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Research paper

Development of a Holonomic Transmission Module for Service Robot

Muhammad Fairuz Abdul Jalal [1]*, Dhiviandran Chadaran[1], Khairul Salleh Mohamed Sahari[1]

Department of Mechanical Engineering, College of Engineering, Universiti Tenaga Nasional,
Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
**Corresponding author E-mail: mfairuz@uniten.edu.my*

Abstract

The paper presents the development of transmission module for service robot by utilizing the holonomic drive system. Thorough study was done on existing research and all the relevant technical information was reviewed. The analysis on existing transmission module design was made and all the mechanical improvement was made. All the problems were identified and proper solution made. New designs of parts and the development of control module were done. This includes replacement of critical parts such as mounting brackets and drawer for the housing of the transmission module developed. Important mechanical analysis such as motor selection, force analysis, and FEA was made. The final design is analyzed and modelled using commercial software. The control module of robot was designed and developed, involving usage of Arduino IDE, software for programming Arduino controller. Analysis on the transmission module made was to validate the module developed, including workability of the developed mechanical parts, and the omnidirectional drive system. The project was aimed to be the base of the service robot, therefore the robot was tested and the results obtained were discussed.

Keywords: *holonomic, service robot, transmission module.*

1. Introduction

The service robots are usually used for guidance, assistance and performing house chores. The developments of service robots are helpful especially among aging and disabled people. The insufficient number of caregivers has made service robots to replace the place [1].
Advancements of information technology has enabled the integration of both robotic and information technologies to create a home service robot. ISAAC is a home service robot which is equipped with voice-based information services, home security, vacuum cleaning, remotely controlling house appliances and telepresence by mobile communication. The controller was made a CAN-based controller distributed on networks. The experimentation on the serviceability was done in real home environment and was a success [2].
The home service robots are mostly utilized for assisting elderly. The interaction between the robot and the seniors is a considered one of the important area to be studied and explored. Pripfl et al [3] studied the effectiveness of using HOBBIT, an autonomous mobile social service robot to assist the seniors. The novelty lies in the HOBBIT ability to detect emergency automatically and handle the emergencies by the means of calling the relatives for instance. It turned out, the elderly users were happy with HOBBIT’s ability of picking objects, transporting objects, emergency recognition and reminding ability. It was concluded the intuition handling and the functions of HOBBIT actually met the elder user’s needs [3].
Developing a service robot for blind community requires participatory design approach involving both blind (target users) and non-blind parties (designers and visually impaired). The new approach to collaboratively design the specifications of the building service robot proposed by had been proven a success [4]. This collaborative method can be used in further development of the service robot being developed. The solution was to make the robot to detect and approach users. The robot was suggested to guide the user to desired destination through mainstream pathway. It was expected to provide verbal feedback to users upon reaching obstacles and return to the designated area upon request [5].
User interface is an important factor for service robot control and operation. Controlling such robots remotely is the most fundamental issue to be solved. This technology is assumed to produce a flexible, effectual and intuitive human-robot interaction. Touch input devices like iPad are an opportunity for the development of most effective human-robot interfaces for serving the elders [7].
Controlling service robots with minimal practical approach is a challenge addressed. One such method, tele-operating, can be very challenging, as the operator must carry out two separates task simultaneously, monitor the sensors bandwidth and commanding. Compared to field service robot, personal service robot can be in or out of the view of operator. Previous studies showed that video-gamers skills can be applied in controlling robot. Upon test, the highest collision occurred at doorways in manual control mode. Semi-manual control witnessed fewer collisions. The limitations of manually operating the robot are expected to be overcome by semi-manual operation. It was determined that houses have multiple obstacles are not suggested for unexperienced robot operators but the problem may be solved by inducing more autonomous functions to the robot [8].
Developing a cheap robot using Arduino, 3D printed prototype and modified servo motors for faster continuous rotation was achieved and was adopted into this project [9].

As robots are mobile, the motion also plays a role to impress humans. The impression helps to maintain the robot's service quality. The motion was expected to impress human positively if it is closer to human's motion. The assessment was done using semantic differential (SD) method and proven that normative motion induced positive impression on subjects [10].

