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Design of Autonomous Mobile Manipulator for Medical Applications

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Abstract: The need for autonomous robots in all aspects of life has increased significantly in recent times. The robots in healthcare help relieve the medical personnel of their daily duties that consume a lot of their time and make the medical processes easier. A primary focus in healthcare robots is the designing and construction of mobile manipulators. We have designed a mobile manipulator that can be used in hospitals and medical facilities. A robotic arm can be installed on the rover and controlled autonomously to perform medical processes such as ultrasound, temperature monitoring of the visitors, blood pressure measurement of the patients etc. This paper presents the Universal Robot Description Format (URDF) of the robot that is an incredibly versatile tool that offers a straightforward way to model and simulate any robot by describing its link and starting pose in an XML file. For this purpose, an open source development environment CoppeliaSim is used. The CoppeliaSim framework can be worked with using Python or C++ using many community developed open source libraries.

Keywords: Mobile manipulator, Healthcare Robots, CoppeliaSim, Universal Robot Description Format.

I. INTRODUCTION

A rover or mobile robot is a movable and reprogrammable machine that can move in a particular environment by sensing different parameters. Rovers can be designed to operate on both rough surfaces and well-paved floors [1]. In recent times, the field of healthcare has seen an influx of robotics. Healthcare robotics is a rising field across the globe with an increased growth in recent years due to a shortage of healthcare professionals and a relatively aging population [2]. For using mobile manipulators or rovers in healthcare, it is necessary to model and simulate the robot with proper representation of its links and position. The design of a mobile manipulator for medical purposes is presented and calculations on its position using Universal Robot Description Format is given [3].

The design of the mobile robot includes the design of the mechanical parts and its control system of the robot [4]. A Physical structure of rover predominantly contains Chassis, Wheels and bearings [3]. The payload of the rover depends on collective torque of the motor. Mechanical design of rover is a creative activity, which involves estimation and rational decisions using principles of energy, material and mechanics [4].

One of the major applications of healthcare robotics is surgical robots, used in precision and replacement surgeries [1, 6]. Germ-zapping robots are used for disinfections. Therapeutic robots are used in robot-assisted medical therapies. We have presented a mobile manipulator that will assist in medical activities such as ultrasound using a robotic prismatic hand.

A well-designed simulator makes it possible to rapidly test Algorithms, design robots and perform regression testing using realistic scenarios [14]. There are many tools that can be used for simulations like Webots, which is used for industrial simulations, Gazebo is a multi-robot simulator used for wide range sensors and objects and Coppelia Simualtor which is one of most advanced 3D simulator used for industrial robots. The reason for adopting this simulator is that it supports a variety of Programming language and is mostly used in education as well as by the engineers for remote monitoring and safety double checking [14]. It is widely used for streamlining the process of modeling, simulating and launching robots. This software offers formats such as URDF (Universal Robot Description Format) and SDF (Simulation Description Format) which are incredibly versatile tools that offer a straightforward way to model and simulate any robot [13]. For the purposes of simulation, the robot model was made using URDF which produces an XML file format [7]. This file type is the standard for robot modelling and simulating in CoppeliaSim. In this regard, the contribution of this paper is customized flat-terrain ground rover design for medical applications, its Simulation and validation of designed robot in CoppeliaSim software.

The structure of this paper is as follows: Section II describes Mechanical design of the mobile robot, the robotic arm in-fitted on it and the electrical components that we have selected for the performance of its specific function. Section III, we have discussed the estimation of position and orientation of the mobile manipulator. In Section IV we have simulated this design in the CoppeliaSim software and from the results we verified its position and orientation in multiple directions and finally in Section V we have concluded our paper.

II. DESIGN OF MOBILE MANIPULATOR

A. Mechanical design of the rover

The first step in the construction of Mobile Robot is the designing of the chassis. Dimension of the chassis is so selected to hold the robotic arm. The dimensions of chassis are 17.30 inches length, 12.30 inches width and 3 inches height. The chassis will be able to bear up to 50 kg of payload. Detailed 3D model of chassis is designed using SoildWorks.

