International Journal of Science and Engineering Applications
Volume 12-Issue 11, 26 – 35, 2023, ISSN:- 2319 - 7560
DOI: 10.7753/IJSEA1211.1008

A Comprehensive Study on Optimized Mechanical and Kinematic Design for Holonomic Drive Rugby Ball Kicking and Passing Robots

Rutvik Mehenge
Department of Mechanical Engineering
Trinity College of Engineering & Research
Pune, India

Niket Satoskar
Department of Electronics and Telecommunications
Padre Conceicao College of Engineering, Verna
Goa, India

Madhav Mokashi
Department of Mechanical Engineering
Vishwakarma Institute of Technology
Pune, India

Batta Soumith
Department of Aerospace Engineering
Indian Institute of Technology Kanpur
Kanpur, India

Abstract: This paper presents a detailed exposition of the hardware design and kinematic analysis of two specialized robotic systems, MR1 and MR2, engineered explicitly for the purpose of passing and kicking Rugby balls. Employing the advanced holonomic omnidirectional drive, both robots are meticulously scrutinized in terms of their kinematic characteristics. The passing robot is equipped with a pneumatic system, enabling it to precisely lift and pass rugby balls up to a designated distance of 2.5 meters. Conversely, the kicking robot employs a sophisticated motor-powered spring-loaded mechanism, generating a formidable force of 8.41 N. This force is adeptly harnessed to kick the rugby ball horizontally for a distance of 5 meters and vertically for 1.5 meters. The study delves into the intricacies of the electronic control system, encompassing motion planning and the meticulous orchestration of omnidirectional wheels. These wheels serve as the neural epicenter for the swift movements of the robots and are precisely controlled by Arduino Mega 2560 microcontroller boards integrated with EMS 30A H-Bridge drivers and motor controllers. The study provides a foundation for future research and development in the field of robotic sports technology, specifically in the realm of replicating human sports activities through robotic ingenuity.

Keywords: Kinematic Analysis, Omnidirectional Drive, Passing Robot, Kicking Robot, Pneumatic, Arduino Mega 2560.

1. INTRODUCTION

In the field of technological study, the mechanical replication of human sports activities is a priceless tool for expanding the design of improved athletic goods and honing the abilities of players. Due to the inherent variety among human kickers, studying kicking tactics within the context of rugby is a significant problem. Humans are naturally unable to maintain the fine control required to control elements like foot placement, pace, and precise point of contact with the ball over a series of kicks. Innovative approaches are required to overcome this fundamental constraint and promote reliable and controlled experimentation.

This study paper examines the painstaking design and execution of two robots made expressly for the purpose of passing and kicking rugby balls with astounding uniformity, duplicating the performance levels displayed by professional rugby kickers. These robots provide an unmatched opportunity to investigate the complex mechanics, kinematics, and dynamics behind the skill of place-kicking a rugby ball since they consistently perform at a level that human athletes are unable to match. These robots' design and operating settings are thoroughly discussed, enlightening the scientific community on the procedure used to ensure accuracy and dependability in mimicking human sporting motions.

Reviewing sports robots suggests two major areas of use. Research in general robotics, which covers kinematics, routing, obstacle avoidance, detection of objects, and manipulation, is the first and largest area. Here, autonomous soccer robot contests like Robocup are frequently used as benchmarks for measuring the progress of humanoid robots [1]. Examples of humanoid robots include the Qrio [2], and Nao [3] models. Additionally, there are batting arms [4], pool-playing robots [5], and martial arts robots [6]. These robots are all powered by electric motors, which makes them all incredibly feeble and slowly moving [7].

For testing and research in sports, there is a second, smaller category of sports robots. In this case, creating powerful mechanical machines is more important than creating humanoid robots. According to Holmes et al. [8], a mechanical kicking machine for soccer and rugby balls, Adidas is funding additional studies in this field [9]. Roboleg, a robotic soccer ball-kicking leg, was created to evaluate soccer footwear and balls utilizing spring-loaded actuators [10]. However, due to issues with the control system, Roboleg was abandoned as a test robot [10].

The aim of this research is to meticulously design two distinct robotic entities, denoted as MR1 and MR2, tailored for specific functions within the realm of rugby gameplay. MR1 serves as a passing robot, while MR2 is engineered as a Kicking robot, both possessing the capability to execute consistent and powerful kicks akin to those demonstrated by seasoned professional rugby kickers. This paper critically examines the collaborative synergy between these two robots, elucidating their coordinated efforts in passing the rugby ball from MR1 to MR2 and subsequently executing a successful kick over the crossbar of the conversion post.

