ABSTRACT

This paper describes the kinematic control of the attitude of a robotic wheelchair on uneven terrain. The developed system is capable of overcome uneven terrain. A checklist of problems and barriers in various surfaces is analyzed. The proposed robotic system is based on parallel cooperative multi-manipulator architecture. This architecture allows to horizontally stabilize the robotic wheelchair, even at irregular surfaces and terrains. In order to control the attitude of the robotic wheelchair, a kinematic model of the proposed system is developed.

KEYWORDS: robotic, cooperative manipulators, accessibility.

1 INTRODUCTION

The robotic solution proposed in this paper refers to kinematic control of the attitude of a robotic wheelchair on uneven terrain. We identify the types of land and existing deficiencies that hinder the movement for wheelchair users. After analyzing how these obstacles affect the accessibility of users, the proposed robotic solution was adapted to the barriers that do not satisfy the standards, thus raising the conditions of accessibility for wheelchair users. In this sense we rely on theoretical frameworks that have helped us to analyze the urban routes with a focus on universal accessibility, choosing some elements of that standard that we use to develop our proposal. In this way, we conducted a study in the area of parallel cooperative multi-manipulator architecture to develop the proposed robotic system. A cooperative multi-manipulator can be defined as: "A system composed of several manipulators who assist or cooperate in the execution of one or more tasks" [1]. Some works in literature discuss the implementation of industrial cooperative robotic systems with two or more manipulators. Lewis [2] introduced the concept of relative Jacobian applied to the path planning of two cooperative manipulators. Owen et al [3] applied the concept of relative Jacobian proposed in [2] for solving the trajectory planning for two planar robots performing a machining task. Dourado [4] developed an inverse kinematic method based on helicoids for the path planning in operational space of two and three planar robots. Ribeiro et al [5, 6] defined the concept of Cooperation Jacobian based on helicoids, using Denavit-Hartenberg formulation, to calculate the kinematics of cooperative multi-robot systems. Other works focused on force control and collision avoidance of involving two or more manipulators [7-10].

According to [11], the development of parallel manipulators appeared in the early 60’s, with the presentation of the design of a machine with six actuators for tire tests. In 1965, Stewart has developed a platform with parallel structure for flight simulators with six degrees of freedom. According to [12], in the early 70’s, Minsky presented several parallel architectures, and in 1979 MacCallion and Pham made the first design of a parallel manipulator for installation on workstations. A parallel structure can be understood as a closed chain mechanism, composed of a set of connected rigid bodies, where a mobile platform is connected to a fixed base for at least two independent kinematic chains [13]. The term kinematic chain can be defined as a set of bars or parts connected by joints or kinematic pairs. The kinematic chain is called closed when its ends are connected. Otherwise it will be called open chain. Two kinematic chains of a given mechanism are dependent if the motion of one is affected by movement of the other one, otherwise, the kinematic chains are independent.

The actuators that transmit movement to the active chains in a parallel mechanism are usually at the base or near to it. Active chains are open kinematic chains that connect the base to the mobile platform. A parallel mechanism applied in
robotics is also known as parallel robot or Parallel Kinematic Machine PKM [13].

A fully parallel mechanism is one that has n degrees of freedom whose mobile platform is connected to the base through n independent kinematic chains, each with a single actuator. In the other hand, a parallel hybrid mechanism has a number of degrees of freedom greater than the number of independent kinematic chains connecting the mobile platform to the base.

In the fully parallel mechanisms, the movement of the end-effector follows the movement of the mobile platform. In hybrid parallel mechanisms, the movement of the end-effector can be independent of the mobile platform.

According to [14], there is a significant amount of parallel architectures proposed with four degrees of mobility. The potential advantages of parallel mechanisms with respect to serial mechanisms, include: increased speed of the movement, due to the smaller mass of the moving parts that generate smaller inertial forces [15]; greater rigidity, provided by several kinematic chains; and greater accuracy, since the actuators are not mounted in series. Souza [16] describes the influence of errors of the actuators on the position and orientation of the Stewart Platform. The main disadvantages of parallel mechanisms are: the high volume occupied by the mechanism in relation to the work space; the possibility of collision between the kinematic chains; the need of more complex controllers; as well as, the difficulty for their calibration [15].

2 CONTROL OF THE ATTITUDE

In order to design a robotic wheelchair capable of overcome small obstacles, maintaining its adequate height and tilt, performing the control of front and rear wheels, providing the system up or down obstacles smoothly and always keeping the platform horizontally.

A common problem is the inexistence of a ramp to access the sidewalk from the crosswalk. In this case, it is very difficult for a traditional wheelchair climb the curb. The standard maximum curb height is 23cm. However, most of the existing mechanical and electromechanical wheelchairs not overcome these obstacles, either climbing or descending. The robotic wheelchair proposed in this paper overcomes small obstacles and climbs or descends the curb or stairsteps with height up to 23 cm.

The lift system allows the user to interact with other people almost face to face, resulting in an improved life quality.

3 THE PROPOSED ROBOTIC WHEELCHAIR

Two alternative mechanical projects were developed for the proposed robotic wheelchair: one with four parallel manipulators and other with six parallel manipulators, as shown in figures 1 and 2, respectively.

