Design of a Two Wheeled Mobile Welding Manipulator for Spherical Objects

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***Abstract*—Mobile manipulators have gained a lot of attention from research community. This paper presents the multi-axis robotic welding system. The robotic system is designed to weld a seam on Sphere with known coordinates automatically. The methodology includes system design, inverse kinematics and analysis of the robotic system. The system is proposed for an arc welding on Spherical objects which has a lot of application in the industry. The robotic welding system may be used in house as well as at remote site.**

Keywords—*Mobile Robots, Robotic Manipulator, Welding, Workspace*

I. Introduction

Welding is a labor-intensive process and a risk for a human to carry out the task manually or in unfavorable environments. Most of the welding robots installed in production plants are fixed cells that have limited dexterity. Welding manipulators are being studied by researches and used in industries extensively now a days [1]–[6] . A main advantage of using these welding manipulators is that they can be used for small scale production in harsh working conditions where it is difficult for human beings to reach out [7]. Currently, depending upon the industrial storage and layouts welding manipulators with mobile base has gained more attention of the industry and research community. The importance of developing a mobile welding manipulator can be effectively seen in hazardous environments where human's presence is hazardous like in nuclear plants and for increased production in plants and minimization of inaccuracies in the welding process. The commercial robots suffer from one disadvantage i.e. their lack of mobility because they are fixed at one place. The importance of developing a mobile welding manipulator can be effectively seen in hazardous environments where human's presence is unsafe like in nuclear plants and for increased production in plants and minimization of inaccuracies in the welding process. The commercial robots suffer from one disadvantage i.e. their lack of mobility because they are fixed at one place. A fixed manipulator has a limited range of motion. Most of the welding performed manually suffered from inaccurate welded seam due to inaccurate welding speed and position. The need is to enhance the manipulator workspace by mounting the manipulator on a mobile platform and control the mobile base and manipulator for trajectory track on curve Spherical paths.

The main hurdle in developing such mobile robots for welding on a spherical surface is the workspace of the robot. Many researchers have proposed different solutions to this problem [8]–[10]. Kam, et al proposed a mobile welding robot for straight welding path using sensors [11]. Literature review shows that a three linked manipulator mounted on a two wheeled mobile base has been proposed but it travels along a straight path [12]. Motion planning for a spherical surfaces has been proposed in [13] by Ziqiang et al. Researchers have proposed intelligent mobile robots for welding on spherical tanks where the robot base is fixed on tank surface and manipulator travels on the spherical surface [14], [15].

In this paper we intend to propose a mobile welding manipulator that is capable of doing welding operations on spherical objects. The paper presents the design of hardware and software in section II. The modeling solutions for dynamics and kinematics of mobile base and the manipulator in section III while in section IV analysis of the workspace of the proposed manipulator of a two wheeled mobile welding manipulator is presented to complete the design.

II. Design of Welding Manipulator

A design for the two wheeled mobile welding manipulator for spherical objects should meet the criteria of mobility, spherical workspace, structure stability and load tolerance. The mobility is required to approach the seam. Spherical workspace is required to cover the whole of spherical shape. Structural stability is required to maintain certain range of shape. Load tolerance is required to manipulate objects.

The design of mobile welding manipulator was divided into four categories: design of mobile base, design of the robotic arm, design of software algorithm and design of the electric circuitry. Design of the base and the arm of the mobile welding manipulator was developed using SolidWorks®. All parts of the mobile welding manipulator were made separately and then assembled together.

The base of the welding manipulator is proposed to be made up of rigid frame. Fig. 1 shows the rigid base frame of the mobile welding manipulator. The material for the base of robot is proposed to be aluminum which is a light weight but strong material. The dimensions of the robot base are assumed as: length 40 cm, Width 40 cm and height is 20 cm. It is driven using differential drive wheels with feedback sensor and controller.

