DESIGN OF A DOCKING STATION FOR A MOBILE ROBOT

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ABSTRACT

Over the past few decades, a lot of emphasis is being given on designing a sufficient intelligence into a robot to perform tasks such as mapping and navigation. This paper, aims to design a mechanical system where the robot has sufficient knowledge to question itself how much power does it have remaining? Thus the emphasis is given on creating a docking system for the robot, which supplies power to the robot when it is critically very low.

Keywords: Automatic Docking, Mechanical Design, Mobile Robot.

I. INTRODUCTION

Today the Automatic Guided Vehicles or AGVs can definitely perform its tasks autonomously without or with minimum human intervention. Since it is categorized as automatic, one would expect it to be automatic in every aspect. But the fact is that, they are autonomous as long as they are fed with enough power. Once its power source gets exhausted, it has to stop working and inform the operator to switch batteries or recharge the batteries. When the battery is completely discharged, the power supply was manually disconnected from the robot and connected to the charger. During this time the robot remains non-functional and hence to attain complete autonomy it has to be addressed. To attain complete autonomy, a method is proposed bearing in mind the certain factors; like the cost, compatibility with existing robots, compliance and simplicity. In this paper, a docking system is designed for the National Instruments robotics starter kit robot 1.0 also known as DaNI 1.0 robot.Docking mechanism was designed to accommodate alignment errors, which occur due to various entry angles and positions, and will be described in detail later. Autodesk Inventor was used for performing the mechanical design of the system.

II. LITERATURE REVIEW

The same problem of auto recharging has already been recognised and many researchers have tried different methodologies. Some of the successful models created are discussed below.

Silverman *et al.* [1] designed a docking station having two Degrees of Freedom, where one is the rotation about z-axis and the other is the translation along z-axis. A cone is used to direct the robot docking mechanism to the station. Extension springs were used for rotation and compression springs were used for the vertical movement of the cone. The robot docking mechanism consists of a small stick which is connected behind the robot and can rotate along the z-axis. The copper covered spherical tip of the mechanism aids in docking as well as acts as the positive terminal. The main disadvantage is concern for safety due the protruding rod from the robot and the advantage being possibility for wide range of entry angles.

In Luo *et al.* [2] the docking mechanism on the robot has 2 protruding conical connectors goes into the respective holes in the docking station. A guide stick is fixed below the connectors which lead them into the holes. The robot docking mechanism can move horizontally and can rotate along the z-axis using compression springs while the docking station is stationary.

The docking station in [3] has a toggle switch which when pressed locks the robot on to the station by two arms. The station also allows the accommodation of any error occurring in the horizontal direction.

An innovate solution is discussed by Roh *et al.* [4] where magnetic force is used for alignment. The male part is on the robot and female part is on the docking station with both being shaped like a chamfer. The female part can rotate in the vertical axis and extension springs are connected to bring it back to normal and the whole part is connected to the wall through a compression spring to withstand any shock while docking. The male part can move horizontally and again springs are used to enable this movement. Magnets are positioned inside the connectors such that when the robot is docked, the magnetic poles in the male and female parts attract and bond to each other. While docking, due to the magnetic force of attraction or repulsion, the female part rotates or the male part translates. In another prototype by Park *et al.* [5] a peg which can rotate about its axis, translate both vertically and horizontally is connected to the robot. The docking station consists of a chamfered hole which lets the peg to enter and solenoids are used to lock the peg in the hole.

In all the above described papers the docking station is fixed at a position. But in Ferreira *et al* [7] the docking station can be placed anywhere on the ground to aid mainly search and rescue robots where its usage environment changes every time. The docking station which has a pyramid shape is placed on the ground at a constant angle. A bi-conical metal guide is used at the tip of the pyramid. The robot uses a camera to locate the station and docking is done by pulling the conical shape in to a hole in the robot (with sliding doors). Docking here is used for power transmission and communication.

The ideas discussed above were sometimes specific for a robot type. For instance Kim *et al.* [3] dealt with circular shaped robots while Wu *et al.* [6] designed for large sized humanoid like robots. Ferreira *et al.* [7] tried to implement on rescue robots and others tried on specific models of robots. The main disadvantage in designs of Silverman *et al.* [1] and Luo *et al.* [2] are the pointed extensions from the robot which can be classified as unsafe in industrial environments.