The robotic multi-manipulator 1 consists of four manipulators performing tasks in cooperation. The system has four single wheels, each of them driven by a vertical prismatic joint, characterizing a hybrid parallel architecture. In a similar way, the robotic multi-manipulator 2 consists of six manipulators performing tasks in cooperation. The system has six single wheels, each of them driven by a vertical prismatic joint, also characterizing a hybrid parallel architecture. In this paper we only describe the multi-manipulator 1.

Each single manipulator acts independently, trying to keep the platform with the chair always horizontally, even when crossing obstacles. In order to control the pitch and roll angles of the chair, IMU (Inertial Measurement Unit) based sensors were adopted for this purpose, detecting the inclination of the robot in four different positions of the chair with a precision of 0.5 degrees. The sensors were located in front, behind, and at the right and left sides of the chair. The position of the front-right sensor is shown in figure 3.
The wheelchair is controlled through a joystick installed in the right arm support (see figure 4), allowing to move forward and backward, turn right and turn left turn. The sensitivity and speed control can be adjusted in the application.

As shown in the side view in figure 4, the position of the user is very comfortable, especially with the existence of a footrest, which prevents the feet or legs to collide with the curb or other obstacles during climbing or descending movements. According to figure 5, it can be verified that the whole system have four motors, one for each single manipulator.

In Figure 1 shows the automation and control panel of the robotic system (yellow). In this panel are installed the in and out signal interface and the central processing unit.

4 KINEMATIC MODELING AND CONTROL

The robotic system has been modeled as shown in Figure 11, where the rear wheel (subscript r) and the front wheel (subscript f) are supported in two stairsteps with gap H between both of them. In this paper, only the control on the sagittal plane of the wheelchair is studied. For control purposes, it is assumed that all movement occurs in relation to the rear wheel axis (reference frame (0) fixed to the rear wheel axis). Thus, the joints 1r (rotational), 1f (prismatic) and 2f (rotational) are passive virtual joints, while the prismatic joints 2r and 3f are the joint effectively actuated together to balance the mechanism. The passive virtual joints model, respectively, the rotation around the rear wheel axis (joint 1r), the horizontal movement of the front wheel on the upper step (joint 1f) and rotation around the axis of the front wheel (2f joint).

This system has been modeled as two independent robotic manipulators (Figure 12), cooperating to position the reference frame {3} (attached to the extremity of the chair). The first arm (rear portion of the mechanism) has two joints: the virtual joint 1r, rotational and passive (movement around the axis of the rear wheel) and the rear joint 2r, prismatic and active. The second arm (front portion of the mechanism) has three joints: the virtual joint 1f, prismatic and passive (horizontal movement of the front wheel along the top stairstep surface), the virtual joint 2f, rotational and passive (movement around the axis of the front wheel) and the rear joint 3f, prismatic and active.
The Denavit-Hartemb erg parameters for both manipulator arms are presented in Table I, where, \( a \), \( \alpha \), \( d \) and \( \theta \) are, respectively, the length of the link, the torsion angle of the link, the displacement of the joint and the joint angle:

![Figure 7. Modeling of two independent robotic manipulators.](image)

The direct kinematics functions for the rear (1) and front (2) manipulator arms are, respectively:

\[
\begin{align*}
1 & : \\
2 & : \\
\end{align*}
\]

Due to mechanical couplings, the virtual variables \( \theta_{1r} \) and \( \theta_{2f} \) are equal. The position of the reference frame \( \{3\} \) with respect to the base reference frame \( \{0\} \) is the same for both manipulators. Naming \( h \) the x component of vector (height of the chair from the base), from the direct kinematics of rear and front arms, we have, respectively:

\[
\begin{align*}
3 & : \\
4 & : \\
\end{align*}
\]

The objective of the kinematic control is to level the chair horizontally \( (\theta_{1r} = 90^\circ) \) at a specified height \( h \). Taking the time derivative of and after some algebraic manipulations, we obtain the differential kinematic relationships that allows to control the angle \( \theta_{1r} \) and height \( h \) by adjusting the displacement of the active prismatic joints:

\[
\begin{align*}
5 & : \\
6 & : \\
\end{align*}
\]

5 SIMULATION WITH WEBOTS

This performing the control of front and rear wheels, providing the system up or down obstacles smoothly and always keeping the platform horizontally. This project uses the Webots[17] simulation software, where studies have been performed and verified the files and robots relating to various applications such as: shrimp.wbt (fig. 8), sojourner.wbt (fig. 9). In Fig. 10 we have an image of the robot for the file sojourner.wbt. In fig. 11 we have an image of the robot with six wheels. In fig. 11 and 12 we have an image of the robot with six wheels and four wheels respectively. Simulations are carried out, with two alternative mechanical projects for the proposed were developed robotic wheelchair, one with four and other parallel manipulators with six parallel manipulators.

![Fig. 8. Top View.](image)

![Fig. 9. Top View.](image)

![Fig. 10. Top View.](image)
6 RESULTS

This project is in its preliminary stage. In this paper, as shown in the figures presented above, the initial results of the work, are the design of a robotic wheelchair developed specifically for safe transportation of users with special needs. Also, the kinematic model of the proposed system was developed.

7 CONCLUSIONS

The cost of robotic systems developed by industries and research centers is generally high. In educational environments and industries, the robot must be developed to meet the objectives of the research or industry-specific solution. This paper proposed the kinematic modeling and control of the robotic system was derived in this preliminary work, the design conception of the proposed robotic wheelchair was described. Future works include the conclusion and implementation of the prototype implementation of path planning, localization, and mapping.

8 REFERENCES