Fig. 1: Rigid Base of the Two Wheeled Mobile Welding Manipulator

The next part of the manipulator is the robotic arm. The robotic arm, being the most important part of the manipulator is designed with three degrees of freedom. The arm consists of three links and the end effector. The first link of the robotic arm is capable of giving 360° rotation along y-axis. Second and third links are capable of angular rotation of 180°. End effector is fixed on third link. Fig. 2 shows the two wheeled mobile robotic manipulator with base, designed for spherical objects.

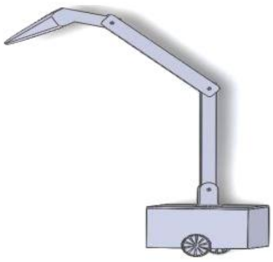

Fig. 2: A Two Wheeled Mobile Welding Manipulator for Spherical Objects

The two wheeled welding mobile manipulator for spherical object is shown in Fig. 2. The manipulator works automatically. An algorithm designed to automate the manipulator operation is shown in Fig. 3 in the form of a flow chart. The designed algorithm checks coordinates of the seam to be welded, calculate the joint angles of the arm and final position of wheels of base knowing a fixed speed of wheel motors. The algorithm gets feed back from sensors, update the torques required to minimize difference in desired position i.e. coordinates of the seam to be welded and present positions.

In order to implement the algorithm and actuate & control the system four electronic devices are proposed: Arduino, Relays, IR sensors and regulator. Relays are proposed to work with H-bridges to control the direction of wheel motors and joint motors. IR sensors are proposed to track the line drawn around the spherical object. Wheels are to track the path. The power requirement is evaluated such that it requires voltage 12V and maximum current 7Ah. Use of the portable batteries to provide designed power rating is recommended for the system.

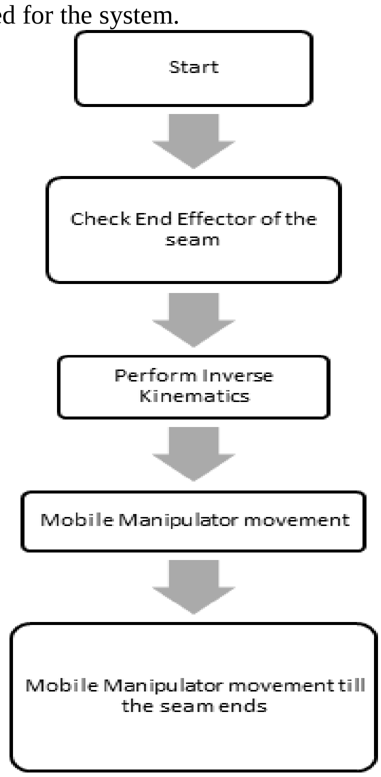

Fig. 3: Working Algorithm for Two Wheeled Mobile Welding Manipulator for Spherical Objects

III. MODELING OF WELDING MANIPULATOR

This section gives details about the dynamic modeling of the mobile robotic base and kinematics model of the manipulator as follows in sub section A & B.

A. *Dynamics Modeling of Two Wheeled Mobile Base*

A brushless DC motor was proposed to be connected to the wheels of mobile base. Modeling of DC motor is done in [16] & [17]. To model motors dynamics, we assumed that frictional torque is proportional to the angular velocity of the motor shaft. Position control of the DC motor is modeled as (1).

$$\frac{\theta(s)}{V\,(s)} = \frac{k}{s(Js+b)(Ls+R)+k^2} \tag{1}$$

In equation (1), $\boldsymbol{J}$ is inertia of the motor, $\boldsymbol{R}$ is the terminal resistance, $\boldsymbol{L}$ is the inductance and $\boldsymbol{k}$ is the torque constant. Whereas θ is the output speed and $\boldsymbol{V}$ is the input armature voltage applied.

B. *Kinematics Modeingl of the Welding Manipulator*

Kinematic model of the two wheeled welding manipulator is developed using the inverse kinematics method. Inverse kinematics is adopted when the final position of the manipulator is known and leg lengths and joint angles are desired accordingly. A schematic diagram of the welding manipulator is shown in Fig. 4.