Even though all of them serve the purpose, a much simpler and safe idea is incorporated in this report. The proposed docking mechanism does not have any pointed ends or protruding from the robot which makes it safer than [1] and [2]. The locking mechanism while docking not only transfers power, but also ensures that docking is not lost even when disturbances occur on the robot.

III. PROPOSED DESIGN

Figure 1: Different Views of the Male and Female Parts of the Mechanism

The docking mechanism involved a male part which was connected to the robot and a female part mounted on a frame mounted on the wall through springs and bearings. *Figure 1* shows design of the mechanism which is also called a double roller catch mechanism. The female connector comprises of two metallic rollers kept pressed to each other with the tension from a spring. The rollers can rotate with respect to its frame along the vertical axis. This rotation allows a wide range of approach angles by the robot. The connector acts as a power transmission medium as well as a support for the robot during physical disturbances. The whole mechanism will be made out of a conducting material. The rollers pushing against each other will ensure that the robot will remain docked even when minor movements that could happen when an operator tries to do install or uninstall any hardware on the robot. The mechanism is purchased whose plastic rollers are replaced with its metal equivalents for conductivity.

Figure2: L- shaped bracket for female docking mechanism

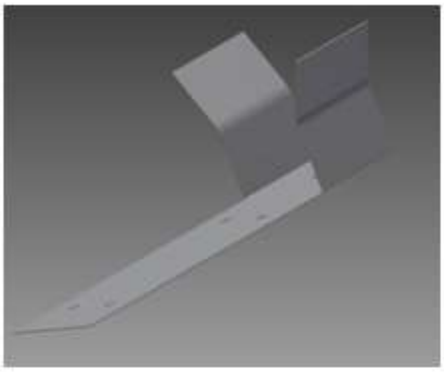

Figure3: Funnel shaped female mechanism mount

The female connectors are mounted on anL-shaped frame (*figure2*) which will be connected to a non-metal plate. This plate has the ability to move in horizontal direction (2cm) as well as rotate in the vertical direction(30°) as it is connected to a funnel shaped frame (*Figure*3) which is suspended between a U-shaped fixed frame through a rod end bearing (*Figure*4). The bearing is connected to a mount (*Figure* 5) which is then connected on to the U-shaped mount (*Figure* 6) through rods with compression springs (see *figure* 7 &8 for the assembly) added on to it. The funnel shaped frame is connected to the U shaped frame through springs and bearings.

Two tension springs were connected between the frames will let the funnel to rotate or move in the horizontal direction and come back to zero position once the robot leaves the station. The back side of the funnel frame is connected to the U frame through spherical rod end bearing. This rod end bearing is mounted on a holder and the holder is in turn connected to the U frame through rods and 2 compression springs are added on the rods to enable lateral movement. So the bearing helps to rotate about its axis and the springs on the rod will let the whole bearing move laterally.

Since there are three contacts required for power transfer, there will be three female connectors (*figure 8*) placed vertically one above the other at a suitable distance and at the corresponding heights, the male part will be fixed on the robot. The male part has a bi-conical shape which aids in locking once the robot docks. As the rollers of the female connector are made of plastic, metal rollers are designed specially as replacements to let power transfer. The U shaped fixed mechanism is then mounted on to a square base.

The whole docking station rests on a metal surface which has compression springs at the bottom to let the base move down when the robot is on it. A foot switch is placed under the base which gets activated when the base presses on its surface. This switch will then turn on the power supply of the docking station.

The funnel shaped frame is designed to let the robot channel into the docking mechanism. The frame will rotate or translate based on the angle and position of the robot approach. The dimension of the funnel shaped frame is designed to accommodate the protruding servo motor mount of the robot which acts as a guide.

Suppose the robot is not entering at right angles to the docking station. The robot will initially hit the funnel and due to the force from the robot, the funnel will rotate (as the rod end bearing will) until the guide on the robot completely enters the funnel. At this position, the robot and the docking station would be facing each other perfectly without any error in angle.

Figure 4: Spherical Rod End Bearing.