An omnidirectional robot platform that uses a holonomic approach for precise robot movement is used in this investigation. It offers an omnidirectional three-wheel design for MR1 and a four-wheel design for MR2 to boost the mobility of the pass and kick robots and enable them to move in any direction and with any orientation [11-12]. The holonomic wheels on the robot allow it to travel in any direction, doing away with the need for a conventional drive mechanism. Even the kinematic model features an Omni-wheel drive that has been modified to fit the robot's size. Refer to Figure 1 for an illustration of the Omni wheel, which is differentially powered by the DC motor. With less friction and additional motion, this arrangement enables the robots to move in any direction [13]. The robot's movement will be more effective because of the reduced friction. Additionally, while the robot is moving at a high speed, its wheels can move more dynamically [14].

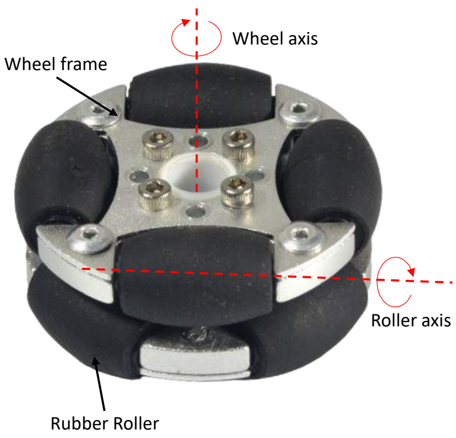


Figure 1: Omni Wheel

2. DESIGN OF RUGBY PASSING ROBOT (MR1)

The primary objective of the MR1 Rugby passing robot is to adeptly pick up a rugby ball positioned on a tee and accurately pass it to the MR2 Kicking robot, covering a distance of 2.5 meters. The foundational structure of the robot is constructed using equilateral truncated triangular elements, meticulously welded from hollow box sections of Aluminium 6061. This structural framework provides robustness and stability to the robot during its operational tasks. Additionally, the MR1 robot is outfitted with a specialized mobility system comprising three-wheel holonomic omnidirectional wheels. These wheels enable the robot to move seamlessly in various directions without the need for complex maneuvers, ensuring precise and efficient ball handling. The subsequent sections delineate the intricate components of the MR1 robot, providing detailed insights into its design and functionality.

2.1 Design of Omni-directional Platform

In the realm of omnidirectional mobile platform design, a multitude of options exist for configuring wheel assemblies. A fundamental criterion for such configurations is the necessity for the layout to facilitate sufficient constrained motions of the assemblies, ensuring both omnidirectional translation and rotation of the platform. Crucially, the stability of the platform must be maintained regardless of the internal arrangement of the assemblies, including which wheel within each assembly makes contact with the ground. To achieve a platform endowed with three full degrees of freedom and devoid of kinematic redundancy, the simplest layout mandates three assemblies. When positioned at the apexes of a triangular framework, this arrangement not only ensures effortless platform load stability but also establishes a 120-degree orientation relationship between the three constrained motion directions, thereby conferring exceptional directional control capability.

The MR1 robot, integral to this study, adopts a truncated triangular structure and employs a three-wheel drive configuration, a choice motivated by its superior maneuverability and straightforward control mechanism. These wheels are of a specific type featuring small rollers, allowing them unrestricted movement in any direction [15]. Their primary motion occurs along the diameter, akin to conventional wheels. However, the presence of smaller rollers on the periphery permits free rotation orthogonal to the powered rotation. The omni wheels are actuated by three DC motors, each intricately coupled to omni wheels positioned at angles of 120 degrees apart. The representative coordinates of the robot, according to the inverse kinematics model, were in its centre [16]. Refer to Figure 2 which depicts a three-wheeled omnidirectional robot with a schematic view.

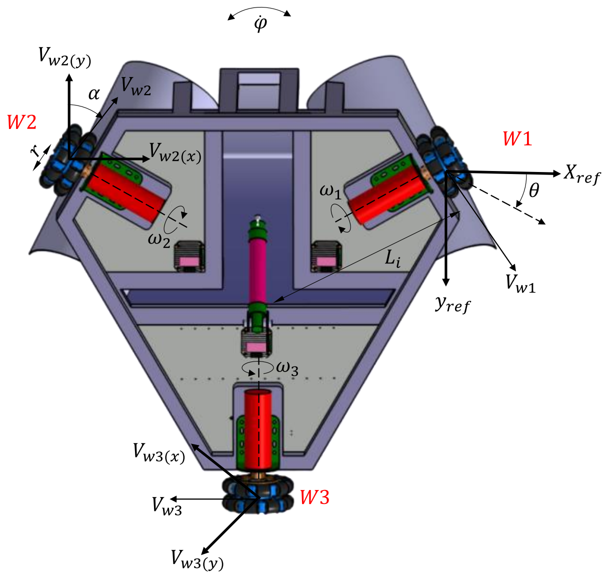


Figure 2: Three-wheel omnidirectional robot schematic view

The arrows with the numbers 1, 2, and 3 on them represent the constrained directions of movement of each assembly in the schematic Figure 2. Let φ represent angular velocity (in rad/s) of the platform's internal reference frames (X_{ref}, Y_{ref}) with regard to an absolute reference frame (x, y). Platform translational velocity is indicated by the letter $|V|$ and θ, where $|V|$ stands for the platform's magnitude (in m/s) and θ stands for the platform's direction (relative to the internal reference frame). These conventions allow for the following computation of the driving shaft velocities of the wheels, ω_i (in rad/s):

$$\omega_1 = \frac{|V|}{2R}\left(\sin\theta - \sqrt{3}\ \cos\theta\right) + \frac{\varphi L_1}{R} \quad (1)$$

$$\omega_2 = -\frac{|V|}{R}\sin\theta + \frac{\varphi L_1}{R} \quad (2)$$

$$\omega_3 = \frac{|V|}{2R}\left(\sin\theta + \sqrt{3}\,\cos\theta\right) + \frac{\varphi L_3}{R} \tag{3}$$

