ISSN 2250-3153

Design, Simulation and Mathematical Modeling of a RPR Manipulator for Collecting Waste from Beans

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Abstract- Robotics has nourished our life with a great instinct which breaded so many automated machines to perform the functions of human beings to bring much comfort and safety. As time passing by, every little field it being filled up by automated machines instead of human activities. This paper aims at a phenomenal analysis of the current situation of waste collection from the dust beans and then a complete mathematical as well as CAD model is established here to introduce a easy to go robot who performs his activity with a 3 DOF RPR manipulator, to take waste from dust beans to make the environment cleaner and to perform hazardous jobs instead of men.

Index Terms- Manipulator, Degree of Freedom, Jacobian, Singularity, Algorithm.

I. INTRODUCTION

Automation is quite a common phenomenon now a day. The speed at which developed countries are heading towards automation is quite upsetting for the third-world counties especially in the Asia pacific. This is due to the reason that the population here, are not earning that much livelihood to buy or even produce huge automated machines in their day-to-day life. So, it is needed that they should be accustomed with some automated servants with light cost and high efficiency. There is the point of view of our research work. Here, the robot consists of a waste collector vehicle; a sensor and a robotic manipulator with 3 degree of freedom with 3 links connected with revolute, prismatic and revolute joints accordingly from the base to the end effector. This robot is to be controlled with microcontroller and the programing algorithm for this robot is also developed with this research work. This paper provides the mathematical model and CAD design of such a robot that can collect the wastes from dust beans more swiftly and timely with respect to men.

II. BACKGROUND RESEARCH

Current scenario of developing countries like Bangladesh is quite optimistic regarding waste management. It is due to the appropriate use and placement of dust-beans as well as introducing green banking system and other green technologies. In past days, there were no sufficient dust beans to collect gathered waste instead of leaving them to spread out throughout roads and localities. But success of keeping the environment clean lies with a strong chain of regulation of 4 factors. One is the placement of beans at proper places; secondly the gathering of wastes in the beans; thirdly the regular collection of the wastes from the beans; and finally to monitor whether the beans are at right place and the workers are working properly. The basic failure of such previous initiatives was observed as the failure of this chain due to lack of enough responsible workers. T.Ch. Ogwueleka investigated these phenomena over Nigeria and showed that low morale of environmental protection agencies workers as a result of poor remuneration and stagnation in promotion affects the workers service in developing countries [2]. As a result waste management system fails. There is the difference between men and robot- men seek leisure while robots seek job. Besides, there is always a heath factor present regarding waste issues. J. Hansen showed in 1997 with an investigation laid over the Danish waste management workers that the physical deterioration of the waste collectors is at an alarming line [3].

So, this research work is laid to introduce such waste collecting vehicle which will perform its duty with the selected dust beans throughout a city at selected places and keep the chain of action strong enough to keep the public convinced to put there wastes nowhere else rather than those specific beans. It's been a long time manipulators are introduced in industries or even in agricultural sectors. Now it is time to introduce them into waste management system. J. J. Creig described the basic mathematical calculations of Manipulator kinematics [4] and dynamics. R. L. Kress,in 1995 developed a mean to simulate the robotic arm [5]. E. Macho derived singularity analysis for his parallel RPR type manipulator [6]. I.D. walker developed a means for failure mode analysis for a hazardous waste cleaner manipulator [7]

In this research work we have used the CAD platform to simulate Factor of Safety and calculated the joint torque and singularity of the RPR manipulator with a system algorithm.

III. COMPUTER AIDED DESIGN

The CAD model of the vehicle as well as the operational procedures of collecting waste are designed in the popular platform solid works 2010[7].

