Design of an Omni-Direction Robot with Spherical Wheels

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Abstract

We proposed the design of an omni-direction robot which embeds 4 spherical wheels. The wheels are connected to 4 DC motors and controlled through an L298N boards which is powered with 2 LIPO batteries. A low-cost Arduino board oversees the system by controlling the motion and speed of the motor.
The wheels of the robot integrate an omni-directional mechanism and all components have been designed in Fusion 360 (Autodesk ®), manufactured with a 3D printer (Ender 5) an then assemble and integrated with the hardware and software of the sytem.
Preliminary tests show that the proposed solution is promising and provide a good reference for the manufacturing of low-cost robot.

Keywords: omni-directional wheel, Osaka wheel mechanism, wheeled robotics.

1. INTRODUCTION

In the last few years, the market of robots has increased substantially, due to the fact that current robotic applications allow a significant increment of interaction between the robotic devices and the human end-users. In this context, the human robotic interaction has become more and more important and the market is looking with interest at the development of humanoid robots which can interact with the end-user on the daily life and on the typical domestic environment (Chu, 2020; Secco, 2022; Manolescu, 2022).

Therefore, it is pretty important to be able to design robots which are able to move not only in the 'industrial' environment, rather in domestic environment where spaces and rooms are not designed in function of the robotic device itself (Innes, 2022).

In this context, here we proposed the integration of an omni-direction 4 wheels design with a wheeled mobile platform (This Forklift Moves In Any Direction!, 2021). The adoption of 4 omni-directional wheel should provide high mobility to the system, as wheel as an approach which can be easily scalable in commercial designs and products (Omni wheel, 2021).

2. MATERIALS & METHODS

Here we present the mechanical design and the electronics components of a Omni-Direction Robot with 4 Spherical Wheels. The first section shows the main parts which are required to integrate the robot with the main designs of these parts.

2.1 Mechanical Design

A. The wheel

The omni-ball design, as it is proposed in the literature, is made of 2 hemispheres that rotate independently from each other with a shaft connecting them together; then the shaft that comes out the side of the wheel can be turned in a way that the system provide a forward motion (Bruton, 2021a; Bruton, 2021b). The reason that the two hemispheres rotate is the same reason why the omni wheels rollers turn; the task of the mechanism is it to allow free movement of the wheel even if it is not being rotated itself, no matter the orientation of the wheel. If the wheel just had two hemi spheres only, then the ball would get dragged on each peak (in case the ball is oriented that way): therefore another tiny wheel is added to each top of each hemi-sphere. This ball is perpendicular to the shaft such that - when the ball is at one of the peaks of the hemispheres - it allows the free movement of the robot, instead of dragging that ball and damaging the system.

B. Overall design

The proposed design aims at manufacturing a 4-wheel system. Each wheel is situated on each side of a square plank to provide stability. The wheels is driven by 1 motor each, to make sure that the robotic device has enough torque on each axis. The actuators are controlled by an open source embedded system, namely an Arduino Uno board which allows the motion of the robot.

