The Paquitop project: innovative modular mobile robot for personal assistance

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***Abstract*— In the last decades, an unprecedented decrease in fertility and mortality rates in industrialized countries yielded a general ageing of the population. Such phenomenon affected the everyday life of individuals as well as organizations, either government or private, to the point that they are nowadays seeking the solution to the increasing demand of health care, housing, care-giving, and social security. In this scenario, this piece of research aims to fulfil a design task, specifically oriented towards the field of assistance machines. The functionalities which should be guaranteed are mainly two: to follow and monitor reduced mobility subjects, to maintain a constant view contact with its targets, and to accomplish such duties in a non-structured and possibly peopled environment.**

Keywords*— *over-actuated mobile robot, assistive service robot, health care, modular design

I. INTRODUCTION

The ageing of the population and the increasing attention to automatized caregiving are pushing nowadays research towards the development of autonomous machines, tailored on the purpose of assistance to weak or non-self-sufficient subjects [1]. The last months, in particular, stressed on the need of freeing many of such activities from the presence of human operators: the pandemic emergency caused by the Covid-19 highlighted the importance of social distancing, especially due in those structures, such as geriatric wards and hospices, where patients are endangered by the closeness to other people. Although several tasks can only be performed by human staff, many others of lesser importance can be delegated to robotized agents properly instrumented. In this scenario, this project aims at assessing the design of a modular robotic device, able to fulfil a variety of monitoring and basic assistance tasks such as the delivering of light weighted objects, as drugs, medical disposables, or even small parcels. The idea which lies at the base of the project is a moving platform that can be provided with different sets of sensors and instruments depending on the specific field of use. Pursuing this objective automatically implies a variety of technical challenges. In the era of electronics, one is led to think that the major part of them can be approached through proper control [2]. Nonetheless, also the mechanical design plays a crucial role in the success of a mobile robotics applications [3]. Also over-actuated robots have been widely studied, especially the aspects about the non- or quasi-holonomic constraints they involve [4], and about the difficulties aroused by the control of the over-abundant set of actuators [5]. As a matter of fact, the most part of the devices which involve an actuation redundancy make use of omni-wheels, whose efficiency is strictly related at the possibility of maintaining a slip less contact with the ground. Then, their use in non-structured environments can be extremely complex, especially in presence of obstacles.

II. ROBOT CONCEPT AND MOBILITY

With such premises, the researchers of the Politecnico di Torino presented a mobile robot [6], named Paquitop (Personal Assistant Qu Italy TOrino Politecnico), with the aim of enhancing the achievable limits of both differentially actuated and omni-directional wheeled mobile robots. The platform, whose conceptual design is shown in Fig. 1, is an over actuated robot suspended on four wheels. Two of them are driven steering wheels, while two are standard off centered passive castor wheels. Such scheme provides a redundant set of actuated constraints with respect to the degrees of freedom, yet it allows taking advantage of omni-directional mobility without the disadvantage peculiar of omnidirectional wheels (which poorly fit the use in domestic environments). Due to its peculiar workspace, the robot should be shaped on a human scale, in order to access all the spaces which are usually lived by persons. Therefore, a non-axisymmetric footprint is preferable to a symmetric one so that the robot is able to offer, when needed, a reduced size to pass through confined spaces.

At last, it is worth remarking that the presence of four contact points with the ground implies the need of using an adequate suspensions system, necessary to assess the ground unevenness and to enhance its capability to overpass reasonably low obstacles without compromising its whole equilibrium [7]. As a matter of fact, the most part of indoor robots do not make use of suspensions, while outdoor rovers provided with suspensions usually adopt active systems. In order to contain costs and complexity of the project, a passive suspensions approach is way preferable.

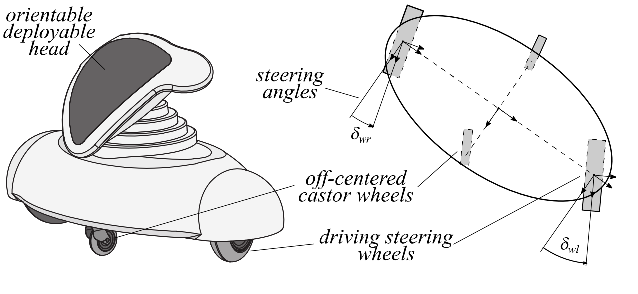


FIGURE I: PRELIMINARY CONCEPTUAL DESIGN OF THE PAQUITOP ROBOT

As highlighted by authors in [6], the mobility of the robot can be distinguished into four different classes of steering configurations, which can be depicted through a critical analysis of the robot kinematics, and which are briefly described hereby and illustrated in Tab. I:

Configuration I, $\delta_{wr} \neq \delta_{wl}$ represents the general case. The robot exploits all of its degrees of actuation to achieve a general motion in the plane.