ISSN 2250-3153

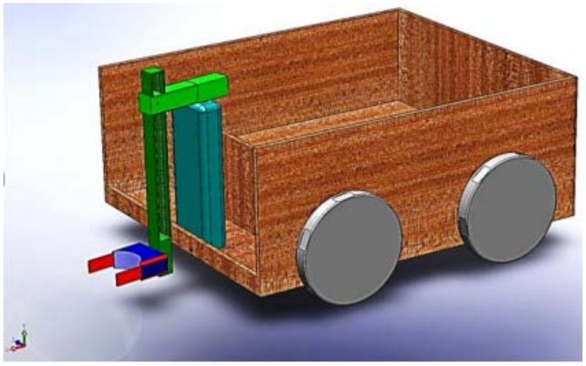
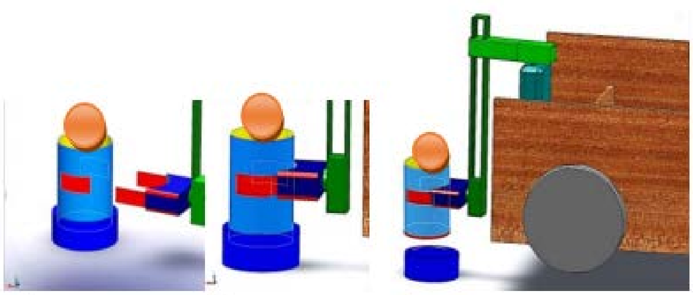


Figure 1: Waste collector Vehicle with a RPR manipulator

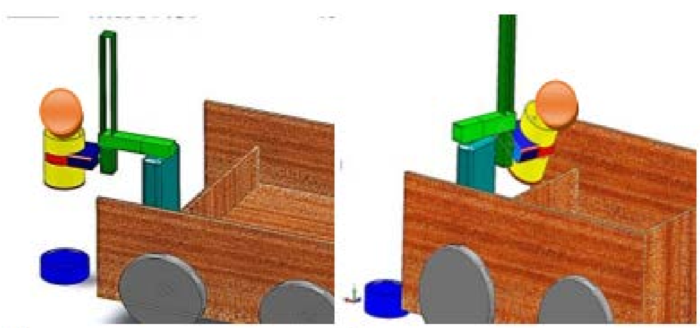
Here, a group of image is provided to describe the system. In this system the dust beans should be of uniform shape and should be placed in an extra pot (deep blue colored parts in the fig.2) which is kept firm to ground.



A B C

Figure 2: Mechanism for the grip to lift a bean up

So, when the vehicle comes to the bean, then the arm end effector will come down and the car wheel will move forward to push the grip to pass though the cut portion of the bean (red portion in the bean and of the manipulator End effector).



A B

Figure 3: Revolute joint takes the bean to the back store

As it firms in the similar diameter concentric spherical shape of the bean, the motor 2 gets on and the prismatic joint drives the bean to the upward direction as shown in fig.3(A). Then after lifting to a certain distance with a calculated revolution of motor, the 1st motor of the base will start moving in right direction and after turning 90 degree, the 3rd motor of end effector(EE) will tilt the bean and turn it 180 degree(fig.6) which will cause the wastes to take their place in vehicle store. But many waste may still get locked inside the bean which need to get jerked.

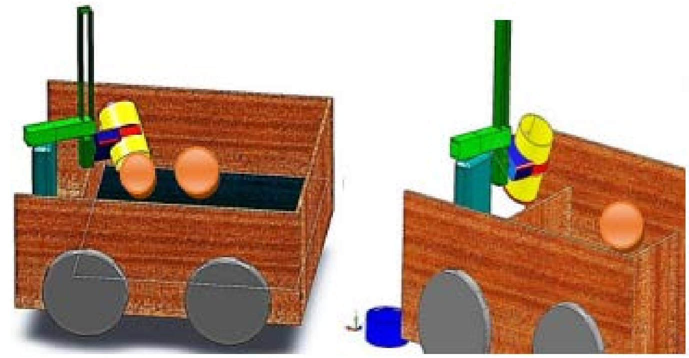


Figure 4: Pouring wastes and turning its position back

So, the motor 3 of the EE will rotate +5 and -5 degrees for 5 times and in the meantime the 2nd motor of pinion will cause a vertical movement for few cm up and down. That will cause the wastes to get into the vehicle completely. Finally the motor 1 of base will turn 180 degree in reverse and the 3rd motor will turn on to take the bean to the vertical (initial) position.