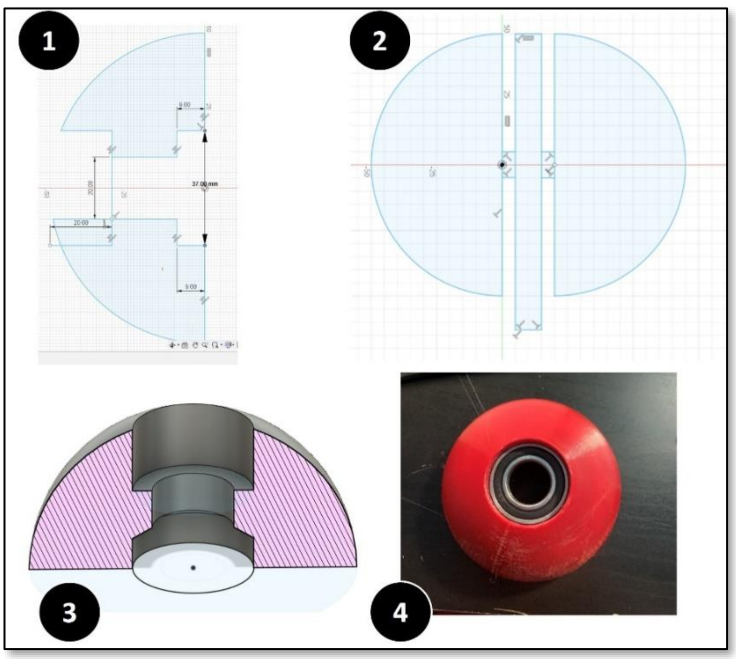

FIGURE 1: 2D render of the omni-ball cut (1) and 2D overall design of the omni-ball (2). Cross-section of the hemi-sphere (3) and prototype of the 3D printed hemi-sphere with the bearing (4).

C. Hemi Sphere

In order to prepare the parts, we used Fusion 360 (Autodesk ®) to design each part. We also used a 3D printer, model Ender 5, which has a bed size of 350 x 350 x 400 mm. We decided to design each hemisphere with a diameter of 100 mm which would allow to have 4 hemispheres on the printer at the same time.

To allow the hemisphere to rotate freely we needed to add a bearing in where the shaft connected. Since the shaft is going through the entire hemisphere - to make sure the small ball on top of the hemisphere is always perpendicular to the shaft - we add two bearings to make sure the rod going through the hemisphere do not shake. The bearings we used were 37 x 20 x 9 mm, outer diameter, inner diameter and depth in respectively.

Therefore, we designed the ball as it is reported in Figure 1 in order to then make the bearing press fit. Later we needed to widen the middle shaft from 20 mm to 25 mm since the inside ring of the bearing did not properly run at the beginning (the shaft causes friction and requires more energy to turn the hemispheres). The final design was then 3D printed with an infil of 20% and triangle shaped since we believed this structure would be strong enough to withstand the weight and dragging of the overall system across the ground. At this stage each bearing was then press fit into the hemisphere: this is shown on Figure 1 for one of the wheels. Finally, 4 wheels were printed, where each wheel required the manufacturing of 2 hemispheres.

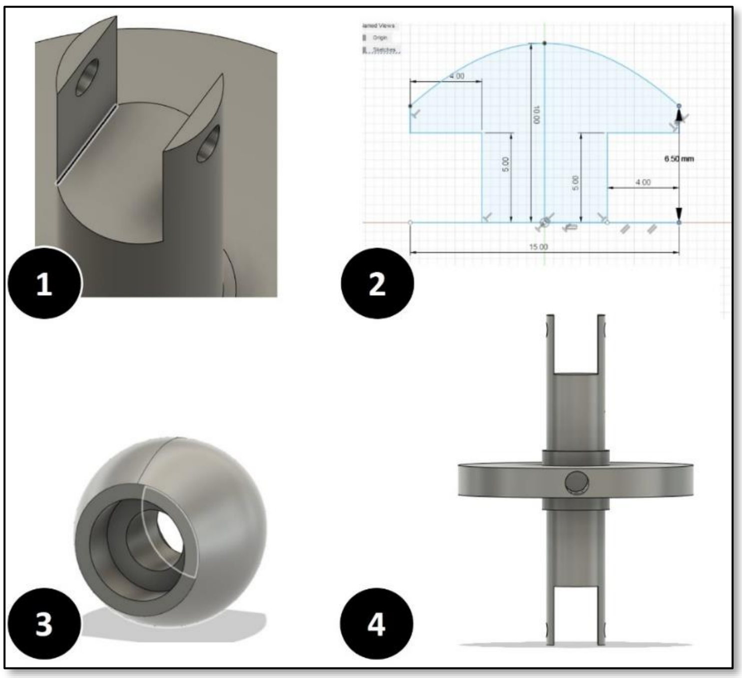

FIGURE 2: Details of the top of the shaft (1). Design of the small wheel (2). Rendering of the small ball (3). Design of the whole shaft of the ball (4).