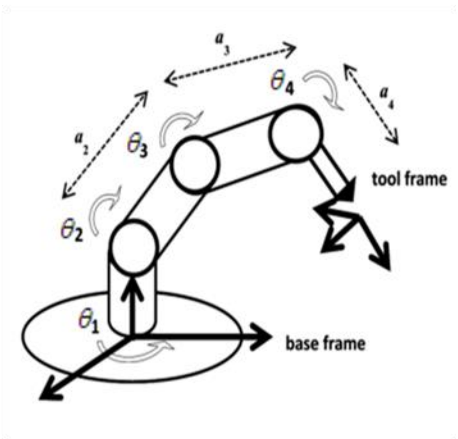

Fig. 4: Schematic Model of the Welding Manipulator

In figure 4 a_1, a_2, a_3 and a_4 represent the lengths associated with the manipulator and Θ_1, Θ_2, Θ_3 and Θ_4 are the joint angles respectively. In following equations and expressions, c represents *cos Θ* and s represents *sin* ***Θ***. With inverse kinematics the value of each joint angle is determined to place the robot at a desired position and orientation. The equations that are derived for finding the joint angles are used directly in robot programming to drive the robot to a desired position. Using (2), value of Θ_3 were found out. Solving (2), for Θ_3 yields (3).

$$x^2 + y^2 = a_1^2 + a_2^2 + 2a_1a_2\cos(\theta_3) \quad (2)$$

$$\theta_3 = \pm cos^{-1}\left|\frac{x^2 + y^2 - a_1^2 - a_2^2}{2a_1a_2}\right| \quad (3)$$

Solving for Θ_2 in x and y axis yield (4) and (5).

$$x = a_1\cos(\Theta_2) + a_2\cos(\Theta_2 + \Theta_3) \quad (4)$$

$$y = a_1\sin(\Theta_2) + a_2\sin(\Theta_2 + \Theta_3) \quad (5)$$

By expanding (4) and (5),

$$x = a_1c_1 + a_2c_2c_3 + a_2s_2s_3 \quad (6)$$

$$y = a_1s_2 + a_2s_2c_3 + a_2s_3c_2 \quad (7)$$

Solving (6) and (7) for Θ_2 will give (8):

$$\Theta_2 = atan2[|a_1s_3x + (a_1 + a_2c_3)y, (a_1 + a_2c_3)x - a_2s_3y|] \quad (8)$$

IV. Workspace Analysis of Manipulator

The inverse kinematics obtained in section III was used to analyze the workspace of the manipulator. Workspace is the region where the end effector of the manipulator can reach. The mobile manipulator has the advantage of infinite workspace. However, during the task execution the mobile base is at stand still and the manipulator workspace is defined as the maximum allowable limits of the arm to reach the target. The reachable workspace describes the volume in space in which the manipulator end-effector can reach. The dexterous workspace is a subset of reachable workspace. The reachable workspace is defined by the motion of the end-effector and the related manipulator arms through their allowable limits. By varying the degrees of freedom in the plane the end-effector is positioned to occupy space within the reach of the manipulator.

Various techniques have been adopted to determine the workspace for the manipulator. These techniques involve iterative and analytical techniques. A code was developed in this research using MATLAB® software to determine the workspace of the manipulator. Fig. 5 shows the algorithm steps used to obtain the workspace.