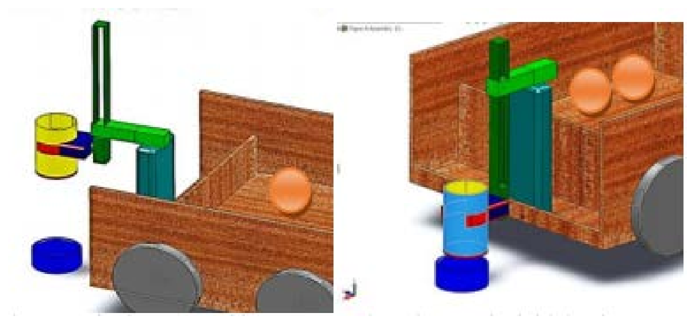


Figure 5: Manipulator turned bean and back its initial position

Then motor 2 will get lowered to achieve the required primary height. After achieving the primary height the motor at the grip turning in the reverse direction opens its end effector to place the bean at its initial state. Thus the robot will perform its activities through the simple use of a RPR manipulator which will require no human involvement for directly collecting the waste.

IV. MATHEMATICAL MODEL

This research work, firstly, Denavit Hertenbeg parameters were used to get the spatial description [3].Then by the help of inverse kinematics the velocities were determined through which the Jacobian matrix, torque, joint angles and singularity was analyzed in this paper.

Table 1: D-H Parameter [8]

Links	α_{i-1}	a_{i-1}	d_i
0 → 1	0	0	0
1 → 2	0	a_1	d_1
2 → 3	-90	0	d_2

General form of transformation matrix:

$$ {}^{i-1}_{i}T = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1} d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \ldots\ldots (i) $$

$$ \therefore\ {}^{0}_{3}T = \begin{bmatrix} c_1c_2 & -c_1s_2 & -s_1 & -s_1d_2 + c_1a_1 \\ s_1c_2 & -s_1s_2 & c_1 & c_1d_2 + s_1a_1 \\ s_2 & -c_2 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

This is the general equation of Transformation matrix for our manipulator. Here, let,

$d_1 = 0$, $d_2 = d = 1m$, $\theta_1 = \theta_2 = 180^o$, $a_1 = 1m$

$$ \therefore\ {}^{0}_{3}T = \begin{bmatrix} 1 & 0 & 0 & -1 \\ 0 & 0 & -1 & -1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{0}p_3 = \begin{bmatrix} p_x \\ p_y \\ \dot{p}_z \end{bmatrix} = \begin{bmatrix} -s_1d_2 + c_1a_1 \\ c_1d_2 + s_1a_1 \\ \dot{d}_1 \end{bmatrix} = \begin{bmatrix} -1 \\ -1 \\ 0 \end{bmatrix} \ldots\ldots (ii) $$

Now, let's determine the **Jacobian matrix**.
We know,

$$ {}^{0}_{3}R = {}^{0}_{1}R\,{}^{1}_{2}R\,{}^{2}_{3}R \ \& $$
$$ {}^{3}_{0}R = {}^{1}_{0}R\,{}^{2}_{1}R\,{}^{3}_{2}R $$

We also know,

$$ {}^{A}_{B}T = \begin{bmatrix} R_{11} & R_{12} & R_{13} & P_x \\ R_{21} & R_{22} & R_{23} & P_y \\ R_{31} & R_{32} & R_{33} & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{A}_{B}T = \begin{bmatrix} R_{3\times3} & & & P_{1\times3} \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

So, first 3x3 matrix is a rotation matrix

So, the desired Rotation matrix

$$ {}^{0}_{3}R = \begin{bmatrix} c_1c_2 & -c_1s_2 & s_1 \\ s_1c_2 & -s_1s_2 & -c_1 \\ s_2 & -c_2 & 0 \end{bmatrix} \ldots\ldots (iii) $$