The distance between the platform's center and the center of the wheel of the is represented by L, while R denotes the circular wheels' radius. The translational velocity $|V|$ projections on the constrained movement directions of each assembly are shown by the first terms on the right-hand side of equations (1) through (3). The final terms stand in for the platform's rotational velocity-related components. The above equations can be slightly changed to show the one-to-one relationship between the joint and Cartesian velocities, which is essential for teleoperation and odometry calculations: if we put

$$V_x = |V|\cos\theta \tag{4}$$

$$V_y = |V|\sin\theta \tag{5}$$

Equations (1) through (3) may be expressed as:

$$(\omega_1, \omega_2, \omega_3)^T = A(V_x, V_y, \varphi)^T \tag{6}$$

$$A = \frac{1}{R}\begin{Bmatrix} -\sqrt{3}/2 & 1/2 & L_1 \\ 0 & -1 & L_2 \\ \sqrt{3}/2 & 1/2 & L_3 \end{Bmatrix} \tag{7}$$

Since the length L_1, L_2, L_3 are positive values and A is invertible and its inverse matrix i.e., A^{-1} is given by:

$$A^{-1} = \frac{R}{L_1 + L_2 + L_3}\cdot$$

$$\begin{Bmatrix} \frac{(-2L_3 - L_2)}{\sqrt{3}} & \frac{(L_1 - L_3)}{\sqrt{3}} & \frac{(2L_1 + L_2)}{\sqrt{3}} \\ L_2 & (-L_1 - L_3) & L_2 \\ 1 & 1 & 1 \end{Bmatrix} \tag{8}$$

$$(V_x, V_y, \varphi)^T = A^{-1}\cdot(\omega_1, \omega_2, \omega_3)^T \tag{9}$$

It is evident from the kinematic relationship equations above that the rotational and translational motions are completely dissociated and can be controlled separately and at the same time, hence making the three-wheeled holonomic omnidirectional drive suitable for a Rugby passing robot movement.

2.2 Design of Rugby Passing Mechanism

The primary function of the passing robot in this study entails executing two sequential tasks: firstly, picking the rugby ball from the tee, and subsequently, delivering the ball to the kicking robot. The designated throwing distance for this task is 2.5 meters. To accomplish the passing action, a sophisticated system has been devised, encompassing two distinct components. The robot platform is equipped with a throwing arm featuring grippers, actuated by a pneumatic cylinder, thereby enabling precise ball handling. Refer to Figure 3 for the schematic design of the MR1 robot.

