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# Design and Development of Spherical Robot for Lab Analysis and Testing Applications

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**Abstract**— Spherical robots, sometimes regarded as polar robots, are stationary robot arms with spherical or near-spherical work envelopes that can be positioned in a polar coordinate system. So, these robots are more sophisticated than Cartesian and cylindrical robots, while control solutions are less complicated than those of articulated robot arms. This may be the reason why sometimes they are used as a base for robot kinematics exercises. Also, it should be noted that spherical robot type takes a significant spot in robot history, as some of the first robot arms can be counted into this type. Modern industrial robot arms kind of evolved from spherical robots and are sometimes regarded as this type, as their work envelope often is sphere-like as well. Polar Robots, or spherical robots, have an arm with two rotary joints and one linear joint connected to a base with a twisting joint. The axes of the robot work together to form a polar coordinate, which allows the robot to have a spherical work envelope. Polar Robots are credited as one of the first types of industrial robots to ever be developed. Polar robots are commonly used for die casting, injection molding, welding, and material handling & in medical field for Lab analysis & testing.

**Index Terms**— Aduino Mirocontroller, Stanford Arm, Unimate, 3D Printring, Python, OpenCV, Polar Robots

## 1 Introduction

The spherical robots' structure is the one you can see at the left side of this picture. As you can see, it has two rotary joints and one linear. Thus, a spherical work envelope is formed. Of course, it is not a sphere, but reachable places can still be calculated in a polar coordinate system.

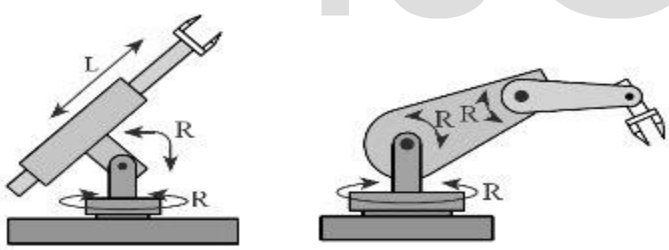


Figure 1: Structure of Spherical Robot

As you can understand, there can be more than three joints. However, these three are the basic ones that form the work envelope. Further joints would add more flexibility, but wouldn't radically change the reachable area. For example, if the gripper could rotate, this would be a 4-axis robot while the work envelope wouldn't change at all.

A robot with an R-R-R structure with three rotary joints can be seen at the right side of the above picture. As you understand, robots of this kind have a near-spherical work envelope. Most modern industrial robots are derivatives of this type.

**Spherical Coordinate System**

In mathematics, a spherical coordinate system is a coordinate system for three-dimensional space where the position of a point is specified by three numbers: the radial distance of that point from a fixed origin, its polar angle measured from a fixed zenith direction, and the azimuth angle of its orthogonal projection on a reference plane that passes through the origin and is orthogonal to the zenith, measured from a fixed reference direction on that plane. The radial distance is also called the radius or radial coordinate. The polar angle may be called colatitude, zenith angle, normal angle, or inclination angle.

### 1.1 THE STANFORD ARM

The Stanford arm was designed in 1969 by Victor Scheinman who at the time was a student working at the Stanford Artificial Intelligence Lab - SAIL. The arm has five rotary joints and one linear joint. The mechanical structure is the same I discussed above plus three rotary joints. The arm is all-electric, it had DC motors with potentiometers for position feedback and analog tachometers for velocity feedback. Also, it can be regarded as one of the first robots designed specifically for computer control. It seems needless to say as you probably understand it already - the Stanford arm is significant as it helped to form the knowledge base about robot control, we use today.