Similarly

$$ {}^{0}_{1}R = \begin{bmatrix} c_1 & -s_1 & 0 \\ s_1 & c_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \therefore\ {}^{1}_{0}R = \begin{bmatrix} c_1 & s_1 & 0 \\ -s_1 & c_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{2}_{3}R = \begin{bmatrix} c_2 & -s_2 & 0 \\ 0 & 0 & 1 \\ s_2 & -c_2 & 0 \end{bmatrix} \quad \therefore\ {}^{3}_{2}R = \begin{bmatrix} c_2 & 0 & s_2 \\ -s_2 & 0 & -c_2 \\ 0 & 1 & 0 \end{bmatrix} $$

Now, we know, **for Revolute joints**

$$ {}^{i+1}\omega_{i+1} = {}^{i+1}_{i}R\ {}^{i}\omega_i + \dot{\theta}_{i+1}\ {}^{i+1}\hat{Z}_{i+1} $$
$$ {}^{i+1}v_{i+1} = {}^{i+1}_{i}R\left[{}^{i}v_i + {}^{i}\omega_i \times {}^{i}P_{i+1}\right] $$

$$ \therefore\ {}^{1}\omega_1 = {}^{1}_{0}R\ {}^{0}\omega_0 + \dot{\theta}_1\ {}^{1}\hat{Z}_1 $$
$$ = \begin{bmatrix} c_1 & s_1 & 0 \\ -s_1 & c_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix} $$

$$ \therefore\ {}^{1}v_1 = {}^{1}_{0}R\left[{}^{0}v_0 + {}^{0}\omega_0 \times {}^{0}P_1\right] $$
$$ = \begin{bmatrix} c_1 & s_1 & 0 \\ -s_1 & c_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \left[\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}\right] = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} $$

For Prismatic joint

$$ {}^{i+1}\omega_{i+1} = {}^{i+1}_{i}R\ {}^{i}\omega_i $$
$$ {}^{i+1}v_{i+1} = {}^{i+1}_{i}R\left[{}^{i}v_i + {}^{i}\omega_i \times {}^{i}P_{i+1}\right] + d_{i+1}\ {}^{i+1}\hat{Z}_{i+1} $$

$$^{2}\omega_2 = {}^{2}_{1}R\,{}^{1}\omega_1$$
$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix}$$

$$^{2}v_2 = {}^{2}_{1}R\left[{}^{1}v_1 + {}^{1}\omega_1 \times {}^{1}P_2\right] + d_2\,{}^{2}\hat{Z}_2$$
$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\left[\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix} \times \begin{bmatrix} a_1 \\ 0 \\ d_1 \end{bmatrix}\right] + \begin{bmatrix} 0 \\ 0 \\ d_2 \end{bmatrix} = \begin{bmatrix} 0 \\ a_1\dot{\theta}_1 \\ d_2 \end{bmatrix}$$

Again, **for another revolute joint**

$$^{i+1}\omega_{i+1} = {}^{i+1}_{i}R\,{}^{i}\omega_i + \dot{\theta}_{i+1}\,{}^{i+1}\hat{Z}_{i+1}$$
$$^{i+1}v_{i+1} = {}^{i+1}_{i}R\left[{}^{i}v_i + {}^{i}\omega_i \times {}^{i}P_{i+1}\right]$$

$$^{3}\omega_3 = {}^{3}_{2}R\,{}^{2}\omega_2 + \dot{\theta}_3\,{}^{3}\hat{Z}_3$$
$$= \begin{bmatrix} c_2 & 0 & s_2 \\ -s_2 & 0 & -c_2 \\ 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_3 \end{bmatrix} = \begin{bmatrix} s_2\dot{\theta}_1 \\ -c_2\dot{\theta}_1 \\ \dot{\theta}_3 \end{bmatrix}$$