In the second step, we have designed a robotic arm having five Degree of Freedom i.e Five Joints and Six links and used a gripper as the end-effector. The gripper is removable and can be replaced for different task.

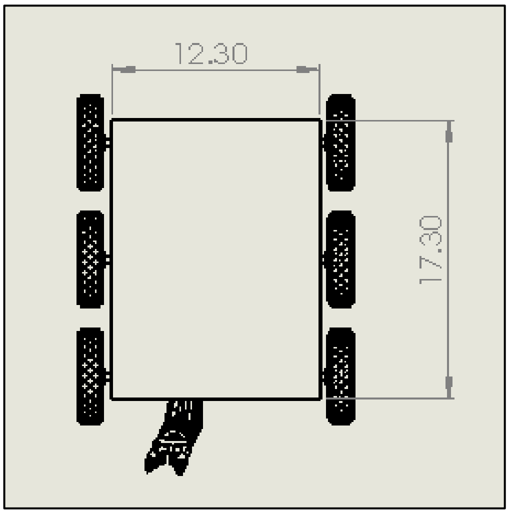

Fig.1 2D Top view of the rover with dimensions

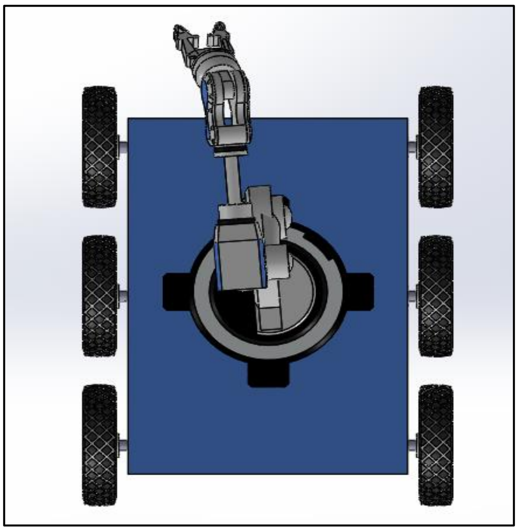

Fig.2 3D Top view of the rover in SolidWorks.

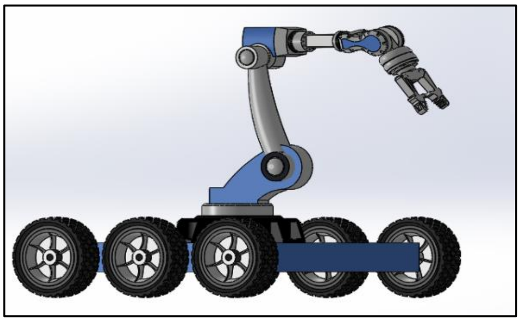

Fig. 3 3D Isometric view of the rover in SolidWorks

We have employed 6 wheels in our manipulator. The wheels are selected considering the weight of the mobile robot, the payload and the dimensions of the chassis. Wheel diameter is 5 inch. All wheels together can handle up to 60 kg of weight.

We have selected differential drive scheme for the mobile robot. Differential drive is a drive system where all wheels move independently. It is used to change the direction of the rover. The problem with differential drive is the difficulty to move the robot in straight line due to slight difference in all motors. However, this problem can be solved to a great extent and the rover can be driven in straight line by driving the motors at exact same speed.

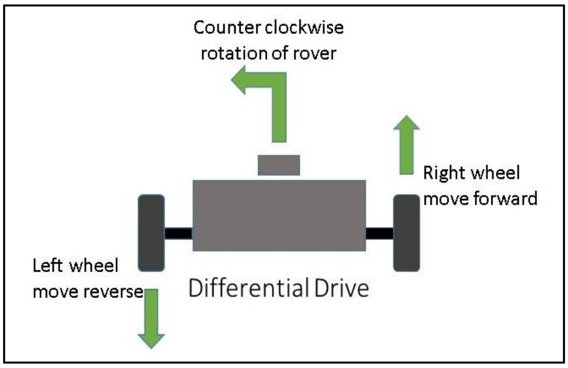

Fig. 4 Direction change in differential drive.