### 1.2 UNIMATE

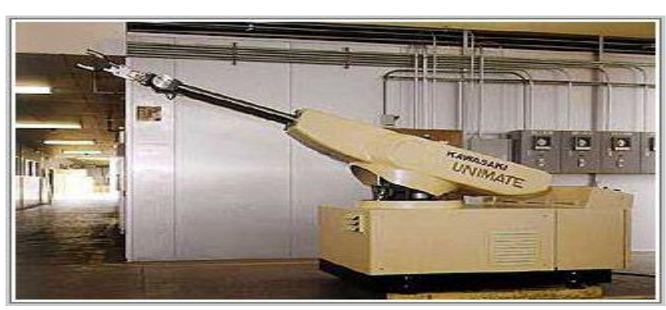

Figure 2: Unimate

Unimate is another historical spherical manipulator. It is widely regarded as the first industrial robot. In 1961 first Unimate began its work at General Motors. At the beginning, it was used for die casting and spot welding as these applications proved to be financially beneficial. This success spawned the industrial robot industry as we know it today. It featured hydraulic drive and could execute commands stored on a magnetic drum. Unimate, cherished by George Devol and Joe Engelberger, was manufactured by the first industrial robot company - Unimation. Another interesting twist of fate took place in 1977. In that year Unimation acquired Victor Scheinman's company - Vicarm. Using this new knowledge that originated from the Stanford arm project they designed Unimate PUMA. In 1989 Unimation was acquired by Stäubli. As you see this type of robot arms is quite important because of its place in history. However, nowadays you won't see many of them actually being used, as articulated (anthropomorphic) robot arms are more flexible, and the software and hardware development allows us to use them with remarkable results.

Spherical coordinate geometry is a scheme for guiding a robot arm in three dimensions. A spherical coordinate system is something like the polar system, but with two angles instead of one. In addition to the two angles, there is a radius coordinate.

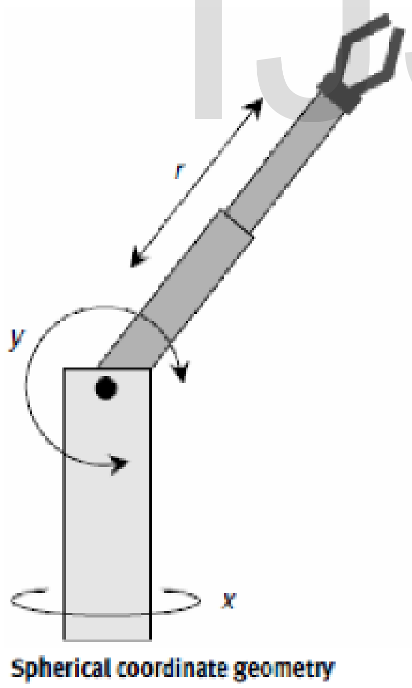


Figure 3: Spherical Coordinate Geometry

One angle, call it x, is measured counterclockwise from the reference axis. The value of x can range from 0° to 360°. You might think of x as similar to the azimuth bearing used by astronomers and navigators, except that it is measured counterclockwise rather than clockwise. As a ray rotates around a full circle through all possible values of x, it defines a reference plane.

The second angle, call it y, is measured either upward or downward from the reference plane. The value of y will ideally range from 90° (straight down) to +90° (straight up). Structural limitations of the robot arm might limit the lower end of this range to something like 70°. You might think of y as the elevation above or below the horizon.

The radius, denoted r, is a non-negative real number (zero or greater). It can be specified in units such as centimeters, millimeters, or inches.

The illustration shows a robot arm equipped for spherical coordinate geometry. The movements x, y, and rare called base rotation, elevation, and reach, respectively.