So, now for calculating **Jacobian** we have,

$$^{3}v_3 = {}^{3}_{2}R\left[{}^{2}v_2 + {}^{2}\omega_2 \times {}^{2}P_3\right]$$
$$= \begin{bmatrix} c_2 & 0 & s_2 \\ -s_2 & 0 & -c_2 \\ 0 & 1 & 0 \end{bmatrix}\left[\begin{bmatrix} 0 \\ a_1\dot{\theta}_1 \\ d_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix} \times \begin{bmatrix} 0 \\ d_2 \\ 0 \end{bmatrix}\right] = \begin{bmatrix} c_2 & 0 & s_2 \\ -s_2 & 0 & -c_2 \\ 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} -d_2\dot{\theta}_1 \\ a_1\dot{\theta}_1 \\ d_2 \end{bmatrix}$$
$$= \begin{bmatrix} -d_2c_2\dot{\theta}_1 + s_2d_2 \\ -d_2s_2\dot{\theta}_1 - c_2d_2 \\ a_1\dot{\theta}_1 \end{bmatrix}$$

$$^{3}J(\theta) = \begin{bmatrix} -d_2c_2 & s_2d_2 & 1 \\ -d_2s_2 & -c_2d_2 & 1 \\ a_1 & 0 & 1 \end{bmatrix}\begin{bmatrix} \dot{\theta}_1 \\ 1 \\ 0 \end{bmatrix}$$

$$\therefore \begin{bmatrix} -d_2c_2 & s_2d_2 & 1 \\ -d_2s_2 & -c_2d_2 & 1 \\ a_1 & 0 & 1 \end{bmatrix}^T = \begin{bmatrix} -d_2c_2 & -s_2d_2 & a_1 \\ d_2s_2 & -c_2d_2 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$
$$\therefore \tau = \begin{bmatrix} -d_2c_2 & -s_2d_2 & a_1 \\ d_2s_2 & -c_2d_2 & 0 \\ 1 & 1 & 1 \end{bmatrix}\begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix}$$
$$\left.\begin{aligned} &\therefore \tau_1 = -d_2c_2f_x - s_2d_2f_y + a_1f_z \\ &\therefore \tau_2 = d_2s_2f_x - c_2d_2f_y + 0 \\ &\therefore \tau_3 = f_x + f_y + f_z \end{aligned}\right\} \ldots\ldots (iv)$$

For calculating **torque** equation (iv) can be used. And, to determine the singularity we can write,

$$S = -d_2c_2(-c_2d_2) - s_2d_2(-d_2s_2) + 0$$
$$= (d_2c_2)^2 + (s_2d_2)^2$$
$$= d_2^{\,2}(c_2^{\,2} + d_2^{\,2})$$
$$= d_2^{\,2}$$

So, the manipulator **will be singular if** $d_2 = 0$ …… (v)

$$^{0}J_3 = {}^{0}_{3}R\,{}^{3}v_3$$
$$= \begin{bmatrix} c_1c_2 & -c_1s_2 & s_1 \\ s_1c_2 & -s_1s_2 & c_1 \\ s_2 & -c_2 & 0 \end{bmatrix}\begin{bmatrix} -d_2c_2\dot{\theta}_1 + s_2d_2 \\ -d_2s_2\dot{\theta}_1 - c_2d_2 \\ a_1\dot{\theta}_1 \end{bmatrix}$$
$$= \begin{bmatrix} c_1c_2(-d_2c_2\dot{\theta}_1 + s_2d_2) - c_1s_2(-d_2s_2\dot{\theta}_1 - c_2d_2) - s_1a_1\dot{\theta}_1 \\ s_1c_2(-d_2c_2\dot{\theta}_1 + s_2d_2) - s_1s_2(-d_2s_2\dot{\theta}_1 - c_2d_2) + c_1a_1\dot{\theta}_1 \\ s_2(-d_2c_2\dot{\theta}_1 + s_2d_2) - c_2(-d_2s_2\dot{\theta}_1 - c_2d_2) \end{bmatrix}$$
$$= \begin{bmatrix} (-d_2c_1 - s_1a_1)\dot{\theta}_1 \\ (-d_2s_1 - c_1a_1)\dot{\theta}_1 \\ d_2 \end{bmatrix}$$

$$^{0}J(\theta) = \begin{bmatrix} (-d_2c_1 - s_1a_1) & 0 & 1 \\ (-d_2s_1 - c_1a_1) & 0 & 1 \\ 0 & d_2 & 1 \end{bmatrix}$$