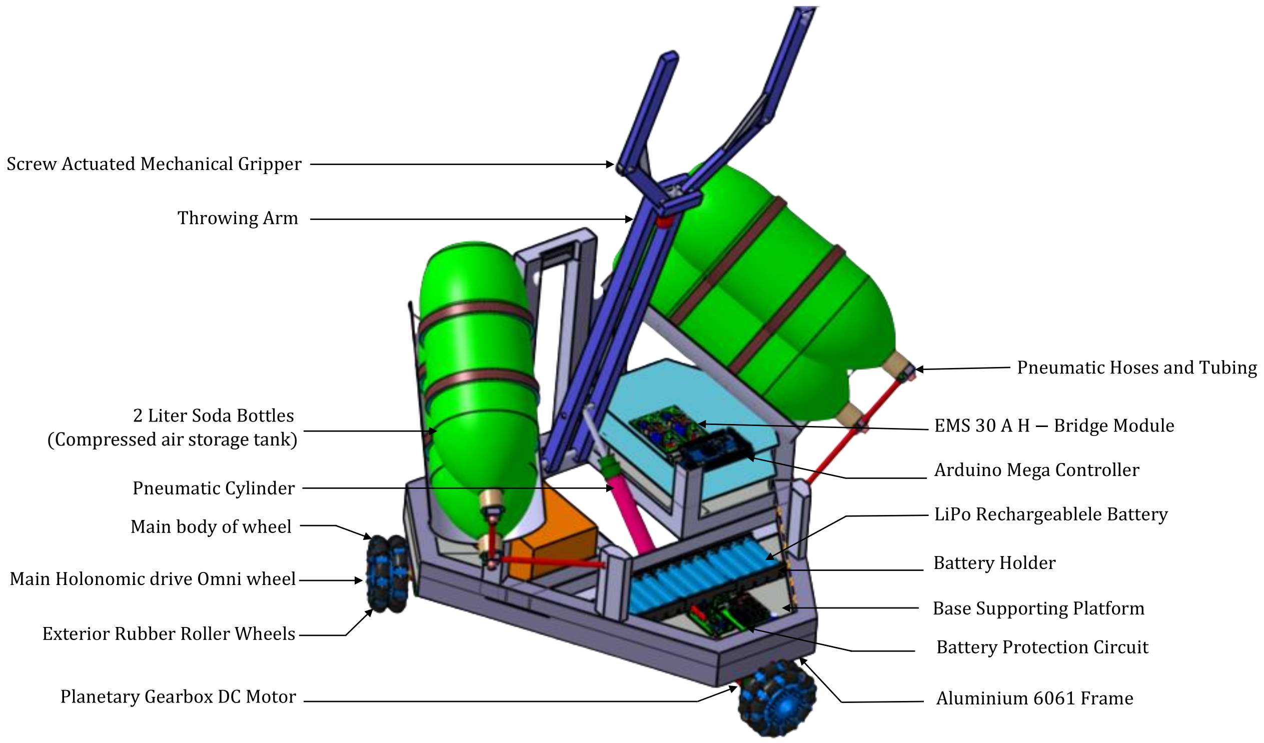


Figure 3: Three-wheeled holonomic passing robot design (MR1)

The mechanism employed for picking up the rugby ball involves a pivotal throwing arm architecture, hinged at the base of the robot platform and activated by a pneumatic air cylinder. The arm integrates a screw-actuated mechanical gripper positioned at its distal end. This gripper utilizes a screw connected to a threaded block, driven by a motor in conjunction with a speed reduction device. Rotation of the screw in one direction causes the threaded block to move correspondingly, opening or closing the gripper fingers. This screw-type actuated gripper facilitates the firm grip required to lift the rugby ball from the tee. The screw operates via a high torque 12V DC Geared motor, rotating at 300rpm and generating 3.5kgcm torque. Notably, this mechanism allows precise control of the gripper's clamping position, ensuring swift and accurate ball handling, thus optimizing efficiency.

The mechanical arm's primary function is to elevate the rugby ball from the tee using the gripper mechanism and subsequently propel it. The ball's throwing action is regulated by a pneumatic air cylinder pivotally attached to the lower end of the throwing arm. This pneumatic system, with a stroke length of 100mm and a bore diameter of 63mm, operates on the principle of pressure differentials within the cylinder. The rise in internal pressure propels the piston, which, in turn, transmits force to the object being moved. To sustain continuous operation, the robot incorporates four two-liter soda bottles, each capable of storing 100 pounds per square inch of air pressure or 6.89 bars [17]. With a total of 24 bars of air pressure across the four bottles, the system can execute eight consecutive throws of the rugby ball. To maintain consistency in performance, a pressure regulator is integrated throughout the mechanisms, ensuring stability and repeatability of results.

The potential energy (PE) stored in the compressed air cylinder at 3 bars of pressure is calculated using equation 10 as 93.6 Joules. Considering the mass of the rugby ball (0.3 kg) and the desired throwing distance (2.5 meters), the required linear acceleration (a) is determined to be 124.8 m/s², calculated by equation 11. This acceleration necessitates a torque of 1.3464 Nm using equation 12, derived from the given angular acceleration and the length of the throwing arm (60 cm) using equation 13, where I is moment of Inertia of throwing arm. Consequently, Formula 13 can be used to determine the angular force (F_a) necessary to generate a specific torque (T) about a pivot point. The computed angular force from equation 14 is of 2.244 N is needed to move the rugby ball the predetermined distance to the MR2 kicking robot. Refer to Figure 4 for a visual representation of the throwing arm's movement, from ball pickup to release.

$$PE = Pressure \times Volume$$

i.e.

$$PE = Pressure \times \left\{\pi \cdot \left(\frac{Bore\ Diameter}{2}\right)^2 \cdot Stroke\right\} \quad (10)$$

$$a = \frac{PE}{mass \cdot distance} \quad (11)$$

$$T = I \times \alpha \quad (12)$$

$$\alpha = \frac{a}{arm\ length} \quad (13)$$

$$F_a = \frac{T}{arm\ length} \quad (14)$$

3. DESIGN OF RUGBY KICKING ROBOT (MR2)

The MR2 Rugby kicking robot is designed with dual primary objectives: firstly, to accurately place the rugby ball at the designated try spot, where it has been previously passed by the passing robot MR1, and subsequently, to initiate the kicking action. The successful execution of the kicking action necessitates propelling the rugby ball over the crossbar of the conversion post. This crossbar, situated at a vertical height of 1.5 meters, is positioned 5 meters away from the try spot. For a goal to be achieved, the rugby ball must travel both a horizontal distance of 5 meters and a vertical distance of 1.5 meters.