Any Omni-directional robots fitted with Mecanum/Omni wheels needs to be programmed to achieve multi motion characteristics and intelligence. The four motors of the prototype were driven by integrating a four channel MOSFET and relay H-Bridge into a driving circuit. Optical mice were selected for navigation and position feedbacks. The microcontroller chosen was the M16C/62 for the programming of the robots actions. The 3-DOF motion was made using three PID controllers and it was proven a similar project can be carried out with limited budget [11].

2. Design of Service Robot Module

Figure 1 shows the general flowchart of this research. The research began with thorough analysis of existing robot and continued to finalizing the engineering requirements. With reference to the requirements developed, improvised final design was modeled and eventually finalized. Next, the research continued with installation of components, programming of robot and concluded with tests to validate the motive of research.

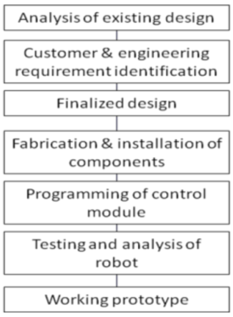

Fig.1: The flowchart of research

2.1. Design requirements

The first prototype has been developed, but requires certain design improvements. Initially, the prototype was only a structure with preinstalled motors and omniwheels. However, modification and improvement are needed so that the transmission module able to transverse smoothly.

Figure 2 shows the final 3D CAD model of the improved robot. It features new custom-made 90-degree slot, mounting bracket and drawer kit. The 90-degree slot features two holes as seen in Figure 3. The holes purposes are to accommodate fastener and house the linear guide rail for drawer assembly.

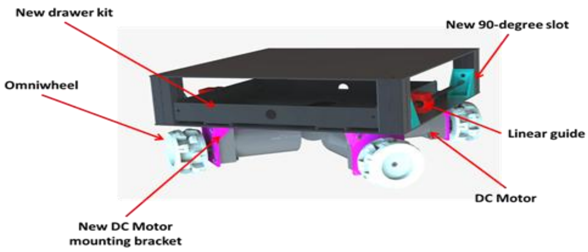

Fig.2: The overall assembly of holonomic transmission module

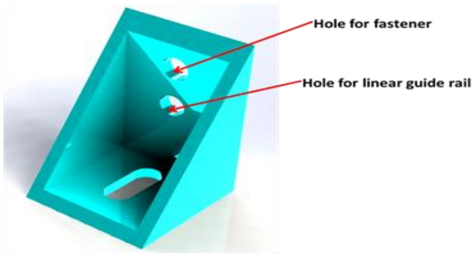

Fig.3: New 90-degree slot

The existing robot base was analysed and the problems identified to some components led to proposal of new designs. Components such as DC motor mounting bracket, 90-degree slot and drawer for module housing was analysed and new designs were produced and fabricated. Figure 4 shows some of the identified problems through visual inspection.

Fig.4: Visual inspection on the existing prototype: Crack at fastening area (left), crack at mounting point of motor shaft (centre), short support for motor body (third from left) and small drawer for control module housing.

The new design requirement is summarised be as seen in Table 1.

Table 1: Summary of requirements for new design

Criteria	Description
DC Motor Mounting	Increase thickness of the new bracket at critical area, especially angular section of the design. Use Aluminium 6061 as the material for fabrication due to the higher strength and manufacturability. Provide extrusion for support of motor body to reduce the swaying impact of motor on the bracket. Increase extrusion width to house the motor circular body. Make a curved design to hold the circular shape of motor. Thicker extrusion to able to absorb the swing of motor.
Drawer	Increase the storage capacity of the drawer by increasing the physical dimensions of new design providing larger volume. Design new drawer that can be slide out in two directions in a single axis Increase the size of holes to accommodate the passage of wires. Aluminium 6061 as material of choice to able to support the heavy mass of batteries and other electronic components.
Control module	Wireless operation of robot. Holonomic mobility for the robot to allow mobility in 3 DOF, therefore easy to move in any building.