D. The shaft

The design of the shaft to hold the balls together is a delicate process as it would have to fit between the hemispheres and go into the holes of the hemispheres, while allowing a small wheel to go on top of it. We first drew a circle of 80 mm and extruded it 10 mm to have enough space between each hemisphere. This approach also allows the weight to be distributed to the other hemisphere while the omni wheel is on the small wheel (Figure 2). Then, on top of that, in the center of the extrusion, another cylinder of diameter of 23 mm and height of 5 mm is placed. The purpose of this is to have a separation between the outside of the bearing and the axil griping onto each other.

On the top of this, a cylinder of 20 mm diameter with an height of 46 mm is extruded as well. This is the shaft that goes through the hemisphere. Moreover, in the center of the highest cylinder a cuboid of dimensions 15 x 20 x 20 mm is also set: here, the top face touches the top face of the cylinder. A hole that is designed where the small wheel on top of the hemisphere sits.

Two more holes are needed to hold onto the small wheel on top of each hemisphere: we deigned these by going in the center of each side and going 5 mm down and cutting circles on both side with a diameter of 5 mm. In this manner, the small wheel can be connected to the shaft and still move freely; a 5 mm diameter 20 mm rod can be placed to hold the small wheel on (Figure 2).

This is mirror on the other side of the beginning 80 mm diameter cylinder. Then a hole is put into the 80 mm cylinder, 5 mm down from the circumference of the top plate of the circle with a diameter of 8 mm and 40 mm deep: with this approach, the steel rod, that would be inserted into the hole, would be perpendicular to the wholes.

E. Small Ball

The gap between the shaft in Figure 2 is 15 mm, which is where the small ball will go. This means the length of the small ball can be no longer than 15 mm. The ball must also fit through the bearing with an inner diameter 20 mm. Therefore, the small wheel cannot have a width that exceeds 20 mm. The sides of the small wheel closest to holes also could not exceed 13 mm. The curve at the top allows the hemisphere and small ball transitions a lot smoother to make sure gears do not get destroyed and broken. The reasons there are holes on the side allows small bearings to go on each end with a measurement outer diameter of 10 mm, inner diameter of 5 mm and depth of 4 mm. Then the hole that goes through the entire small wheel has a diameter of 6 mm; this is so the 5 mm diameter rod - as stated in the shaft section - does not return friction on the small ball.

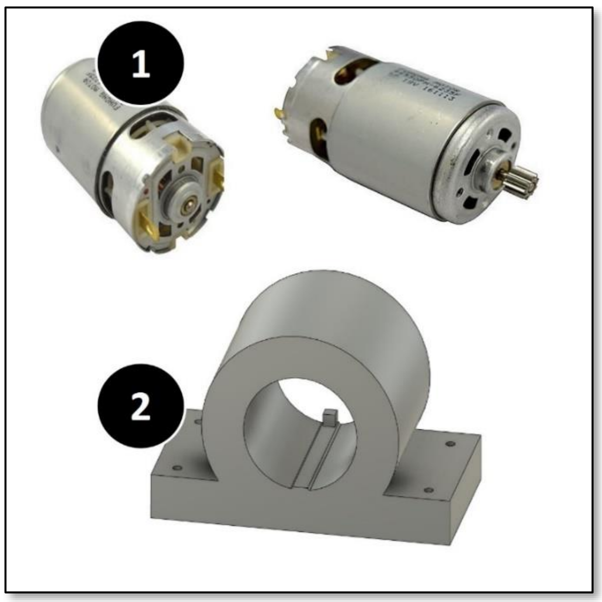

FIGURE 3: The 18V DC Fuhong Motor RS550PH-6235F 550 (1) - The linear actuator and electric motor specialist, 2021 - and the support and holder of the motor (2).