The foundational structure of the MR2 robot is meticulously crafted, employing a rectangular-shaped base constructed from hollow box sections of Mild steel. The square hollow box section measures 19.81mm x 19.81mm with a thickness of

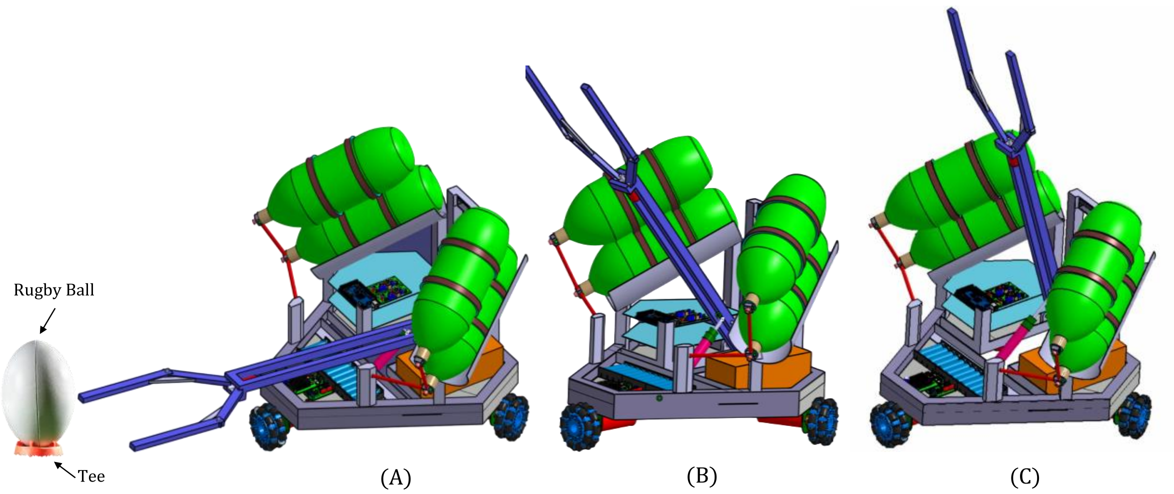


Figure 4: (A) Represent throwing arm picking rugby ball; (B, C) represent the throwing arm movement for rugby passing operation

2mm. This choice of Mild steel, owing to its inherent properties, ensures the creation of an efficient frame characterized by uniform weight distribution. Mild steel, known for its commendable shock-absorbing capacity relative to other metals available in the market, imparts strength and stability to the robot's base. This structural foundation is paramount, conferring robustness and steadfastness to the robot during its operational endeavours.

Furthermore, the MR2 robot is equipped with a specialized mobility system, integrating four-wheel holonomic omnidirectional wheels. The selection of a four-wheel drive system is underpinned by its superior maneuverability and straightforward control mechanism. These wheels are meticulously engineered to facilitate seamless movement in diverse directions, eliminating the need for intricate maneuvers. This design ensures precise and efficient execution of ball-kicking tasks. The subsequent sections of this paper delve into the intricate components of the MR2 robot, providing comprehensive insights into its meticulous design and seamless functionality.

3.1 Design of Omni-directional Platform: Inverse Kinematic Analysis

Wheel assembly configuration choices abound in the field of omnidirectional mobile platform architecture. The requirement that the arrangement enable sufficient confined motions of the assemblies, ensuring both omnidirectional translation and rotation of the platform, is a fundamental requirement for such systems. The MR2 robot has four wheels that are attached to the rectangular base's corners. These wheels can move freely in any direction since they belong to a particular type with tiny rollers. Three DC motors, each intricately connected to omni wheels, drive the omni wheels. According to the inverse kinematics model, the robot's center included its representative coordinates. Refer to Figure 5, which shows a schematic view of a four-wheeled omnidirectional robot.

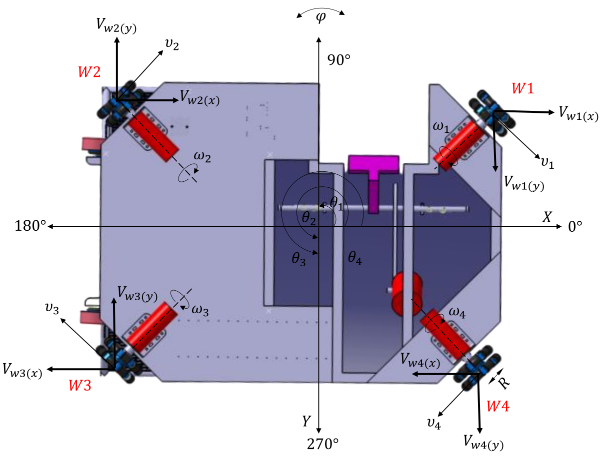


Figure 5: Schematic diagram of a four-wheeled omnidirectional robot

Kinematic modeling constitutes a fundamental aspect of robotics research, involving the analysis of robot motion through a geometric examination of stationary or moving reference coordinate frames, excluding considerations of forces, torques, or specific moments causing movement [18]. In the realm of omni-directional robots, the positioning of Omni wheels plays a pivotal role in shaping the kinematic model. Within the domain of robotic kinematic modeling, two essential models come into play: inverse kinematics and forward kinematics. Inverse kinematics are instrumental in calculating the linear velocity of the four omni wheels, whereas forward kinematics are utilized to ascertain the linear velocity of the robot in relation to global coordinates [19].