## 2 METHODOLOGY

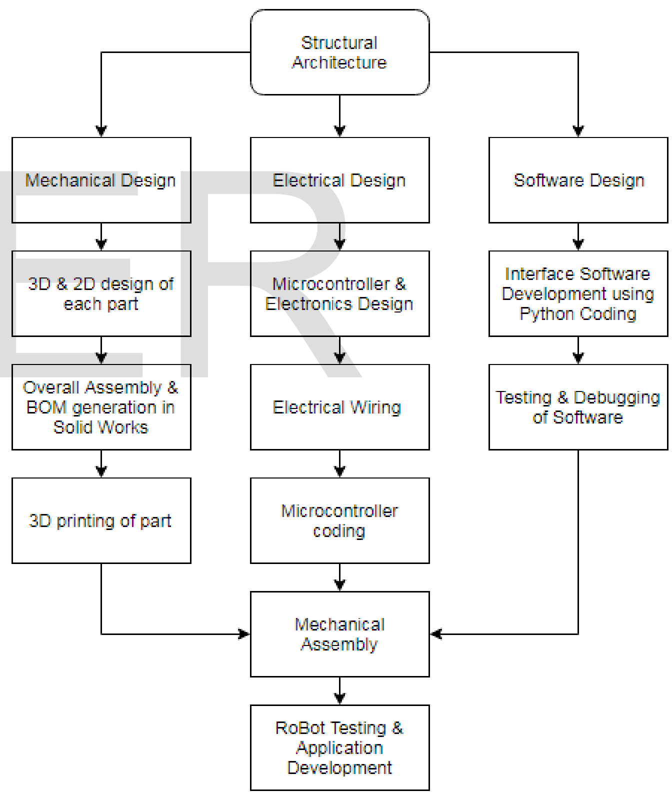


Figure 4: Methodology

### 2.1 DESIGN OF THE ROBOT

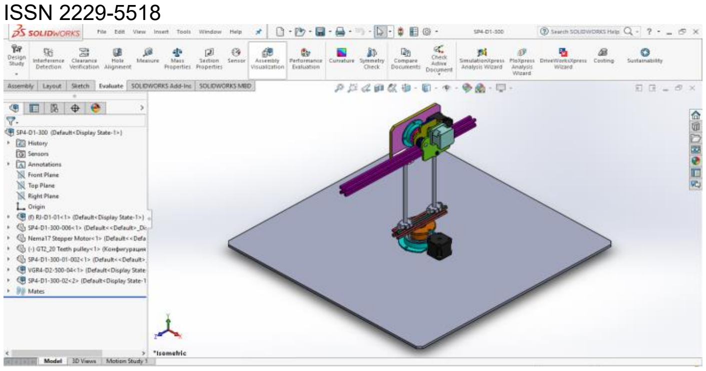

Figure 5: Assembly

1.Manufacturing of parts using 3D printer.
2.Assembling of parts after manufacturing.
3.Electrical wiring and introduction of microcontrollers.
4.Coding and programming.
5.Python programming using OPEN CV library.
6.Testing of the robot.

## 2.2 ARDUINO MEGA MICROCONTROLLER BOARD

Arduino is open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It is intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.

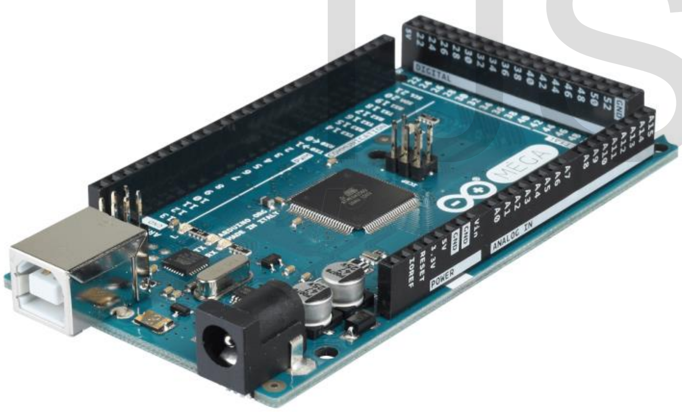

Figure 6: Arduino Microcontroller Board

When cheaper boards are available, why go with Arduino Mega? The main reason behind this is the additional features that are inbuilt with this board. First feature is the large I/O system design with inbuilt 16 analog transducers and 54 digital transducers that supports with USART and other communication modes. Secondly, it has inbuilt RTC and other features like analog comparator, advanced timer, interrupt for controller wakeup mechanism to save more power and fast speed with 16 Mhz crystal clock to get 16 MIBS. It has more than 5 pins for Vcc and Gnd to connect other devices to Arduino Mega.
Other features include JTAG support for programming, debugging and troubleshooting. With large FLASH memory and SRAM, this board can handle large system program with ease. It is also compatible with the different type of boards like high-level signal (5V) or low-level signal (3.3V) with I/O ref pin.
Brownout and watchdog help to make the system more reliable and robust. It supports ICSP as well as USB microcontroller programming with PC.
The Arduino Mega 2560 is a replacement of the old Arduino Mega, and so in general reference, it will be called without the '2560' extension. Due to the many numbers of pins, it is not usually used for common projects but you can find them in much more complex ones like Radon detectors, 3D printers, temperature sensing, IOT applications, real-time data monitoring applications etc.