F. Motor Holder

The motors we are using are shown in Figure 3 and are 18 V DC motors. These produce a lot of torque from a preliminary testing we performed. The motors diameter is 38 mm therefore we designed an housing of the same size. We also needed the wall of the motor holder thick enough to not be broken: a 14 mm size was enough with a 20 % infill. Therefore, we drew another circle around the first being 52 mm. Then we needed to mount the motor to a flat surface: this is why at the bottom of the motor we connected a 100 x 15 mm rectangle making sure it did not obstruct the inner circle by using a trim function where it was needed (Figure 3).

We had to deal with some notches on the back of the motor which are shown in Figure 3. These measure 4 mm cubes; after choosing a side we then drew a 4 mm square and extruded it by 4 mm at the bottom and top of the inner circle. A set of screw holes, that would provide the most stable mounting mechanism, was prepared as well. The holes are 5 mm from each side and have a depth of 3 mm: this allows it to be changed and screwed into any material.

G. Gear

Finally, we had to design two gears, one to fit on the end of the motor, which had a shaft diameter of 3 mm and could not be larger than the motor mount (i.e. 33 mm from the center to the ground) and the other one to fit onto the shaft onto the 8 mm steel rod; this second motor could not be larger than the omni wheel which was 100 mm diameter.

Autodesk Fusion 360 embeds a gear maker: for the small gear, which was going on the motor, we changed the number of teeth to 12, the root fillet radius to 0.5 mm, and the gear thickness to 8 mm. This made the gear have a diameter of 40 mm, which was in the spec we laid out for the small gear.

Similarly, for the larger gear, we used the same module, root fillet radius and gear thickness. We then changed the number of teeth for this big gear to 30. This value allowed us to have a gear reduction of 2.5, meaning that we could have more torque and lower the speed of the machine as well.

```
// intialising all the pins
#define INjoyX  A0
#define INjoyY A1
int EnableMotorA = 3;//  These outputs need pulse width modulation
int EnableMotorB = 5;// this is the reason i have chosen these pins
int EnableMotorC = 6 ;//since they all provide this feature
int EnableMotorD = 9;//
// these are logic pins
int MotorAPin1 = 22;////
int MotorAPin2 = 24;////
int MotorBPin1 = 28;////
int MotorBPin2 = 30;////
int MotorCPin1 = 23;////
int MotorCPin2 = 25;////
int MotorDPin1 = 29;////
int MotorDPin2 = 31;////
// seting the variables i will need
int MotorSpeedHigh = 180; // the speed of the motor which can go from 0 to 255
int MotorSpeedLock = 60; // this will keep the motor from turnign back on its self and use some power so the other motor doesnt blow
int JoyXAngle = 0; // the angles of the joystick from 0 to 1024
int JoyYAngle = 0; // The middle part is 512
```


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FIGURE 4: Initialization process (top panel) and main code structure (bottom panel).

2.2 Electronics

A. Motor Driver & Power

We needed a motor controller, so we decided to use the L298N. The pin layout for said board is reported in L298N Dual H-Bridge Motor Driver, 2021. In brief, the logical outputs of this controller decide which side of the motor A and of the motor B provides the voltage for that motor and which pin is set to the ground. This is performed by changing the logical inputs as high or low where high refers to 5 V and low refers to 0 V.

The enable pins can either be connected to the board using the clips provided to make sure that the motor is at full power. Alternatively, it can be connected to an external pin on the Arduino board by using Pulse Width Modulation (PWM) to control the speed of the motor. We selected the latter option.

The two L298N boards are powered with 2 LIPO batteries with 11.2 V and 2250 mAh for each board. They are wired in series to produce 22 V. The Arduino board is powered by a USB port and a 2 m cable.