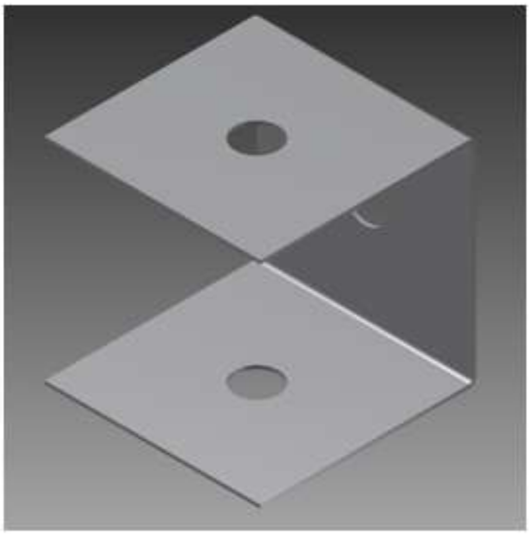

Figure5: Bearing mount

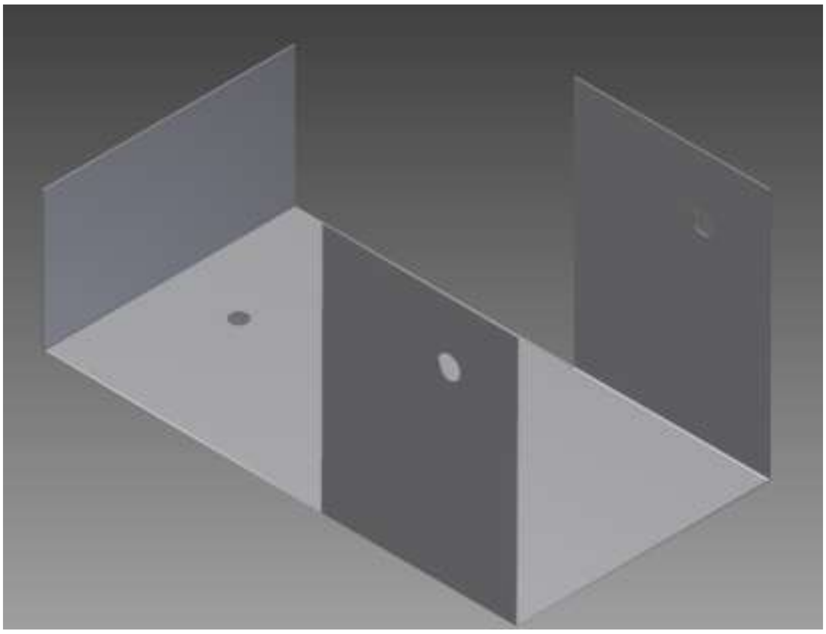

Figure6: Stationary frame

Figure7: Top view of the assembled mechanism

Figure 8: Front view of the assembled mechanism

If an error is due to the lack of alignment with the normal line to the docking station, or if the robot is displaced from the central line, rotation of the docking station will not help to compensate and dock. For this, a lateral movement is added to the funnel shaped frame. The funnel shaped frame will move in either direction depending on the direction of application of force on it by the robot with the help of compression springs seen in *figure*7. *Figure*9 shows the robot in docked condition. In arguably the final concept has advantages in terms of its compliance and simplicity. The docking mechanism can accommodate errors in both entry angle and displacement.

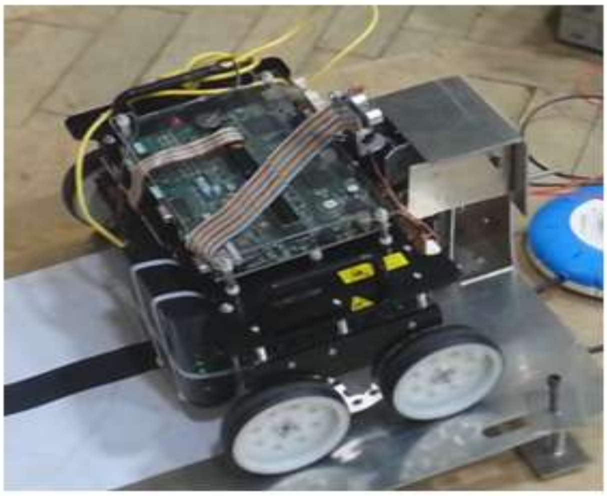

Figure 9: Docked view of the robot

IV. DESIGN CALCULATIONS

4.1 Compression Spring Design

There are two compression springs under the base to activate the docking station. The total weight handled by the springs is weight of robot (*4Kg*) and weight of the parts.