## 2.3 DESIGN CLACULATIONS

### A. PULLEY CALCULATION

Torque: T=FD/2ηi
Where F: force
D: diameter of pulley
i:gear ratio
η:effeciency of motor
Problem:
Given D=12.22mm
T=280mm

280=(FX12.22)/2=**45.82N**
Load Carrying capacity **4.67kg**

Velocity:
P=Fv/1000
where, F in Newton, v in m/s and P in kW
Note: Here P is rated motor power.
**v =625.4mm/s**

### B. ROTARY AXIS-1 (BOTTOM) CALCULATION

**<u>Speed Ratio</u>**

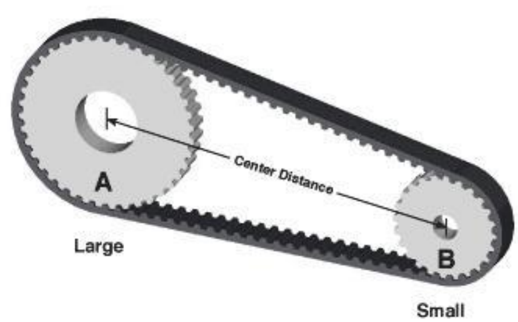


Figure 7: Belt Drive

Large Pulley (A) No of Teeth = 60
Small Pulley (B) No of Teeth = 20
Pitch Diameter - Large Pulley (A) = 38.2mm

Pitch Diameter - Small Pulley (B) = 12.7mm

**Speed Ratio** = 38.2/12.7 = ~3.008

**Torque Increase at Large Pulley** = 280Nmm *3.008 = 842.24Nmm=85.86Kgmm
Note*: G280Nmm = Torque of Stepper Motor is given by Manufacturer

#### C. ROTARY AXIS-2 (TOP) CALCULATION

**Speed Ratio**

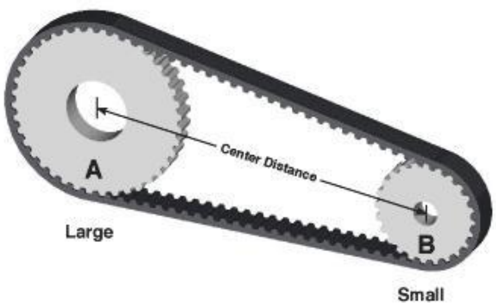


Figure 8: Belt Drive

Large Pulley (A) No of Teeth = 80
Small Pulley (B) No of Teeth = 20
Pitch Diameter - Large Pulley (A) = 50.9mm
Pitch Diameter - Small Pulley (B) = 12.7mm

**Speed Ratio** = 50.9/12.7 = ~4.008

**Torque Increase at Large Pulley** = 280Nmm *4.008 = 1122.24Nmm =114.4kgmm

Note*: G280Nmm = Torque of Stepper Motor is given by Manufacturer.

## 4 RELATED WORKS

1. Design Analysis of a Remote Controlled "Pick and Place" Robotic Vehicle by B.O. Omijeh

In this paper the design of a Remote-Controlled Robotic Vehicle has been completed. A prototype was built and confirmed functional. This system would make it easier for man to unrivalled the risk of handling suspicious objects which could be hazardous in its present environment and workplace. Complex and complicated duties would be achieved faster and more accurately with this design.[01]

2. Robotics Arm Control Using Haptic Technology by Vipul J. Gohil

In this paper the system robotic arm based on real-world haptics. The primary goals of haptic guidance is to facilitate the learning of complex human motion skills by providing haptic cues that are helpful to induce desired movements. The proposed system is utilized to recognize the human motion, Large potential for applications in critical fields as well as for leisurely pleasures. Haptic devices must be smaller so that they are lighter, simpler and easier to use. Haptic technology allows interactivity in real-time with virtual objects.[02]

3. A Review on Robot Arm Using Haptic Technology by Prof. A. Reshamwala, R. Singh

In this paper the proposed system is utilized to recognize the human motion. Controlling the robot arm using Haptic technology is discussed in this paper. The concept which is discussed here will be the implementation of 3-DOF based robot arm using a smaller number of resources. The main focus of the implementation is going to be how it will be easily operated by disable people. As literature survey continues more advanced feature may be part of this implementation such as obstacle detection and how the concept of image processing will be used in robot arm is considered to be future work.[03]