B. Code

Arduino code was prepared in order to control the 4 motors. Figure 4 display the main organization of the code, which was developed under the IDE Arduino Software Environment. The code is taking care of initializing all the variables and it allows the activation and spinning of the 4 motors which are mechanically connected to the 4 omni-directional wheels.

The code controls the activation of the motors which are enabled according to the mapping of the connectors and pins. The speed of the motors is also set for each axis. Part of the code is also design in order to map the rotation of the motor axis vs the X-Y motion of an end-user joystick in order to make the system easy to be controlled from the end-user (Figure 4).

FIGURE 5: The integrated omni ball (left panel) combined with the small wheel (right panel).

3. RESULTS

The proposed mechanical parts and electronic parts were then finally printed, manufactured and assembled and the system was integrated as it is reported in the following section.

C. Assembly

The next step of the project was to place the small wheels into the shaft and press the 5 mm rod threw it and the bearing. By means of a vice it was possible to keep a tight fit on both sides of the shaft. Then the two hemispheres were pressed on either side to finalize the Omni wheel design as it is shown in Figure 5. Then we positioned a 8 mm by 100 mm steel rod in the hole shown in the same figure to have a larger surface area for a super glue bonding the parts.

Then as sliding the 8 mm rod that was attached to the Omni ball we slid through the gear with super glue to hold it to the shaft. The next thing we did was to drill the motors down so the gears on the motors touched the gears of the omni ball. We repeated all these steps 4 times and finally connected all the cables - according to the pin mapping of the code (Figure 4) - and get the final design of Figure 6.

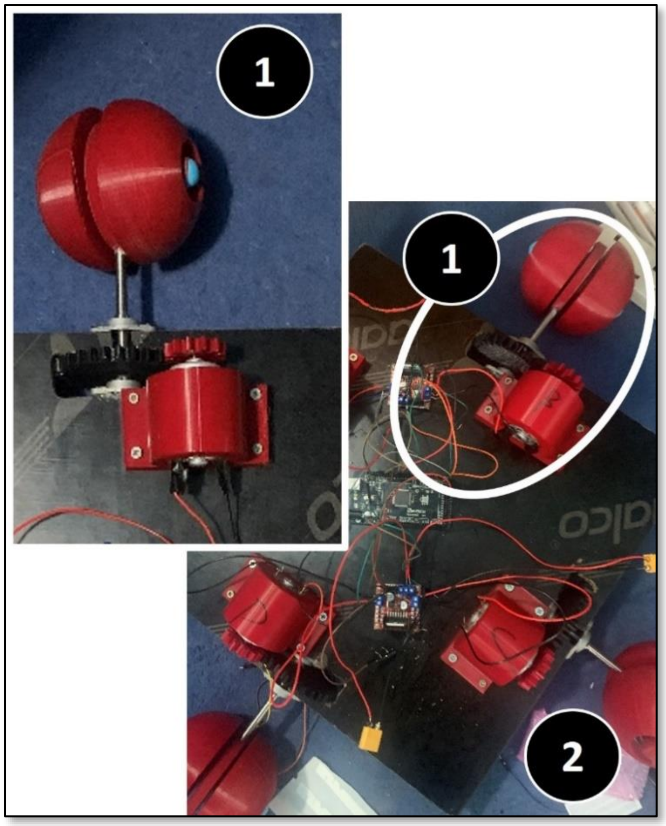

FIGURE 6: The gears motors and the omni ball (1) with the integrated system equipped and the circuit (2).

4. CONCLUSION

We presented a preliminary design of a 3D printed robots combining some mechanical parts with electronic components and an Arduino board overarching a DC motor driver. The main characteristic of the proposed design ids the use of 4 spherical wheels with an omni-ball design. Such a design allows to make an Omni directions robot fairly easy with a set of low-cost equipment and 3D printed parts. The omni ball also allows a robot to get over larger obstacles than an omni wheel of the same diameter, since the rollers of an omni wheel are much smaller than the hemispheres.