B. Control and Electrical Components of the Mobile Manipulator

DC motors drive the wheels of the rover. The estimated weight of mobile robot body is 10 kg. So the selection of motors should be made with the consideration of the weight. Each selected motor has a torque of 12 kg-cm. The selected motors will be operated at 12 volts and has a stall current of up to 2.1 Amp each. Since the application of the mobile rover does not require high speed, therefore the selected speed of each motor is 100 rpm with the gear ratio of 75:1 [11].

Fig. 5 Medium Power DC Motor [11]

All the DC motors are used with differential drive scheme, therefore 2 motor drivers each controlling 3 motors are utilized. Each motor driver has a maximum current capacity of 12 Amp, while required current is 6.3 Amp.

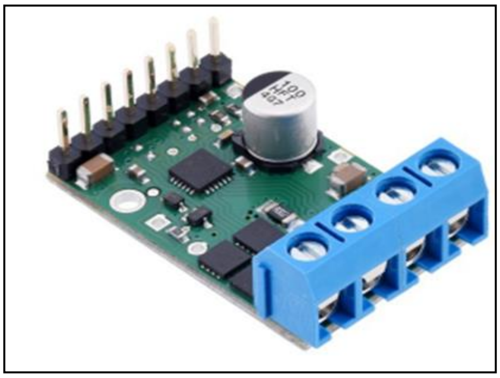

Fig. 6 Pololu G2 High Power Motor Driver [11]

The controller used for this mobile robot is Raspberry Pi 4. We have selected this controller because it is a small yet powerful computer that can easily be interfaced with a lot of hardware components. With about 40 GPIO pins, it is easy to connect several actuators and sensors. Raspberry Pi 4 has a quad-core processor with 1.5 GHz processing frequency [12]. Raspberry Pi 4 can be used with open source meta operating system. We have selected this controller since it offers huge processing power at low cost with many interfaces.

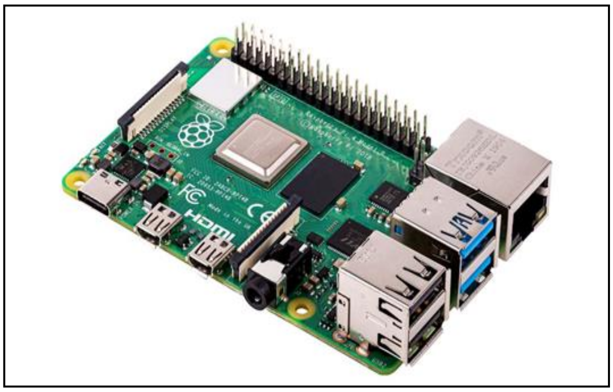

Fig. 7 Raspberry Pi 4 board [12]

III. PROPOSED ESTIMATION OF ROVER POSITION

A. Position Representation of Mobile Robot

For representing the position of mobile robot we must take a geometric approach to detect it within a coordinate system. In geometry a coordinate system refers to a system of coordinate to uniquely determine position of points within a space [4]. Inside a coordinate system we have frames of references according to which we denote position of points.

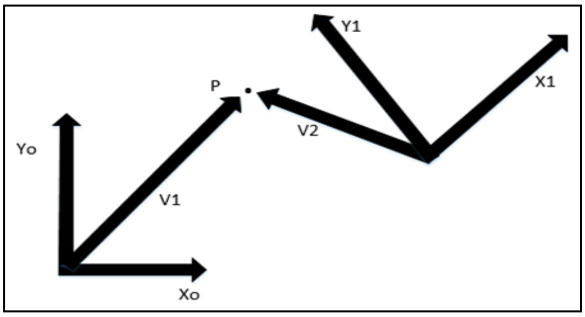

Fig. 8 Two coordinate system plane.

