Theoretical design for a three-degree-of-freedom planar robot without restrictions

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Resumen

En este artículo se muestra el diseño de un robot plano de tres grados de libertad sin restricciones, este robot no está físicamente conectado y es libre de moverse por su espacio de trabajo definido. El robot debe moverse en cualquier dirección con una velocidad variable. Sin embargo, el diseño mecánico detallado, permite controlar completamente este robot. También se muestran las ecuaciones de implementación del controlador de robot. El controlador permite convertir las velocidades rotacionales en las velocidades de las ruedas y cuánta corriente deben proporcionar a cada motor.

Palabras clave—3dof, robot plano, motor DC, controlador de motor.

Abstract

In this paper design for a three-degree-of-freedom planar robot with no constraints is shown, this robot is not physically attached, and it is free to move about its workspace defined. The robot must move in any direction with a variable velocity. However, the detailed mechanical design, allow fully control this robot. In this paper are show the implementation equations on a robot controller. The controller allows to convert the desired, and rotational velocities in the wheel velocities and how much current is to provide each motor.

Keywords— *3dof, planar robot, DC motor, motor driver.*

1. INTRODUCTION

The most common three degrees freedom robot type is a robot arms. However, in addition to ending effectors that provide an additional three degrees of freedom. While robotic arms are ideal for working in a relatively small workspace, there often is a need to have robots that move a considerable distance from their origins. Additionally, robotic arms have a complicated kinematic and encounter problems with singularity and workspace restrictions.

Due to these complications of robotic arms, there are many cases where other types of robotic devices were considered. For instance, other types of robots would likely be considered for uses such as space exploration, dynamic environments, or complicated workspace restrictions.

In this paper was to design a three-degree-of-freedom robot chassis that can travel unrestricted on a plane. The robot is not physically connected to the environment, so it is free to move about the workspace as needed. Since the robot does move about in a plane, the robot has two prismatic degrees of freedom in addition to one rotational degree of freedom.

Depending on the application, it is possible to use an additional arm or a robotic device could to be added to the top of the frame to provide six degrees of freedom or to perform other mechanical functions. The robot can locate its position in the workspace by triangulating feedback from a set of optical sensors. In this report, I have outlined a detailed mechanical design, come up with necessary equations to control the robot, and devised techniques for moving the robot between any two orientations in the workspace.

2. THEORY

The design of a robotic drive system with three full degrees of freedom in a plane is not a trivial task. The robot must be able to move in any direction and rotate by itself at the same time. Planning this type of drive system is hard because the system has a simple wheel designed to provide one degree of freedom forward and backward.

Most vehicles of transportation using wheels have only one degree of freedom. Any motion perpendicular to the wheel is resisted by contact friction.

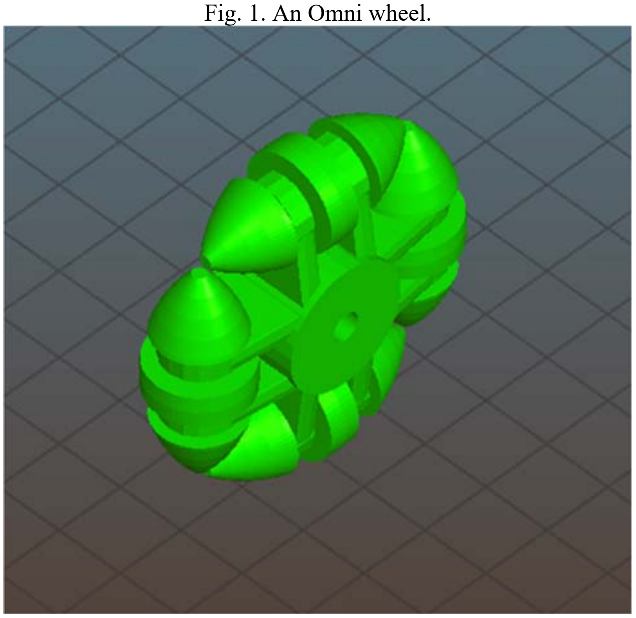
To simultaneously rotate and translate in any given direction, the robot must be able to independently rotate and independently control the speed of each wheel. Such control would require a minimum of eight motors.