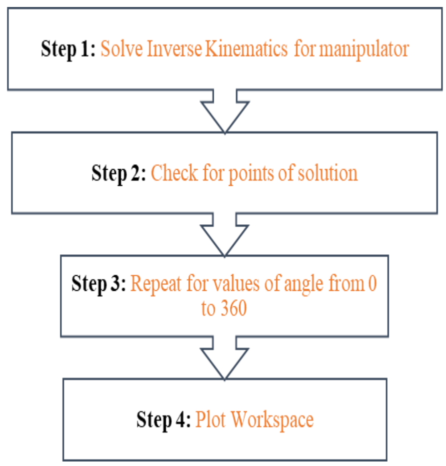

Fig. 5: Algorithm for Workspace determination for Two Wheeled Mobile Welding Manipulator for Spherical Objects

The dexterity of the manipulator was measured by measuring the manipulate ability measure of the manipulator. Equation (9) was used to give the manipulability of the manipulator.

$$w = |\det(J(\Theta))| \quad (9)$$

Where 'w' is the manipulability measure and $J(\Theta)$ is the Jacobian matrix. A good manipulator design has large areas of its workspace characterized by the high values of w.

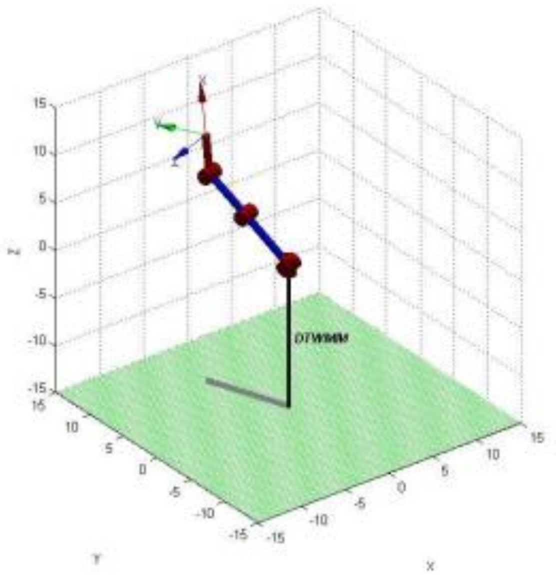

Fig. 6: Peter Corke Model of the Welding Manipulator

Fig. 6 shows the Peter Corke model made in MATLAB® Robotics toolbox for the welding manipulator.

A Graph shown in Fig. 7 demonstrates the workspace for the two wheeled mobile welding manipulator for the spherical objects. The workspace of the manipulator is calculated using MATLAB® as a point cloud that shows the limits based on selected link parameters and allowable degrees of rotation. As a case study three leg lengths $\boldsymbol{a_2}$, $\boldsymbol{a_3}$ and $\boldsymbol{a_4}$ are selected to be 6, 5 and 3 cm respectively. Initial values of these three lengths were taken zero and the position points were plotted with step increment of 1 mm. $\boldsymbol{a_2}$ is kept fixed. The values in the graph in Fig. 7 show the resulting reachable workspace of the manipulator.

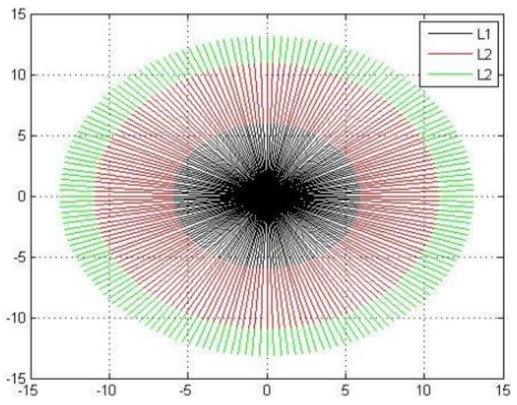

Fig. 7: Workspace of the Two Wheeled Mobile Welding Manipulator

The resulting workspace covers a whole sphere of a dimension. That means the proposed system is capable of approaching of any spherical shape depending on the lengths of the arms.

V. Conclusion

In this paper design, modeling and analysis of the workspace of a proposed design of mobile manipulator for welding is presented. The workspace of the manipulator shows that the manipulator can be used for the welding purpose of spherical objects. Speed of the robotic base needs to be fixed as per size and nature of the seam for the smooth working of the mobile manipulator. This two wheeled mobile welding manipulator may be developed in future to test the experimental verification of utility for weld of spherical objects.

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