In fig. 8 as we can see there are two frame of references and vectors. We can denote the point P with reference to either frame. So, we might assign to P the vector V1 if we wish to refer to it with respect to frame 0 or assign V2 if we refer to it with respect to frame 1. In the previous case, we might assign to P the coordinate vector (5, 6), and in the latter case (−2.8, 4.2). We may call frame 0: $O0X0Y0$ and frame 1: $O1X1Y1$ where O refers to the origin of the frame. So that the reference frame will always be clear, we will adopt a notation in which a superscript is used to denote the reference frame. Thus, we can write [9].

$$p^0 = \begin{bmatrix} X \\ Y \end{bmatrix}, p^1 = \begin{bmatrix} X' \\ Y' \end{bmatrix} \tag{1}$$

To achieve convenient algebraic calculations using the above coordinates it is crucial that all the coordinates are defined with respect to the same coordinate frame. From this we can observe the representation of a point in space which requires us to also have a means of converting the coordinates of the point between multiple frames of reference i.e. a means of transforming coordinates.

B. Orientation Representation of Mobile Robot

For the representation of the relative orientation of two bodies we will attach coordinate frames to each and then using the two frames specify geometric relationships between them [4]. We can expand this method of representation to fit onto a larger scale and more relevant 3-dimensional use case. Each respective axes of frame $O1X1Y1Z1$ is projected onto the base frame $O0X0Y0Z0$, the resulting matrix is given in (2) [9].

$$R_1^0 = \begin{bmatrix} x_1.x_0 & y_1.x_0 & z_1.x_0 \\ x_1.y_0 & y_1.y_0 & z_1.y_0 \\ x_1.z_0 & y_1.z_0 & z_1.z_0 \end{bmatrix} \tag{2}$$

In practice we can observe that a robot can make complex rotation along multiple axes and for this purpose we can tackle these by breaking them down into rotations along individual axis and then each rotation matrix is multiplied this can be referred to as the composition of a complex rotation [8]. It is also essential to assume the order of the rotations as a frame that might rotate about y-axis which will change position of the other axes of the frame after which it may rotate about the new position of the z axis to give the final orientation; this will be giving a different orientation however if the frame were to rotate around z axis first then the changed position along y-axis Composition of rotation can be observed mathematically in (3) [9],

$$R = R_{y,\Phi} R_{z,\theta}$$
$$= \begin{bmatrix} c_\Phi & 0 & s_\Phi \\ 0 & 1 & 0 \\ -s_\Phi & 0 & c_\Phi \end{bmatrix} \begin{bmatrix} C_\theta & -s_\theta & 0 \\ s_\theta & c_\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$
$$= \begin{bmatrix} c_\Phi c_\theta & -c_\Phi s_\theta & s_\Phi \\ s_\theta & c_\theta & 0 \\ -s_\Phi c_\theta & s_\Phi s_\theta & c_\Phi \end{bmatrix} \quad (3)$$

C. Orientation and Motion of Mobile Robot

It is essential while designing a mobile robot to study both the translational movement and its orientation. Therefore, we can make use of a shorter way of representation i.e. a Homogenous Transformation Matrix [9]. This matrix includes both the rotation and translation as represented in (4) [9].

$$H = \begin{bmatrix} R & d \\ 0 & 1 \end{bmatrix} \quad (4)$$

Where R represent the rotation matrix and d represents the Position matrix.

D. Denavit-Hartenberg Convention

Denavit-Hartenberg convention is used to develop equations for the representation of forward kinematics of robot [10]. Firstly, we have to deliberate the constraints of the DH convention. Also, we should know the explanation of DH parameters.

α: For link 1, there is no angle between Z0 and Z1 therefore α is zero; similar is the case for link 3, however we can observe that there is a rotation between Z1 and Z2 by 90 degrees.

θ: This is the joint angle and we can observe that there is a single Revolute joint on Link 1.

d: For each link there is a perpendicular distance between X and Z and in the cases of Link 2 and 3 this distance is variable controlled by the prismatic joint movement.

If we closely consider these relative to our application, we will see that when going through terrain and wheel reference frame transformations these constraints are not upheld.

a: There is no distance between the relative Z axes of the links because the joints are stacked i.e. there is no link length.

IV. SIMULATION

A. Coppelia Robotics

Robot simulator CoppeliaSim is an integrated development environment and is based on a distributed control architecture. Each object can be individually controlled via an embedded script, a plugin, a ROS, a remote API client or a custom solution [13]. This makes CoppeliaSim very adaptable and ideal for the multi-robot applications. Controllers that has been used in this case can be written in C/C++, Python, JAVA, MATLAB, etc. This is used for fast algorithm development, factory automation simulations, fast prototyping and verifications. In our case we have developed our mobile robot with 5 DOF having 5 joints with a gripper which will be used for medical health care purposes. Co-simulation of the robot motion, that we have prepared in Coppelia SimEdu Software.