Since it is so difficult to use standard wheels to achieve three degrees of freedom on a plane, it is feasible to use an Omni wheel such as an elegant way to eliminate some of the problems with standard wheels. An Omni wheel, unlike a standard wheel, mostly does not provide any resistance to force perpendicular to the motion of the wheel.

The design of the Omni wheel is not trivial. This design can be manufactured by machining two identical pieces of polycarbonate or use PLA plastic and use a 3D printer to reachthe part. In both cases, it is necessary to place aluminum rollers. See Figure 1.

The result is a wheel that is free to rotate frequently with small resistance to side forces. The wheels have six inches in diameter. An Omni wheel is an ideal type of wheel to use with a three-degree-of-freedom robotic device because a wheel does not care if there are forces perpendicular to the wheel. However, if two wheels are oriented perpendicular to each other, the two wheels can simultaneously translate in two different axes without any interference.

Fig. 1. An Omni wheel.



By placing two sets of wheels on the chassis, with the two sets perpendicular to each other and with the two wheels of each set parallel to each other, it is, in fact, possible to achieve three complete degrees of freedom. Translational motion in either of the two planar axes can be made by moving the wheels of each set at the same velocity in the desired direction. It to rotate, the speeds of the opposing wheels of each set simply need to be mismatched. If they are mismatched by the same amount and in the same rotational direction, the robot will rotate.

Thus, it to keep a design simple, it was used four wheels, each wheel was oriented 90 degrees from its neighbors. Each wheel is equidistant from the center of the robot, and the robot contains 180º symmetry about any line.Since all the wheels are equidistant from the center, the robot mostly includes four wheels that are tangent to a shared circle. If it was searched the robot to move from point A to point B and rotate by some amount, it´s necessary to use a circle translating and rotating through the plane.

It to rotate in place, all the wheels only move with the same velocity in the desired rotational direction. When it is desired to rotate and translate simultaneously, the more complex control logic is needed.For the chassis was used a 30x30 IPS aluminum extrusion for the structural material. This material has many advantages. It is easy to assemble, lightweight, reliable, and is easy to attach components.

The chassis have a square-shaped with wheels as far towards the corners, the wheels are as far out as possible, and the frame is so little, it would be tough for a component to cause the robot to tip over. Figure 2 show the detailed frame layout of the robot.

Once the frame was laid out and the wheels were in place, the next step was to determine how to power the wheels, for the motors DC motors (Bosch Drill) was used. The motors have to provide a grand amount of power, are lightweight, and have gearboxes that ensure appropriate gearing for a robotic drive system.

Fig. 2. The exact chassis layout of the robot.

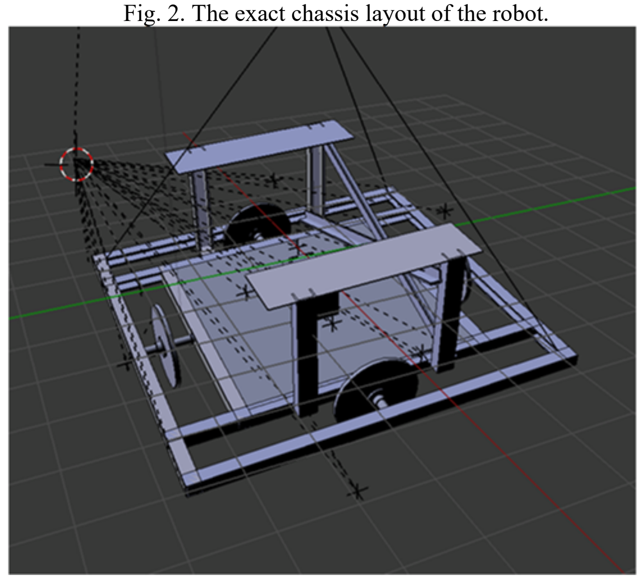
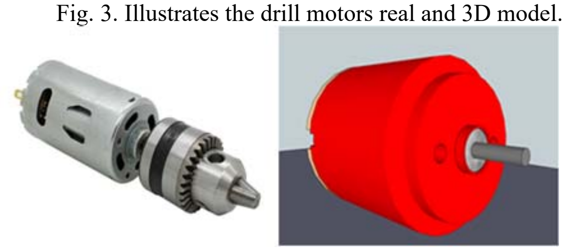