2.2. Holonomic transmission module

The robot features 4 Omniwheels which provides holonomic motion. Holonomic motion is aided with the different direction of rotation of motor/wheel or same direction of rotation simultaneously. Figure 5 illustrates the basic motions of the holonomic robot developed.

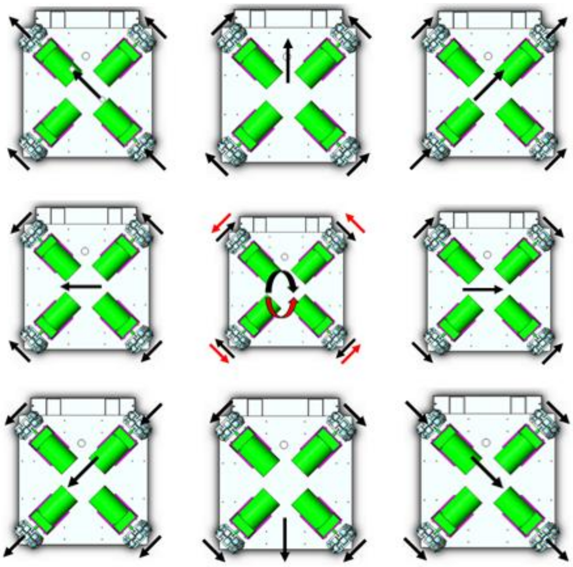

Fig.5: Basic holonomic motion

The directions of motion of robot and linear direction of the wheels are shown for ease of understanding. These motions are basics for any omnidirectional robots. The red marker indicates direction of wheels in a counter-clockwise motion.

2.3. Retractable drawer design

As per requirement, the drawer must be able to be drawn out in two directions on a single axis as seen in Figure 6. This is to allow good accessibility to the maintenance of components in the drawer. The illustration of drawer motion is shown below. Such design will risk disconnections of wire during the sliding motion; therefore proper room for wires to pass through was made. Any disconnection of important wires may result failure of holonomic motion of robot. Increased in size and mass of the drawer will result in tilting if it is fully drawn out, therefore support bar will be added to prevent the tilt as shown in Figure 7.

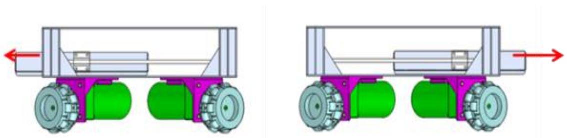

Fig.6: Drawer drawn to left side and right side (two way accessibility)

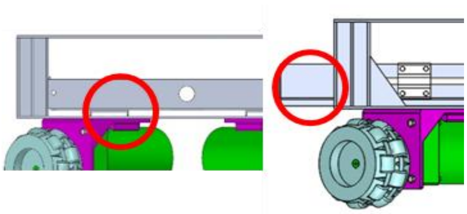

Fig.7: Support plate front view (left), support bar when drawn out (right)

2.4. Control module

The electronic parts was modelled as Figure 8. The control of robot was done using joystick Arduino module, for the purpose of validation of the holonomic motion.

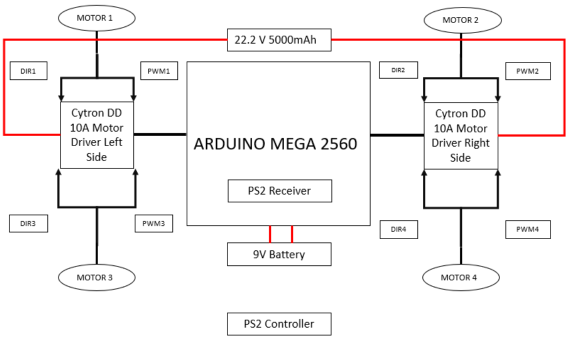

Fig8: Illustration of the control module

Arduino Mega was selected for the control module and to control voltage supplied to the motor, MDD10A motor driver was selected. MDD10A is suitable for high current demanding motors and it had dual channel, therefore easier to control 4 DC motors with two motor drivers as shown in Figure 9.