4. Design and Operation Of Synchronized Robotic Arm by Goldy Katal, Saahil Gupt

In this paper propose the robotic arm can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. For example, robot arms in automotive assembly line perform a variety of tasks such as wielding and parts rotation and placement during assembly. The robotic arm can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. For example, robot arms in automotive assembly line perform a variety of tasks such as wielding and parts rotation and placement during assembly.[04]

5. Design of a Robotic Arm for Picking and Placing an Object Controlled Using LabVIEW by Shyam R. Nair

In this paper propose of LabVIEW controlled robotic arm was successfully designed. The robotic arm was found to be user friendly and the integration of accelerometer was much helpful in attaining the feedback regarding the position of the arm. The LabVIEW is designed to input the coordinates of object in the real time environment. To select the real time object, the corresponding coordinate is inputted. The action of picking or placing is also given through the LabVIEW panel. Once the robot gets the coordinates, it uses the inverse kinematics to calculate the required rotation.[05]

6. Design and Implementation of a Robotic Arm Based on Haptic Technology by A. Rama Krishna

In this paper propose of various aspects to design a robotic arm based on the haptic technology considering various aspects of it, and the basics of machine designing are observed that are explained clearly. These robots have a wide range of industrial and medical applications such as pick and place robots, surgical robots etc. They can be employed in places where precision and accuracy are required. Robots can also be employed where human hand cannot penetrate. The screen shot shows the designed robot and its functionality.[06]

7. Haptic Control Development of Robotic Arm by Mohamoud A. Hussein

In this paper propose a master-slave system with haptic features, especially force feedback, was implemented. This system has a device to measure force when the slave system interacts with virtual model and actuators devices in the master system to exert force on the operator. A position and force control system were developed, creating a bilateral communication between the master and the slave devices. A robotic arm, inverse kinematic model and control was developed using LabVIEW and Arduino. LabVIEW was used to acquire position and force signal from Novint Falcon then send it to robotic arm. Arduino was used to calculate the IK model to evaluate the joint angles of the robot arm. The correct position of the end effector with respect to the base was achieved using the joint angles. The performance of the system is characterized using human input for soft tissues of different stiffness and the results show that system has the ability to display the interaction force effectively.[07]

8. Design of a Robotic Arm with Gripper & End Effector for Spot Welding by Puran Singh

In this paper propose of this robotic technology makes the spot-welding operation more flexible and time oriented. With the help of pick and place mechanism the material handling has been easily carried out. The variation in the mechanical structure and the angle of movement can be changeable. The human hand design forms the basis of this project of developing a robotic gripper and is the source of inspiration to achieve the sufficient level of dexterity in the domain of grasping and manipulation if coupled with wrist and arm.[08]

9. Design and Analysis of an Articulated Robot Arm for Various Industrial applications by S. Pachaiyappan

Using basic formulae from strength of materials. Two possible hollow cross sections, considering the electrical, control and feedback wiring to pass through, is modelled using commercially available 3D modelling tool, SOLIDWORKS, for further study and comparison. The Model is used for analysis using a commercially available analysis tool, ANSYS, taking into account the various critical loads acting on the base arm alone. Since the base arm is the major component in which maximum magnitude of the critical loads considered occur, it is enough to analyze the base arm alone. Considering the shapes, sizes, deflections during working and stresses occurring, both the are workable comparatively. Considering the manufacturability, ease of transport, assembly, and weight, the circular section are preferred over the rectangular section.[09]

10. Design and Development of Search and Rescue Robot by Khalil Azha Mohd Annuar, Muhammad Haikal Md Zi

In this paper propose of Based on this research works, this paper presented the design and development of a robotic vehicle controlled by using mobile devices with additional of a four DOF robotic arm robot as assistive robot for search and rescue mission. This system is presented with the Graphical User Interface (GUI) to ease users' utilization.[10]