Fig. 3. Illustrates the drill motors real and 3D model.



The motor assembly is relatively straightforward. The actual motor press fits into the assembly box. The output shaft of the motor feeds directly into the gearbox, which provides a 64:1 gear ratio. Since the output shaft of the motor spins at 20000 RPM with no load in comparison of other DC motors, the rotational velocity of the output shaft of the gearbox is at approximately 300 RPM. Since the output shaft of the gearbox is so short, it was necessary to use a shaft coupler. Additionally, this particular gearbox is unable to support side loads.

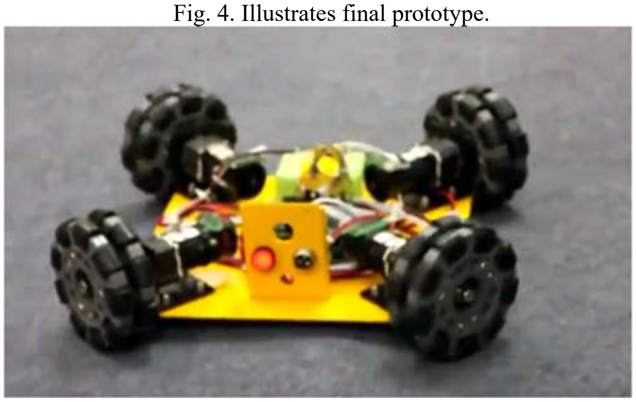
However, it was necessary to install ball bearings before and after the sprocket to ensure that the loads placed on the sprocket by the chain do not put a load on the gearbox. The sprocket is a standard 38-pitch roller chain and contains ten teeth. For the shaft to engage the gear, it is necessary to connect the two to each other physically. Exists a big number of possibilities for this connection, including a standard pin, keyway, set screw, welding, or Dutch key.

A rotational velocity of 300 RPM represent high speed for a robot; there is a 2:1 gear ratio in the motor sprocket and the wheel sprocket. Thus, this causes the wheels to have a maximum possible rotational velocity of 150 RPM.

For a wheel radius of 3", this causes the robot's maximum speed in the direction of a wheel to be about 4 feet per second. The 20-teeth sprockets were attached to the wheels by drilling and tapping holes through the sprocket and polycarbonate and bolting the gear to the wheel.

Finally, the motors assemblies must be connected to the chassis of the robot. As mentioned earlier, four meetings are needed – one for each wheel. The parts can easily be attached to the frame by drilling holes in the base plate of the assembly and bolting it to the extrusion next to each wheel. The sprockets for the wheel and the motor must be aligned. Figure 4 show an image of the entire robot assembly.

Fig. 4. Illustrates final prototype.

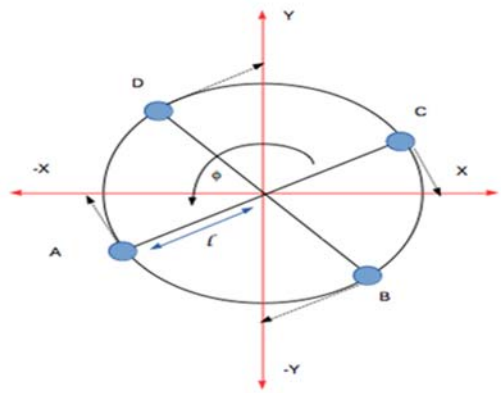


3. OUR CONTROL

One of the most representative aspects of this project is to design the control of robot chassis. There are two characteristics to develop, first, given a robot orientation, desired prismatic direction, and velocity, and desired rotational speed. It is necessary to determine what value to send to the speed controller for each wheel and second, with the obtained information there is a need to set up the move from any point and orientation to a second point and orientation.