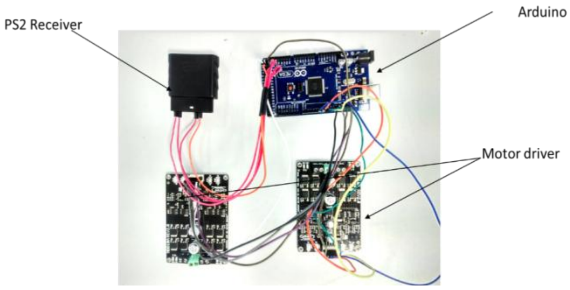

Fig.9: Final circuit of control module

3. Results and Discussions

3.1. Bracket stress analysis

The mounting bracket is a critical component in the robot. The robot weighs 30 kilograms without the upper structure. Adding the upper structure will increase the mass of robot up to 60-100 kilograms, approximately 590-980N. This indicates, each bracket will have to bear at least 150N of force. The Figure 10 shows the free body diagram of single mounting bracket and the assembly of mounting bracket to robot.

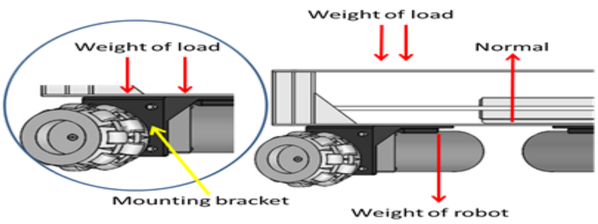

Fig.10: Load illustration on robot

The simulation was made with applied load of 200N on the each bracket. Aluminium 6061 was assigned for the study. The material has ultimate strength of 275MPa. Based on the simulation result as shown in Figure 10, the maximum Von Mises stress applied on the bracket was 46.13MPa.

Therefore, the safety factor obtained was 5.96. It is deduced that, the bracket can withstand 5.96 times of the applied load of 200N. Practically, the full robot should not exceed 100 kilograms therefore, the bracket design is safe.

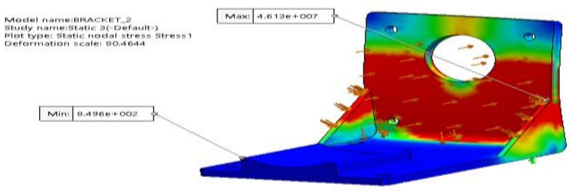

Fig.11: Simulation of stress analysis on mounting bracket

3.2. Kinematics of robot

The kinematics of the robot is modelled to determine the characteristics of each omniwheel. The analysis was made to determine the speed of motors. It was determined using inverse kinematics method [12], [13]. In order to determine the speeds, ω_z is assumed zero. ω_1, ω_2, $\omega_3$and ω_4 was determined theoretically using the inverse kinematics equation. The result was plotted as seen in Figure 13 and Figure 14.

$$\alpha = \tan^{-1}(\frac{Vx}{Vy}) \tag{1}$$

$$Vr = \sqrt{Vx^2 + Vy^2} \tag{2}$$

$$\omega 1 = \frac{1}{r}(V_y + V_x - (l_x + l_y)\omega z) \tag{3}$$

$$\omega 2 = \frac{1}{r}(V_y - V_x - (l_x + l_y)\omega z) \tag{4}$$

$$\omega 3 = \frac{1}{r}(V_y - V_x + (l_x + l_y)\omega z) \tag{5}$$

$$\omega 4 = \frac{1}{r}(V_y + V_x + (l_x + l_y)\omega z) \tag{6}$$

Table 2: Results of kinematics analysis of Omniwheels (refer to Fig.12 for the velocity profile)