Density of aluminium=2700Kg/m^3

Therefore total weight of base plate including all parts is calculated to be approximately 2*Kg*.

Total weight =6*Kg* and force applied is 6x9.8 (acceleration due to gravity) =58.8N and hence each spring withstands 29.4N. For a compression spring, F=kx where F is the force (*N*), k is the spring constant (*N/m*) and x is the displacement (*m*).

The required displacement on full load is 20mm and this result in a spring constant of 0.735N/mm.

Therefore the selected springs have the following dimensions

Rate (*N/mm*) = 0.78N/mm

Free length of the spring= 71.6mm

Outer diameter =15.90mm

4.2 Compression Spring for Lateral Movement

To calculate the acceleration of the robot,

Robot wheel velocity= 1.25rad/s,

Diameter of wheel =10.16cm

Using the above two values, the robot velocity is calculated as,

V= 1.25 x 0.1592 x π x 10.16 = 6.35cm/s

Acceleration, *a* is rate of change of velocity and here it's obtained to be 6.35cm/s^2

Assuming that the robot takes 1 *s* to dock.

Force= mass x acceleration,

= 4 Kg x 6.35 cm/s^2 =0.254N

Displacement required= 10mm. So, spring constant is 0.0254N/mm and appropriate spring matching this design is selected.

V. CONCLUSION

The docking mechanism designed was such that it can translate in the horizontal direction and also rotate in the vertical direction. This was made possible through compression springs and a spherical rod end bearing. In the current design it was observed that since the whole docking mechanism was suspended on a single bearing, it had a tendency to retaliate and hit the fixed metal surface when the robot disconnected from the docking station. This happened as the whole mechanism tended to rotate upwards in the horizontal axis when the robot pulled itself out of the locking. A docking station for a mobile robot is successfully designed taking to account the mechanical aspects of the National Instruments DaNI robot. The future plan includes designing the necessary electrical circuit and LabVIEW program with the necessary algorithms for the robot to locate the docking station and charge its battery automatically.

REFERENCES

[1] Silverman, M.C.; Nies, D.; Jung, B.; Sukhatme, G.S.; , "*Staying alive: a docking station for autonomous robot recharging*," Robotics and Automation, 2002. Proceedings. ICRA '02. IEEE International Conference on , vol.1, no., pp. 1050- 1055 vol.1, 2002

[2] Luo, R.C.; Liao, C.T.; Su, K.L.; Lin, K.C.; , "*Automatic docking and recharging system for autonomous security robot*," Intelligent Robots and Systems, 2005. (IROS 2005). 2005 IEEE/RSJ International Conference on , vol., no., pp. 2953- 2958, 2-6 Aug. 2005

[3] Kim, K.H., Choi, H.D., Yoon, S., Lee, K.W., Ryu, H.S. Woo, C.K., Kwak, Y.K..; “*Development of docking system for mobile robots using cheap infrared sensors”*. Proceedings of the 1st International Conference on Sensing Technology, pp. 287–291, Palmerston North, New Zealand, 21–23 November 2005

[4] S. Roh, J. Park, Y. Lee, Y. Song, K. Yang, M. Choi, H. Kim, H. Lee, and H. Choi,; , "*Flexible docking mechanism using combination of magnetic force with error-compensation capability*," Automation Science and Engineering, 2008. CASE 2008. IEEE International Conference on , vol., no., pp.697-702, 23-26 Aug. 2008

[5] S. Roh, J. Park, Y. Lee, Y. Song, K. Yang, M. Choi, H. Kim, H. Lee, and H. Choi, "*Flexible Docking Mechanism with Error-Compensation Capability for Auto Recharging System of Mobile Robot*," Intl. J. of Control, Automation, and Systems, vol. 6, pp. 731-739, Oct. 2008.

[6] Y. Wu; M. Teng; Y. Tsai; , "*Robot docking station for automatic battery exchanging and charging*," Robotics and Biomimetics, 2008. ROBIO 2008. IEEE International Conference on , vol., no., pp.1043-1046, 22-25 Feb. 2009

[7] F. Ferreira; R. Ventura; “*Autonomous docking of a tracked wheels robot to its tether cable using a vision-based algorithm*”, Workshop on Robotics for Disaster Response, ICRA 2009 - IEEE International Conference on Robotics and Automation, Kobe, Japan, 2009