For all practical purposes, this robot will represent a circle that at any given instant is moving in a plane with some velocity and rotational velocity. Thus, if it is possible to determine the speed of each of the four contact points of the wheels and with this, to determine how fast each wheel needs to spin. In this paper by taking the dot product of the velocity with the direction of the orientation of each wheel the problem was resolved. Figure 5 shows all the variables used in defined el problem:

Fig. 5. Show all variables defined in the image



Given w, the desired angular velocity, and V, the velocity vector, it should be possible to determine, wb, wc, and wd. To determine these formulas, I or 1, first ascertain the velocity of points A, B, C, and D for any given angular velocity:

$$\vec{V}_A = \vec{V} + wl(-\sin\varphi\,\hat\imath + \cos\varphi\,\hat\jmath \;\ldots\ldots\ldots\ldots\ldots\; (1)$$

$$\vec{V}_B = \vec{V} + wl(-\cos\varphi\,\hat\imath + \sin\varphi\,\hat\jmath \;\ldots\ldots\ldots\ldots\ldots\; (2)$$

$$\vec{V}_c = \vec{V} + wl(-\sin\varphi\,\hat\imath + \cos\varphi\,\hat\jmath \;\ldots\ldots\ldots\ldots\ldots\; (3)$$

$$\vec{V}_D = \vec{V} + wl(-\cos\varphi\,\hat\imath + \sin\varphi\,\hat\jmath \;\ldots\ldots\ldots\ldots\ldots\; (4)$$

Next, it is necessary to take the components of these velocities that point in the directions of the wheels and with this give me the speed at which each wheel should be contacting in the ground. These velocities can be calculated by taking the dot product of each absolute point velocity with the direction of clockwise spin of each wheel.

$$\vec{V}_{EA} = \vec{V}_A[\hat\imath - \sin\varphi + \hat\jmath\cos\varphi] = [\vec{V} + wl(-\sin\varphi\,\hat\imath + \cos\varphi\,\hat\jmath\widehat{]} * [-\sin\varphi + \hat\jmath\cos\varphi] \ldots\ldots\ldots\ldots (5)$$

$$\vec{V}_{EB} = \vec{V}_B[\hat\imath - \cos\varphi + \hat\jmath\sin\varphi] = [\vec{V} + wl(-\cos\varphi\,\hat\imath + \sin\varphi\,\hat\jmath\widehat{]} * [-\sin\varphi + \hat\jmath\cos\varphi] \ldots\ldots\ldots\ldots (6)$$

$$\vec{V}_{EC} = \vec{V}_C[\hat\imath - \sin\varphi + \hat\jmath\cos\varphi] = [\vec{V} + wl(-\sin\varphi\,\hat\imath + \cos\varphi\,\hat\jmath\widehat{]} * [-\sin\varphi + \hat\jmath\cos\varphi] \ldots\ldots\ldots\ldots (7)$$

$$\vec{V}_{ED} = \vec{V}_D[\hat\imath - \cos\varphi + \hat\jmath\sin\varphi] = [\vec{V} + wl(-\cos\varphi\,\hat\imath + \sin\varphi\,\hat\jmath\widehat{]} * [-\sin\varphi + \hat\jmath\cos\varphi] \ldots\ldots\ldots\ldots (8)$$

$$\vec{V}_{EA} = \vec{V}_x\sin\varphi - wl\,sin^2\varphi - V_y\cos\varphi - wl\,sin^2\varphi] = \overrightarrow{Vx}\sin\varphi - \overrightarrow{Vy}\cos\varphi - wl(cos^2\varphi\,\hat\imath + sin^2\varphi\,\hat\jmath] \ldots (9)$$