Direction of robot	Vr (m/s)	Vx (m/s)	Vy (m/s)	ωz (rad/s)	ω1 (rpm)	ω2 (rpm)	ω3 (rpm)	ω4 (rpm)
Forward	0.5	0.0	0.5	0.0	10.0	10.0	10.0	10.0
Reverse	0.5	0.0	-0.5	0.0	-10.0	-10.0	-10.0	-10.0
Left	0.5	-0.5	0.0	0.0	-10.0	10.0	10.0	-10.0
Right	0.5	0.5	0.0	0.0	10.0	-10.0	-10.0	10.0
Forward left	0.5	-0.35	0.35	0.0	0.0	14.1	14.1	0.0
Forward right	0.5	0.35	0.35	0.0	14.1	0.0	0.0	14.1
Reverse left	0.5	-0.35	-0.35	0.0	-14.1	0.0	0.0	-14.1
Reverse right	0.5	0.35	-0.35	0.0	0.0	-14.1	-14.1	0.0

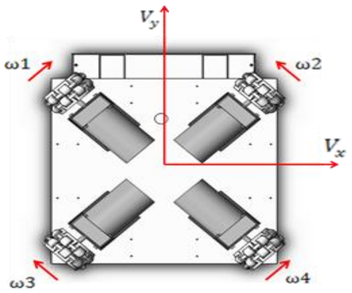

Fig.12: Velocity profile of robot

In order to determine velocity in x and y direction, initial resultant velocity was assumed to the right side, which is V_x=0.2m/s. The following Equations 1-2 are used to calculate the angle between vector velocities and to determine the resultant velocities V_r. V_x and V_y need to be determined to obtain the individual speeds of motors. Equations 3-6 are used to determine the speeds of motor. The speeds obtained are tabulated in Table 2. The resultant velocity was fixed at 0.5m/s for any direction of motion as seen in Table 2. It has to be noted that the positive and negative directions indicate the direction of rotation. It is also noticed that, maximum rotation of motors obtained in the diagonal directions namely, forward left, forward right, reverse left and reverse right. This is true in the case of a holonomic robot, as in these directions, only 2 motors are rotating. The diagonal movement indicates α = 45 degrees. Therefore, inverse of the angle gives ratio of V_y and V_x as one. The obtained values are 0.353m/s for both V_y and V_x [12].
The directions of wheel rotation in basic and diagonal motion are shown in Figure 13 and 14 accordingly.

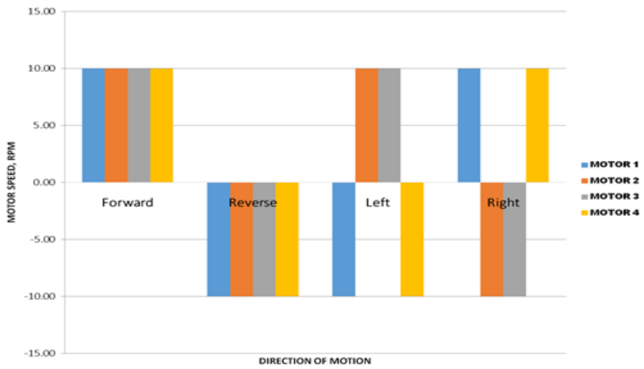

Fig.13: Motor speed direction for basic motion

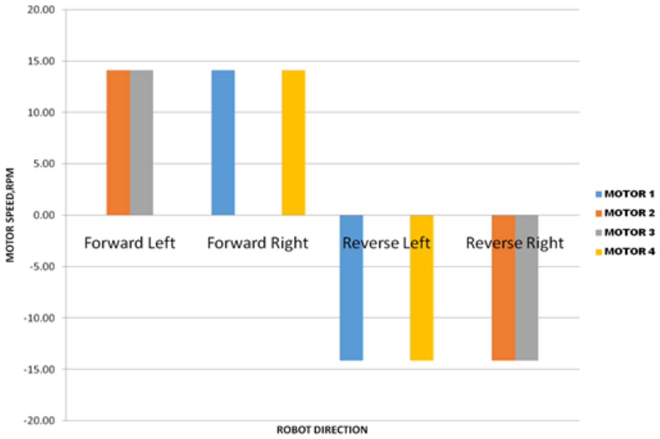

Fig.14: Motor speed direction for diagonal motion

3.3. Load analysis

The estimated mass of the robot structure is 30kg. This robot required 4 motors to be assembled to the 0.1m diameter omniwheel. Selecting the right motor is important to allow optimum mobility for the robot. A load analysis was made to determine the maximum and minimum force required to initiate movement of robot on an inclined surface. Figure 15 illustrate free body diagram of the analysis.