$$^{0}J^{-1}(\theta) = \frac{Adj\ {}^{0}J(\theta)}{\left|{}^{0}J(\theta)\right|}$$

$$\left|{}^{0}J(\theta)\right| = -d_2(c_1 + s_1)(d_2 + a_1)$$

$$Adj\ {}^{0}J(\theta) = \begin{bmatrix} -d_2 & 0 & d_2(-d_2s_1 - c_1a_1) \\ d_2 & 0 & -d_2(-d_2c_1 - s_1a_1) \\ 0 & -(c_1 - s_1)(d_2 + a_1) & 0 \end{bmatrix}^T$$
$$= \begin{bmatrix} -d_2 & d_2 & 0 \\ 0 & 0 & -(c_1 - s_1)(d_2 + a_1) \\ d_2(-d_2s_1 - c_1a_1) & -d_2(-d_2c_1 - s_1a_1) & 0 \end{bmatrix}$$

$$\therefore {}^0J^{-1}(\theta) = \frac{\begin{bmatrix} -d_2 & d_2 & 0 \\ 0 & 0 & -(c_1 - s_1)(d_2 + a_1) \\ d_2(-d_2 s_1 - c_1 a_1) & -d_2(-d_2 c_1 - s_1 a_1) & 0 \end{bmatrix}}{-d_2(c_1 + s_1)(d_2 + a_1)}$$

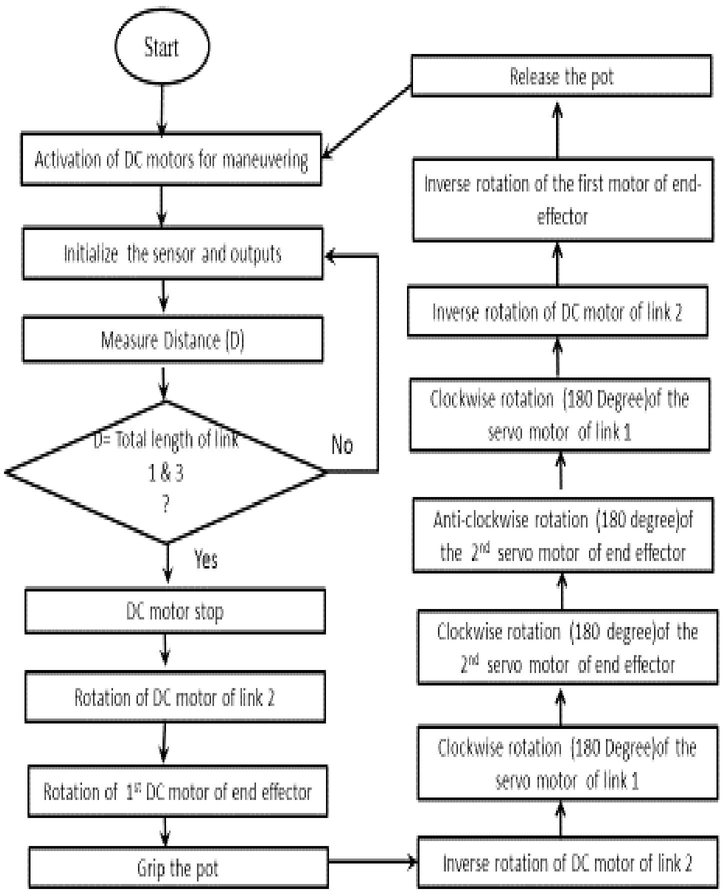
$$= \frac{1}{-d_2(c_1 + s_1)(d_2 + a_1)} \begin{bmatrix} -d_2 & d_2 & 0 \\ 0 & 0 & -(c_1 - s_1)(d_2 + a_1) \\ d_2(-d_2 s_1 - c_1 a_1) & -d_2(-d_2 c_1 - s_1 a_1) & 0 \end{bmatrix}$$

$$\left.\begin{aligned} \therefore \dot{\theta}_1 &= \frac{-d_2}{-d_2(c_1 + s_1)(d_2 + a_1)} = \frac{1}{(c_1 + s_1)(d_2 + a_1)} \\ \therefore \dot{\theta}_2 &= \frac{0}{-d_2(c_1 + s_1)(d_2 + a_1)} = 0 \\ \therefore \dot{\theta}_3 &= \frac{d_2(-d_2 s_1 - c_1 a_1)}{-d_2(c_1 + s_1)(d_2 + a_1)} = \frac{(d_2 s_1 + c_1 a_1)}{(c_1 + s_1)(d_2 + a_1)} \end{aligned}\right\} \ldots\ldots (vi)$$

Equation (vi) are the equations for joint angles.