$$\vec{V}_{EB} = -\vec{V}_x\cos\varphi - wl\,cos^2\varphi - V_y\sin\varphi - wl\,sin^2\varphi] = \overrightarrow{Vx}\cos\varphi - \overrightarrow{Vy}\sin\varphi - wl(cos^2\varphi\,\hat\imath + sin^2\varphi\,\hat\jmath] \ldots (10)$$

$$\vec{V}_{ED} = \vec{V}_x \cos\varphi - wl\,cos^2\varphi - V_y \sin\varphi - wl\,sin^2\varphi] = \overrightarrow{Vx}\cos\varphi - \overrightarrow{Vy}\sin\varphi - wl(cos^2\varphi\,\hat{\imath} + sin^2\varphi\,\hat{\jmath}] \;......\; (11)$$

Finally, the equations for the rotational velocity of each wheel can be derived by dividing the velocity of each wheel contact by the radius of each wheel:

$$W_A = \left(\overrightarrow{Vx}\sin\varphi - \overrightarrow{Vy}\cos\varphi - wl\right)\%r \;...........\; (12)$$

$$W_B = (\overline{-\overrightarrow{Vx}}\cos\varphi - \overrightarrow{Vy}\sin\varphi - wl)\,\%r \;.........\; (13)$$

$$W_C = (-\overrightarrow{Vx}\sin\varphi - \overrightarrow{Vy}\cos\varphi - wl\,)\,\%r \;.........\; (14)$$

$$W_D = (\cos\varphi - \overrightarrow{Vy}\sin\varphi - wl)\%r \;................\; (15)$$

Since the Bosch Drill motors are geared at such a high ratio, the motors are going to accelerate to peak velocity and back to zero in a very short amount of time. In addition to the low speeds of the robot, makes the effects of inertia on the system negligible. Since we are using DC motors, the speed of the motor is going to be proportional to current. Therefore, the values we feed into the speed controller will be some constant times the desired rotational velocity of the wheel.

4. RESULTS

Present the results are taken such as reference the equations (11), (12), (13) and (14), it is possible to use these formulas over time for wheel velocity in relation over time.

Using R and GNUPLOT allows to calculate how a robot would take 10 seconds to move from (0,0) to (10,5) over a period of ten seconds and turn around 180º in the process.

Figures 6, 7, 8 and 9 show the behavior graphs.

Fig. 6. Behavior Speed vs. Current.

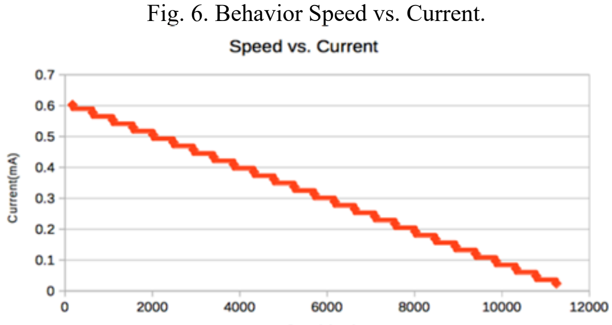


Fig. 7. Behavior Current vs. Torque (Bosch Drill motors).

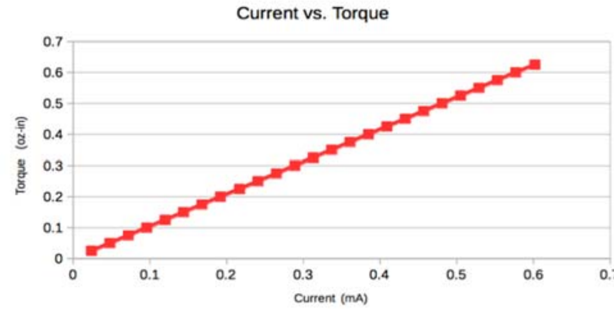


Fig. 8. Behavior Power vs. Efficiency (Bosch Drill motors).