$$F_{required} = F_{gravivty} + F_{friction} + F_{drag} \quad (7)$$

$$F_d = \frac{1}{2} \times \rho \times U^2 \times C_d \times A \times \cos\theta \quad (8)$$

$$F_g = mgsin\theta \quad (9)$$

$$\mathrm{F}_r = C_r W cos\,\theta \quad (10)$$

$$\frac{\mathrm{T}}{r} - \mathrm{F}_r\text{-}F_d - F_g = ma \quad (11)$$

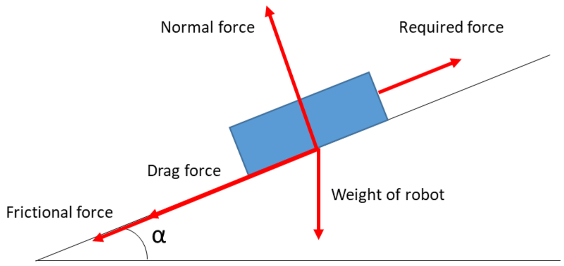

Fig.15: Free body diagram of robot

The result from load analysis is as shown in Figure 16. Maximum force required was 324N while minimum force calculated was 176N. The minimum total torque required was 8.8Nm at 0 degrees inclination and maximum torque required was 16.2Nm at 8 degrees inclination. This indicates each motor required 2-4Nm of torque to initiate movement.

The motor selected has rated torque of 7.8Nm, therefore, it is safe. The effective minimum safety factor of motor is 1.95, therefore the maximum load can be applied for the motor is 1.95 times of original mass, approximately 58 kilograms.

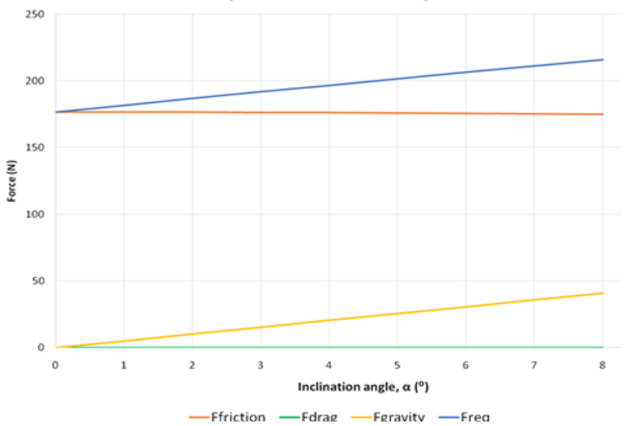

Fig.16: Graph of forces against angle of inclination

3.4. Holonomic motion testing

The robot features 4WD omniwheel robot configuration. This means the robot will be able to manoeuvre in holonomic motion. This test was conducted to prove the code developed for the robot as well as to prove the alignment and wheel configuration of robot. A simple set up was made as shown in Figure 17. The setup measures 1.8m by 1.8m in dimension. Red tape was selected to obtain clear image and video evidences during testing.

Fig.17: Set up to show holonomic motion of robot

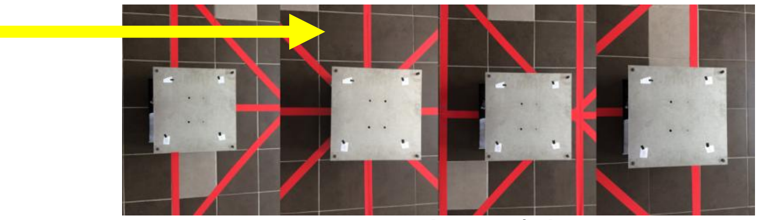

Fig.18: Forward motion of robot

The robot was able to move in a straight line or forward direction. Alternatively, reverse direction of robot was also obtained in a straight line.