The kicking robot, denoted as MR2, is equipped with a configuration comprising four omni wheels. The angles formed between these wheels and the robot's reference point are represented by θ_i i.e., $\theta_1, \theta_2, \theta_3, \theta_4$ along the X-axis. Each wheel's angular velocity is symbolized as ω_i represented by $\omega_1, \omega_2, \omega_3, \omega_4$ and their translational velocities are denoted as υ_i, defined as $\upsilon_1, \upsilon_2, \upsilon_3, \upsilon_4$. Refer to the schematic design showing the configuration of the omnidirectional robot base.

Equations (15) and (16) can be used to express the translational velocity for each wheel.

$$\upsilon_i = \sin(\theta_i)\upsilon_x + \cos(\theta_i)\,\upsilon_y + R\alpha \tag{15}$$

$$\upsilon_i = \omega_i \cdot R \tag{16}$$

Where R is the omni-wheel's radius, υ_x is the MR2 robot's translational speed along the X-axis, and the translational velocity on the Y-axis is given by the expression υ_y. The angle created by the robot's orientation is given by α. The angular speed for each motor can be obtained from equation (17) by utilizing equation (15) and performing the inverse kinematics on equation (16).

$$\omega_i = \frac{1}{R}\left(\sin(\theta_i)\upsilon_x + \cos(\theta_i)\,\upsilon_y + R\alpha\right) \tag{17}$$

Equation (18) can be used to give the inverse kinematics equation for every wheel derived from equation (17).

$$\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_3\\ \omega_4\end{bmatrix} = \frac{1}{R}\begin{bmatrix}\sin(\theta_1) & \cos(\theta_1) & R\\ \sin(\theta_2) & \cos(\theta_2) & R\\ \sin(\theta_3) & \cos(\theta_3) & R\\ \sin(\theta_4) & \cos(\theta_4) & R\end{bmatrix}\begin{bmatrix}\upsilon_x\\ \upsilon_y\\ \alpha\end{bmatrix} \tag{18}$$

3.2 Design of Rugby Kicking Mechanism

The passing robot in this study is designed to execute sequential tasks: first, receiving the ball from the MR1 Passing robot, where a square-based basket structure is employed. This basket contains a gate that opens upon command, allowing the ball to roll into the designated try spot. The basket features a slope-like structure inclined at 40 degrees, guiding the ball precisely over the extruded glide pathway to the try or kicking zone. The gate operation is controlled by a DC motor using a rack and pinion arrangement. When the motor shaft rotates, it drives the pinion, which, in contact with the rack, converts circular motion to linear motion, facilitating the opening and closing of the gate, refer to Figure 6.

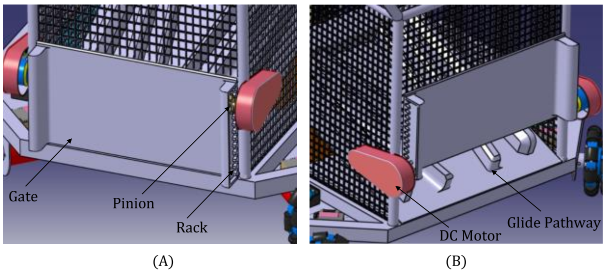


Figure 6: DC motor-powered gate opening and closing system, (A) gate closed (B) gate open

Once the ball is positioned on the ground, the robot aligns itself to initiate the kicking action. For successful kicking, the rugby ball must travel a horizontal distance of 5 meters and a vertical distance of 1.5 meters, clearing the crossbar of the conversion post.

The kicking mechanism involves a sophisticated setup featuring a kicking leg actuated by a combination of springs and motors, ensuring precise ball handling. Specifically, a kicking leg equipped with four springs, known as a four-spring-loaded kicking leg, is utilized. Refer to Figure 7 for the schematic design of the MR2 robot. Positioned at a height of 50 cm and pivoted at the upper point from the robot base, this kicking leg is actuated by a DC planetary geared motor. The motor lifts the kicking leg at an angle of 170 degrees, allowing the springs to stretch. The potential energy stored in the stretched springs is converted into kinetic energy when the springs are released, propelling the ball. The precise movement of the kicking leg is facilitated by a high-torque DC planetary geared motor with a stall torque of 23.55 kg cm. After being kicked, the ball follows a projectile motion, achieving a height of 1.5 meters and covering a total horizontal distance of 5 meters, passing through the conversion post with accuracy. To calculate the required force for kicking the ball 5 meters horizontally and 1.5 meters vertically, as well as determine the spring stiffness, the principle of conservation of energy is applied. The potential energy stored in the stretched springs is converted into kinetic energy in the rugby ball. The calculated spring stiffness is 5.466 N/m using equation 19. The horizontal distance (d) travelled by the ball is calculated as 6.523 meters using equation 20. The potential energy stored in the spring is then determined as 6.523 J using formula 21, and the required kicking force is calculated as 8.41 N using equation 22. It was observed from equation 21 that the spring compression (x) is high, necessitating the use of four consecutive springs for optimization. Refer to Figure 8, illustrating the schematic design of the ball kicking operation.