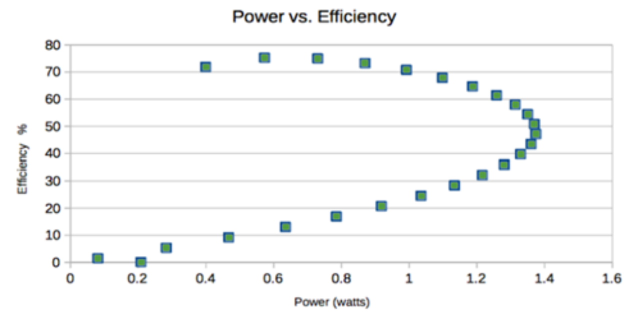
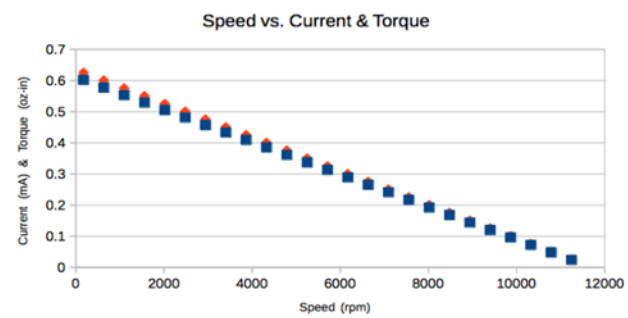
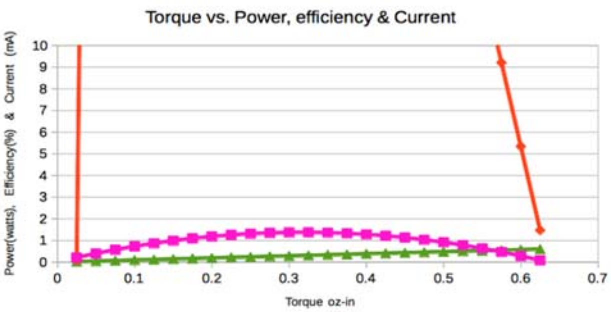


Fig. 9. Behavior Speed vs. Current & Torque (Bosch Drill motors).



Finally, to ensure that the robot does not move off the intended trajectory. The above equations will only provide a rough data to move the robot over time. However, the robot has to have a way of checking its coordinates repeatedly and adjusting its trajectory plans if it falls off target. The final behavior of each motor Bosch Drill is shown in figure 10.

Fig. 10. Final parameters of Bosch Drill motors.



5. CONCLUSION

In our design was added a set of servos and a set of optical sensors. The purpose of this is to sweep back in forth 360º and find a pole with a strip of light-reflecting tape along it is circumference. This it will let the robot know what angle it is at on its surroundings.

Once it locks on to the pole, the second servo can rotate the second optical sensor downwards until it locks onto the same tape. Using the angles (provided by instructions to the servos) of the position of the robot in the workspace can be triangulated.

Once the position in the workspace to calculated, the trajectory can be recalculated from scratch. As the robot gets closer, there will be less and less room for error in the relation of other literature robots. Thus, although the trajectory may not be perfect at first, it will approach the target more rapidly as it nears the target.

Since the sensors need to move, it will take some amount of time before they locate the object. This time delay could ultimately cause the robot to overshoot its target or oscillate back and forth around the target.

Another alternative to optical sensors is using an off-robot camera to locate the position of the robot in the workspace. However, this somewhat defeats the purpose of designing a robot that can move freely on its own, since the camera is not part of the "free" robot. Additionally, the camera would need to feed back into the robot controller, and thus radio communication would be an added complication to the system.

One other possibility is to use infrared sensors to detect angular position. Perhaps the most elegant solution, however, is to use GPS to keep track of the robot position and a compass to keep track of orientation. This would allow the robot to in fact move freely around the surface of the earth, given that the robot is moving along relatively flat, hard land.

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