V. ALGORITHM

The programing is developed for the system and is mentioned here.



VI. ELECTRONICS COMPONENTS

In order to design and control the wheelchair DC motors, Servo motors, ATMEGA 32 micro- controller, Ultrasonic sensor and L293D motor driver are used as the electrical components.

A. Servo motor

Tower Pro MG 995 is a metal geared servo motor. It operates between 4.8V to 7.2V and temperature ranges from 0 °C to 55 °C. The stall torque of this motor varies between 8.5Kg/cm to10Kg/cm at 4.8V to 6V. Its speed of operation is 0.20 sec/60 degree to 0.16 sec/60 degree. Its weight is 55g.

Figure 6: Servo motor (MG 995)

B. Ultrasonic sensor – HC-SR04

It has 2cm to 400cm non-contact measurement function. Its capacity is up to 3mm. It consists of ultrasonic transmitter, receiver and control circuit. The working voltage, current, frequency and measuring angle of HCSR-04 are DC 5V, 15mA, 40Hz and 15 degree respectively. 10uS TTL signal is the trigger input signal.

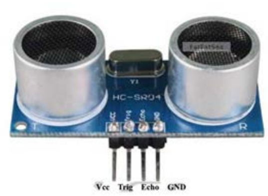


Figure 7: Ultrasonic Sensor

C. DC Motor

The DC motor that has been used here is a gear motor. It supplies 2.0Kgf.cm-30Kgf.cm torques and output power varies from 0.5 to 2.3w. Its speed varies from 3000rpm to 6000rpm.

Figure 8: DC motor

D. ATMEGA 32 microcontroller

The self -programmable Flash program memory of this microcontroller is 32 Kbytes, 1024 Bytes EEPROM, 2 Kbytes internal SRAM, 8 channel-10 bit ADC and 32 programmable I/O lines. Operating voltage varies between 4.5V-5.5V.

Figure 9: ATmega 32 and motor driver IC

E. L293D motor driver

L293D is known as quadruple high-current half-H drivers. It supplies bidirectional drive currents up to 600mA at voltages from 4.5 V to 36 V. It is used to drive inductive, high current/high voltage loads such as relays, solenoids, DC motors etc. in positive supply applications.

VII. Result and Discussion

So, from the equation (II) to (VI) the position with respect to base, rotation matrix, torque, singularity and joint angles can be determined. Following these solutions the trajectory can be planned very easily and such a manipulator will perform our desired activity more smoothly and accurately in comparison with human being. Just following the algorithm in a microcontroller, this robot can perform its job quicker than a man. Yet this research has lots of scopes for working still now. The control system can be designed and many features can be added to the manipulator for more perfect operations. Hence, this research was regarding the mathematical model and performance of the manipulator which the vehicle carries; this paper will help the researchers at this field as well as those who are trying to make a mean of utilizing manipulators in the field of waste management for reducing the possibility of health diseases to human beings and to reduce the anxiety of regular collection of waste in municipal areas.

VIII. Conclusion

As days passing by, every work field is heading towards automation. Now it's time to reduce human tasks in the field of hazardous and dusty environment where there is health risk as well as lack of motivation is present. The Computer platform model and mathematical model of the robot that is presented here can perform such hazardous and disgusting works in shortest time with one time investment without any annoying behavior. Yet, there should be in need of a monitoring body who will check the performance and workability of such robots for providing proper maintenance. If this robot can get implemented, then the environmental pollution will get reduced to a great instant indeed.

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