$$k = \frac{Gd^4}{8D^3N} \tag{19}$$

Where D is the diameter of the spring coil (m), d is the diameter of the spring wire(m), N is the number of turns and G is the Modulus of Rigidity (Pa).

$$d = \frac{v^2 \sin(2\theta)}{g} \tag{20}$$

d is the horizontal distance in (m), v is the initial velocity of the ball in (m/s), θ is the angle at which the ball is kicked (in radians) and g is the acceleration brought on by gravity (about $9.81\ m/s^2$).

$$PE = \frac{1}{2}\,kx^2$$

Were, (21)

$$x\sqrt{d\cdot\frac{2}{k}}$$

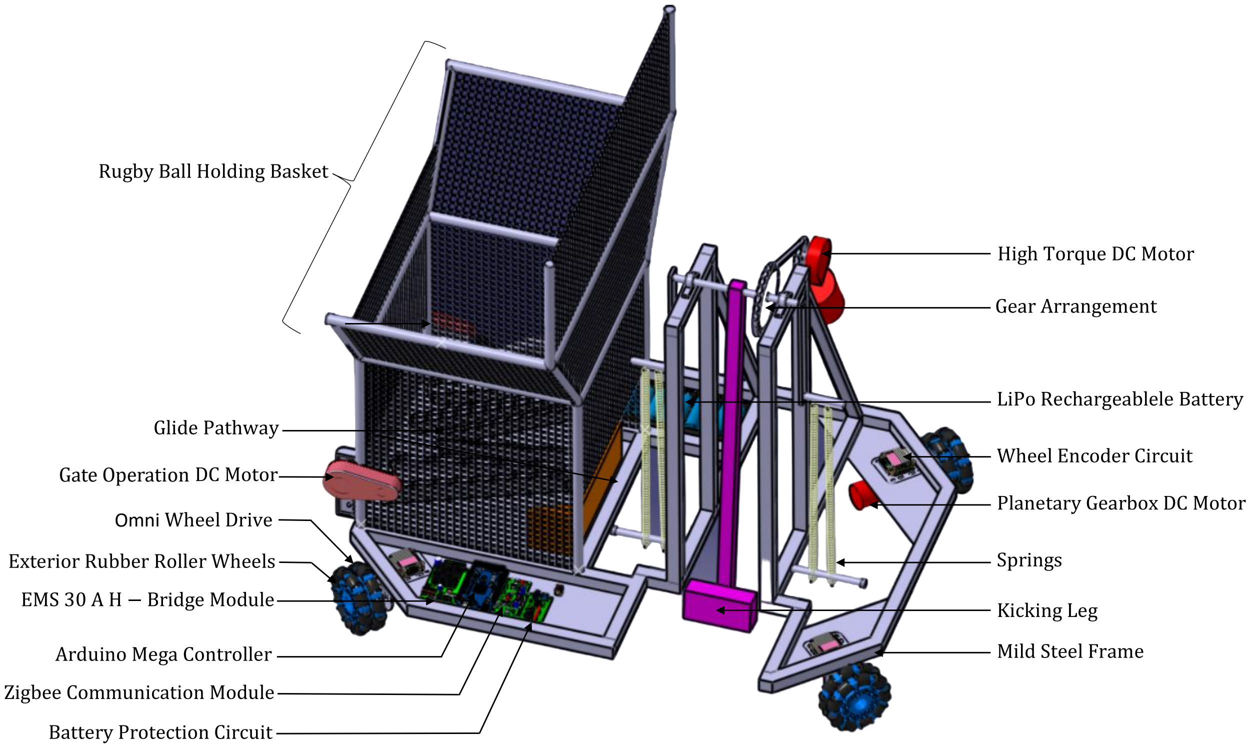
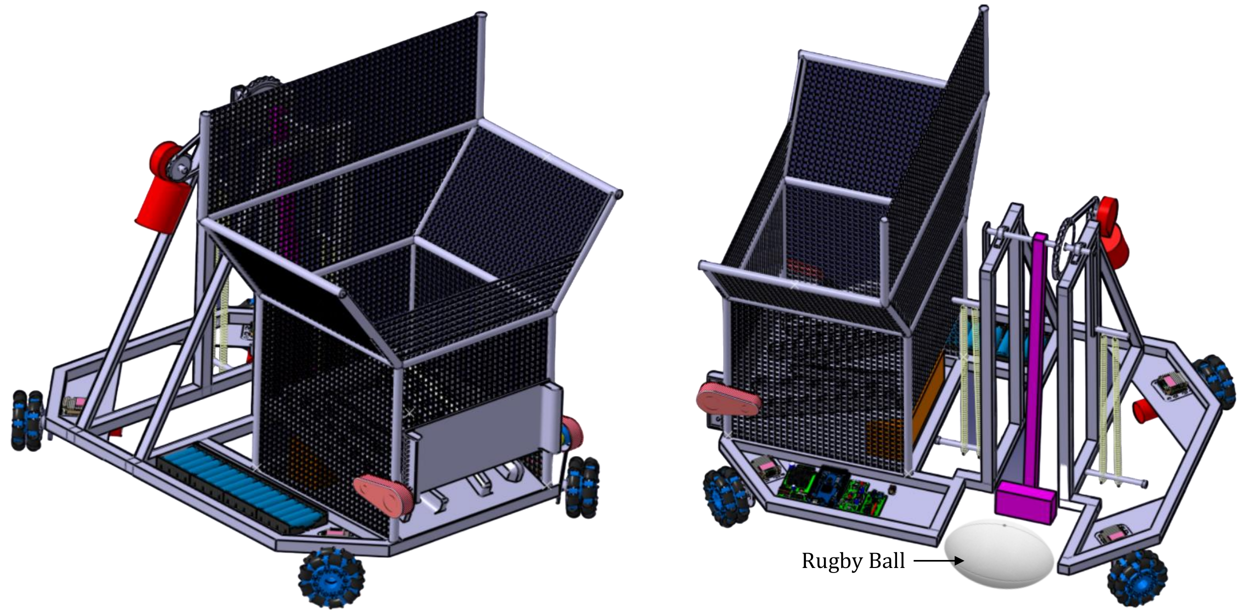