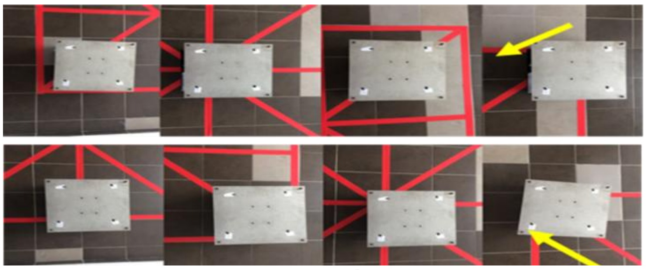

Fig.19: Diagonal motion

All diagonal motion was tested and the robot was able to move in those directions, both diagonal left and diagonal right directions.

3.5. Load test

Service robot may be as heavy as a full-size adult human (approximately 50-100kg); hence the load test was conducted to determine the relationship between applied load and the time taken to reach a fixed distance of 1.8m. This test was compared with robot with no load and applied load and the time taken to reach the desired destination.

Fig.20: Load test set up

The test was conducted to determine whether the increased load slows down the robot motion in the set up shown in Figure 20. It was found that with the load of 30kg on top of the robot, the motion was still available but has slow down, due to increased work done. Due to limitation of resources for the load test, a maximum of 30kg of load was applied for the test and the results are as seen in Table 3.

Table 3: Results of load test

Time taken with no load	Time taken with 15kg load	Time taken with 30kg load
16 seconds	14.3 seconds	13.2 seconds
The test was conducted with a set up measuring 1.8m and the time taken for the robot to reach end point was measured using stopwatch		

It is concluded that, more load applied to the robot, the speed decreases, but the high torque of the motor has given the robot an ability to carry more load but travel at low velocities.

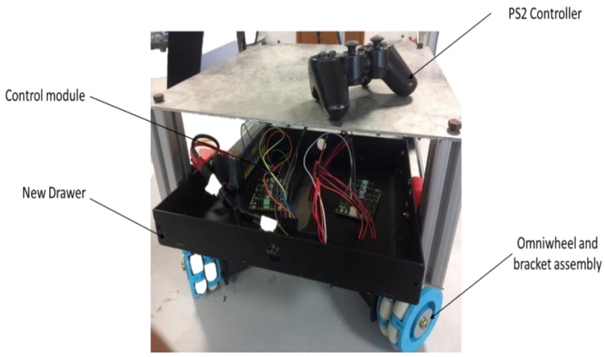

Fig.21: Final prototype

4. Conclusions

Overall the existing design was analyzed and the research gap was fulfilled. The research was done on the existing designs. Initially, the previous robot was lack of control module and was not entirely completed in terms of construction. It was a prototype therefore; certain parts such as mounting bracket for DC motor and 90-degree slot were not fabricated with proper material. Some of the parts was cracked and needed to be replaced. All the possible causes of the damages were identified in the early stage of the project. The identified causes were used for helping the development of engineering requirement for the new parts. All the resources gathered aided in the development of transmission module for the robot.

The development of the module commenced. This was particularly challenging as several inspections and measurement surveying was done before beginning the design of parts. This is to ensure that the robot will be precise after the installation of newly developed parts. Furthermore, the robot used omniwheel for its locomotion. Omniwheels are commonly used to provide holonomic motion and is very suitable in developing a home service robot. Finally, all the newly designed parts are analyzed and simulated to determine the safety factor and to obtain the final 3D model.

Proper engineering analysis was made in developing the robot and validating it. This includes kinematic analysis and static analyses. The analysis was used to determine the maximum torque of the pre-installed DC motors. The kinematic analysis was used to prove the theory of holonomic drive system.

Programming the robot was a challenging task. It required serious electrical and electronic skills to fulfill the project objective. Suitable motor drivers, battery supply and microcontroller were selected to be installed in the robot.

Finally, the validation of the transmission module developed was made and tested with simple experiments. Transmission module developed was valid and further research can be done to improve the workability of the robot.

Acknowledgement

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