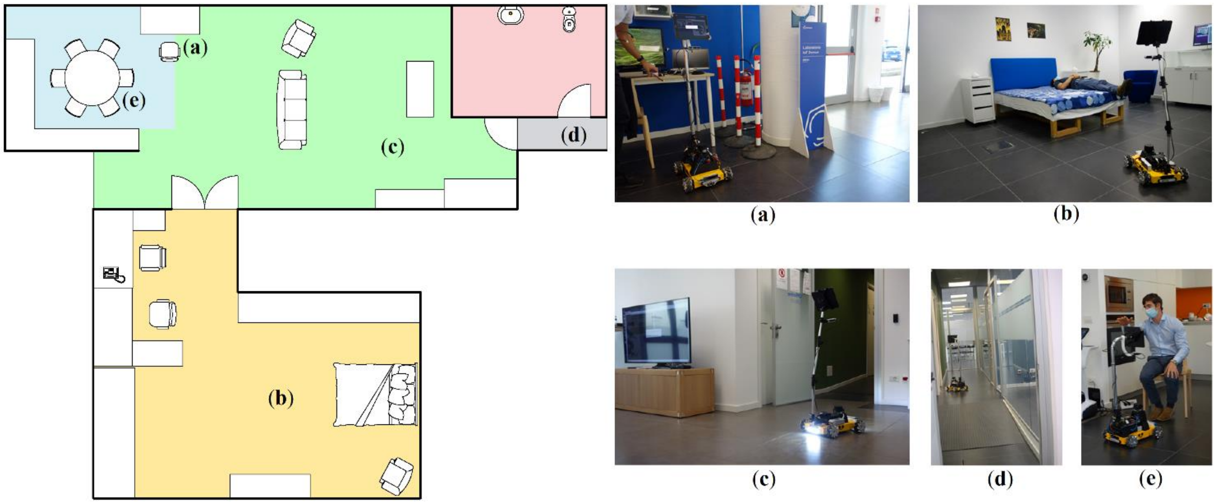

Fig. 3 Simplified map of the Domus area at Officine Edison, Milan, with the four rooms, kitchen, living room, bedroom, and bathroom, respectively in yellow, orange, green, and blue. Letters on the map indicate the various goals saved in the environment, associated with the corresponding image: (**a**) starting point, (**b**) bedroom keypoint, with user's pose recognition, (**c**) living room keypoint, with lights turned on, ready for night assistant task (**d**) bathroom keypoint, (**e**) kitchen keypoint, with demonstration of the positioning device capabilities.

on the positioning device, the robot managed to efficiently track and follow the person. This allowed to continuously monitor the user, classifying their pose in any instant, and calling for help during potentially dangerous situations. Moreover, the rover showed no difficulties in autonomously navigating between the various rooms, avoiding static and dynamic obstacles arranged in different configurations, and accompanying the user to the desired destination. In particular, the robot was also able to manage its handling upon less conventional surfaces, such as the skirting board of fire doors and a small ramp placed in the corridor before the bathroom. Finally, the positioning device's flexibility, in conjunction with the platform maneuverability, guaranteed the user an easy operation of the tablet, standing, sitting, or lying down.

IV. Conclusions

In this work, the design of Marvin has been presented. The autonomous mobile robot is conceived as a robotic assistant solution tailored for the practical use case of monitoring elderly and reduced-mobility subjects in domestic environment, although its applicability can be easily extended to the alternative person monitoring scenarios in indoor environments. Marvin is characterized by a four mecanum-wheel platform provided with a custom positioning device for the human-machine interface and state-of-the-art Artificial Intelligence methods for perception and vocal control. The robot has been fully prototyped and qualitatively tested in a domestic-like environment and it proved to be successful in the execution of the identified service functions: *user monitoring, night assistance, remote presence, and connectivity*.

Future works will investigate Marvin's proactive behavior in social domestic environments and its awareness of the context through more sophisticated visual techniques. To improve the robot ability in the interaction with the environment, custom solutions to provide the robot with basic manipulation capabilities will be studied. Finally, the adoption of this prototype will be investigated in other challenging applications like inspection and maintenance, to explore service robotics in all its facets.

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