B. Coppelia Simulator

CoppeliaSim is a robot simulation environment used for the prototyping. It provides a set of tools to experience CoppeliaSim robot simulation software in Virtual Reality. The prime attention of this software is to create a platform that enables the fast prototyping and verification of robotic systems [13].
Furthermore, the generality of the toolbox ensures that it can be valuable in other contexts like robotics education, human–robot interaction or reinforcement learning. We have used this software to investigate the motion of our six-wheeled mobile robot and the orientation of the robotic arm with a gripper for medical applications.

C. Results of Simulation

Here, we have concluded the results of our simulations that were acquired in Coppelia Simulator and by adopted Dynamic Simulations. The motion of mobile manipulator and maintenance of its balance is represented in Fig. 9-a and Fig.9-b as the values of object position and object orientation. It was observed that our proposed mobile manipulator has been successful in maintaining balance of position and orientation. The analysis of real time dynamic simulation of our six-wheeled rover on Coppelia Simulator verified the swift motion of the rover with relevant values of position and orientation.
Fig. 9-a and 9-b illustrates the pictures for the Six-Wheeled Mobile Manipulator with a 5 DOF Robotic arm in CoppeliaSim Edu environment and its position and orientation.

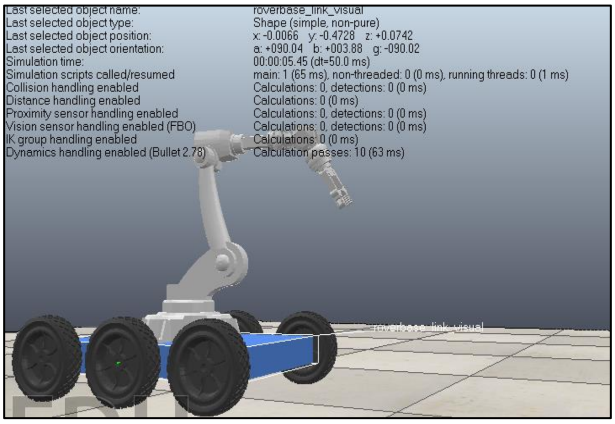

Fig. 9-a Position Control of the rover in another direction in real time.

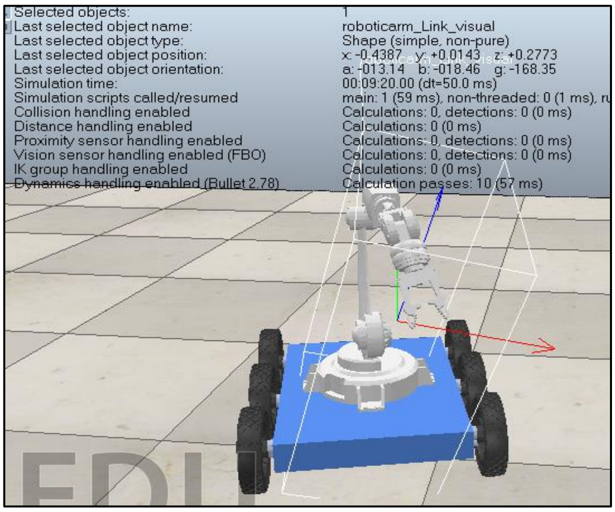

Fig. 9-b Position Control of the robotic arm in another direction in real time.

V. CONCLUSION

In this research paper, we have designed a mobile robot with 5 DOF Robotic arm that can be operated on well-paved surface for medical healthcare applications. Fundamentals of Forward Kinematics and control engineering practices towards the healthcare purposes are utilized. This rover and the robotic arm is modelled in SolidWorks and by using Coppelia Simulator software, we have verified its mechanical stability. The integration of knowledge towards the given application is successfully validated and can be seen in our simulation results. With the help of this study, we can develop a working prototype of the hardware of the mobile manipulator for medical application.

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