Following the deign and integration of the system, a proper set of experiments and validation should be performed. However, a set of preliminary test was done and it was notice that, despite the low-cost of the system, the system has shown some issues: the fist problem we came across was that the omni wheel maybe inherently too slippery and can sometime just not move the robot but spin in place. To solve this drawback, we may consider to use a grippier material like, for example, Thermoplastic Polyurethane which has been also proposed by Bruton, 2021. A further improvement concerns how the gears attach to the steel rod and the motors shaft: here we may design a fastener that could use a nut and bolt to lock onto the shaft.

The next step of this work should include the exploration for integrating other low-cost computational features into the robot (Isherwood, 2022) as well as the design and integration of end-user interfaces and techniques in order to make this device very user-friendly and adaptable to daily life tasks (Chu, 2022; Ormazabal, 2022).

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5. REFERENCES

Bruton J, 2021a. Are Ball Shaped Wheels Practical?. [online] Youtube.com. Available at: <https://www.youtube.com/watch?v=rHDCIng0Wak&ab_channel=JamesBruton> [Accessed 3 March 2021].

Bruton J, 2021b. Testing Ball-Shaped Wheels on an Omni-Directional Robot. [online] Youtube.com. Available at: <https://www.youtube.com/watch?v=zKLMCO0-How&ab_channel=JamesBruton> [Accessed 3 March 2021].

Chu TS, Chua AY, Secco EL, A Study on Neuro Fuzzy Algorithm Implementation on BCI-UAV Control Systems, ASEAN Engineering Journal (AEJ), 2022

Chu TS, Chua AY, Secco EL, A Wearable MYO Gesture Armband Controlling Sphero BB-8 Robot, HighTech and Innovation Journal, 1(4), 179-186, 2020, http://dx.doi.org/10.28991/HIJ-2020-01-04-05

Components101.com. 2021. L298N Dual H-Bridge Motor Driver. [online] Available at: <https://components101.com/sites/default/files/component_datasheet/L298N-Motor-Driver-Datasheet.pdf> [Accessed 4 April 2021].

Gimsonrobotics.co.uk. 2021. 18V DC Fuhong Motor RS550PH-6235F 550 Cordless Tool - Gimson Robotics | The linear actuator and electric motor specialist. [online] Available at: <https://gimsonrobotics.co.uk/categories/dc-electric-motors/products/18v-dc-fuhong-motor-rs550ph-6235f-550-cordless-tool> [Accessed 6 May 2021].

Innes M, Secco EL, Design of an interactive BB8-like Robot, 7th International Congress on Information and Communication Technology (ICICT 2022)

Isherwood Z, Secco EL, A Raspberry Pi computer vision system for self-driving cars, Computing Conference 2022

Manolescu VD, Secco EL, Design of an Assistive Low-Cost 6 d.o.f. Robotic Arm with Gripper, 7th International Congress on Information and Communication Technology (ICICT 2022)

Ormazabal M, Secco EL, A low-cost EMG Graphical User Interface controller for robotic hand, Future Technologies Conference (FTC 2021), Lecture Notes in Networks and Systems, 2, 459-475, 2021, Springer

Secco EL, McHugh DD, Buckley N, A CNN-based Computer Vision Interface for Prosthetics' application, EAI MobiHealth 2021 - 10th EAI International Conference on Wireless Mobile Communication and Healthcare

Youtube.com. 2021. This Forklift Moves In Any Direction!. [online] Available at: <https://www.youtube.com/watch?v=0DBXuZv38l8&ab_channel=Futurism> [Accessed 6 June 2021].

Youtube.com. 2021. onmi wheel. [online] Available at: <https://www.youtube.com/watch?v=BTp2UAaihaI&ab_channel=ikinamo> [Accessed 3 February 2021].