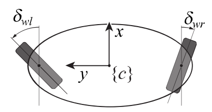
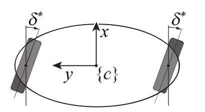
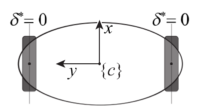
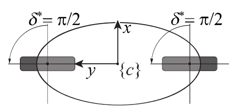
Configuration II, $\delta_{wr} = \delta_{wl} \neq 0, \pi/2$ shows the axes of the two driven wheels parallel, yet non-coincident; the robot is able to translate while rotations are inhibited. This might be a very useful configuration for person tracking tasks since it allows the robot to maintain a fixed direction of observation while translating in the plane.

Configuration III, $\delta_{wr} = \delta_{wl} = 0$: this steering configuration corresponds to the well known scenario of a differential actuation, being the axes of the steered wheels coincident. As a consequence, the robot is able to exhibit an angular velocity, but loses the possibility of owning a transversal directed velocity.

Configuration IV, $\delta_{wr} = \delta_{wl} = \pi/2$: this mono-trace configuration is similar, under many aspects, to Configuration II. The angular velocities of the driven wheels must be the same and their axes are parallel and not coincident. Yet it is authors' opinion that this configuration deserves a own mention for its peculiar static and dynamic characteristic which allows high accelerations of the robot. Moreover, a small steering variation to just one of the two wheels, or opposed small angles around π/2, would also allow the robot to approach curved trajectories without relevant modifications to its ability to absorb higher accelerations in that direction.

To enhance the reader comprehension on the robot manoeuvrability, an example trajectory is proposed in Fig. II. Geometrically, the path is composed of two straight parallel lines connected by two circular sections each one providing a 90° change of direction. The trajectory in Fig. II is performed while the robot is operating a pointing task: the platform runs the S-shaped line while keeping the longitudinal axis of chassis towards a fixed point in the space. The trajectory was planned using only the Configuration I; this represents a particularly interesting test case for it simulates the main usage expected for the robot, i.e. the following and tracking of elder or disabled people. As visible, the robot can follow up the planned trajectory while exhibiting smooth paths also for the actuated wheels. For space reasons, the behaviour of the actuated velocities cannot be shown here. Nonetheless it is quite easy to understand that such smooth behaviour also leads to continuous angular velocities time profiles for both the actuated wheels and the respective steering degrees of freedom.

TABLE I: POSSIBLE STEERING CONFIGURATIONS

Configuration I	Configuration II
$\delta_{wr} = \pi/2, \delta_{wl} = \pi/2 + \delta^*$ 	$\delta_{wr} = \delta_{wl} \neq 0, \pi/2$ 
Configuration III	**Configuration IV**
$\delta_{wr} = \delta_{wl} = 0$ 	$\delta_{wr} = \delta_{wl} = \pi/2$ 

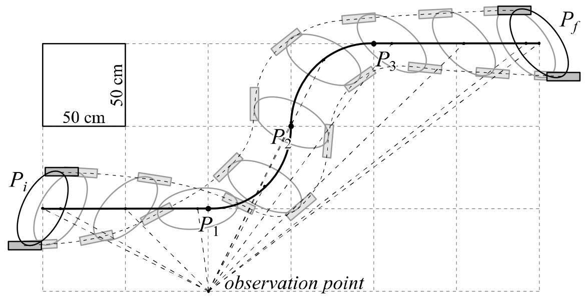


FIGURE II: PAQUITOP RUNNING A CURVED TRAJECTORY WHILE MAINTAINING LINE OF SIGHT WITH AN OBSERVATION POINT

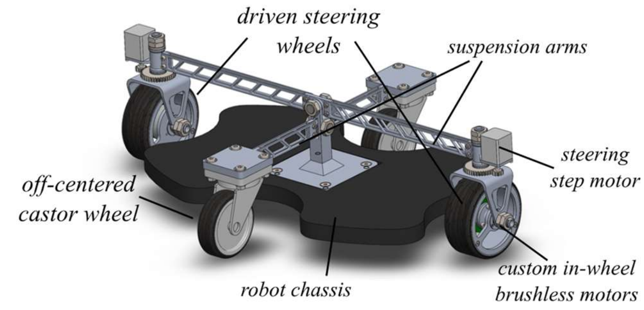


FIGURE III: PAQUITOP PLATFORM PRELIMINARY MECHANICAL DESIGN

III. CONCLUSIONS

The Paquitop project is aimed at designing an innovative mobile robot, with high manoeuvrability and performance, for assistive indoor applications. The project is at present at the mechanical design stage. As shown in Fig. III, the whole mechanical layout has been configured. The kinematics and the dynamics of the machine were considered for the definition of the suspension system, and the choice of proper actuators. Authors are confident that, in a close future, the first experimental tests on a concept prototype will be available.

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