11. Survey of Robotic Arm and Parameters by Ritu Tiwari

Based on this research works discussed robotic arm and their different parameters. Understand which factor affect the performance of a robotic arm and how it changes a robotic arm in work efficient arm. Know how multiple axis uses to change the mass of an arm, DOF increased by simply by adding joints, working envelope and space should decide according to the situation, kinematics improved movement of the robot, speed and acceleration vary in different works, accuracy and repeatability is the important factor for any robotic arm. Also, use diagrams for making proper understanding of robotic arm. Then discussed gaps in research and issues, its use as a guideline for future research work, at last give suggestions how we try to improve a robotic arm by working on effective algorithms and simulations.[11]

## 4 RESULTS AND CONCLUSION

### 4.1 RESULTS:

All the results of direct kinematics, inverse kinematics are tested and positioning is analyzed. These joints can be utilized to select the proper step motor for each link. They also can be used for programming the required controllers of the robot. 3Dof freedom is used in this robot as shown below,

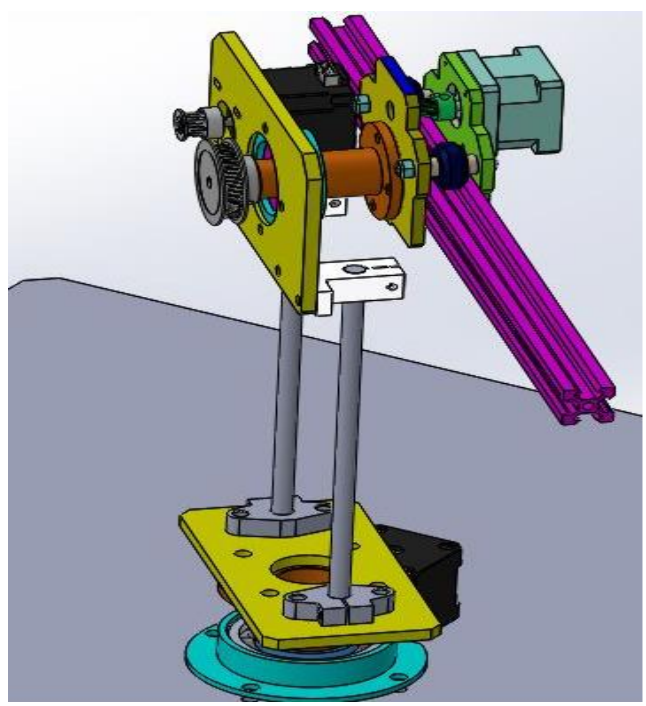

Figure 9: Spherical Robot 3D Model

The Vertical Axis (Z axis) is rotate according to the flange, itis used to rotate by the motor is connected to the flange by belt below the base plate for the Cylindrical axis. A DC motor will rotate the flange accordingly in clockwise and anticlockwise direction using GT2 280 belt drive.

Horizontal axis (linear axis) is mounting on Z-axis Plates at the top using MS Flange and acrylic plate which is rotated similarly as z Axis rotation, over these plates an Aluminum profile in linear-axis by belt using DC Motor, at the end of the aluminum profile a gripper which holds the picking objects and places accordingly. For controlling of all these three axes and a vacuum gripper, python-based control software is used and programmed according to the task to be perform.

### 4.2 CONCLUSION:

This study on robot arms was fulfilled to get enough material on how to design robot arm for specific needs. After, comparing and benchmarking industrial different robot arms, we came out with the right design for my project. The inverse kinematics equations were a bit tricky to solve. Moreover, the algorithms challenge was in the sequence of execution of the steps that will avoid trouble making while moving objects.

The project of designing, constructing, and controlling a spherical robot ended with success. It required a great deal of knowledge from many fields of science, and all of the encountered issues were resolved. The mechanical design was chosen so that the robot could be characterized by multiple degrees of freedom and was able to immediately change its direction of movement.

Spherical robotic arm was developed using Stepper Motor open-loop control system to carry out tasks where the usage of electric components can be also introduced the research and development of such a system with low cost. It is becoming possible to apply industrial robots to tasks that cannot do repeatedly and thus rely heavily on human workers. The design of the Robot employed Open loop control using a microcontroller and Stepper Motors provided precise and improved control of the joint angle with high accuracy & very good performance.

## 5 ACKNOWLEDGMENT

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**10.** Design and Development of Search and Rescue Robot by Khalil Azha Mohd Annuar, Muhammad Haikalmdzi. (International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS Vol:16 No:02)

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