Figure 7: Four-wheeled omnidirectional kicking robot (MR2)



(A) (B)

Figure 8: (A) Robot's gate open for allowing rugby ball to tumble through (B) Robot kicking the rugby ball

Potential energy (in joules) k = Stiffness of the spring (N/m) x = Stretch or compression of the spring from its equilibrium position (m).

$$F = \frac{2 \cdot PE}{x} \qquad (22)$$

4. ELECTRONIC CONTROL SYSTEM AND POWER MANAGEMENT FOR MR1 & MR2

The Omni wheel holonomic robotic platform is controlled by a sophisticated array of electronic components that are integrated into the control system used in this investigation. This section carefully examines the diverse electronic components integral to the MR1 and MR2 robots.

4.1 DC Motor

Direct current (DC) motors serve as pivotal components in omni-wheel drive systems. In the context of our specific application, where the MR1 robot has a mass of 6 kg and the MR2 robot has a mass of 8 kg, both robots are designed with a maximum velocity of 2.5 m/s. To meet these requirements, three 12V DC planetary motors equipped with a 45 mm diameter gearbox were employed for MR1. This motor configuration features a planetary-type gearbox with a 10.2:1 reduction ratio, resulting in a rotation speed of 487 RPM and a torque value of approximately 43 N-cm. Conversely, for MR2, four 12V DC planetary motors with a 35 mm diameter gearbox were utilized. These motors incorporate a 19.2:1 reduction ratio, generating a rotation speed of 262 RPM and a torque of around 45 N-cm. Refer to Figure 9 for MR1 and MR2 motors used.

Additionally, a 12V DC planetary motor with a 35 mm diameter gearbox and a 50.9:1 reduction ratio was employed for the kicking leg rotation mechanism in the MR2 robot.

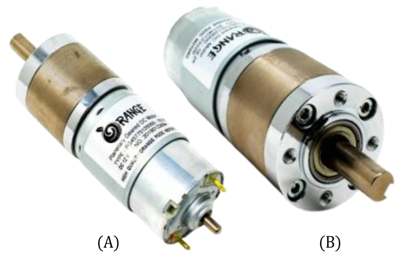


Figure 9: (A) MR1 planetary DC Motor (B) MR2 DC Motor

This motor configuration yields a rotational speed of 96 RPM and generates a torque of approximately 121.7 N-cm, fulfilling the necessary requirements for enabling the turning of the kicking leg against the opposing force exerted by the springs. For the precise operation of the gate opening and closing mechanism, two high-speed motors, specifically the Orange RS775 12V 3000RPM Base DC Motors, were integrated. These motors boast a high RPM of 3000, enhancing the efficiency of the gate's operation. Refer to Figure 10 for kicking leg operation motor and door motors.

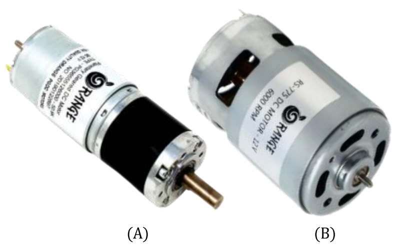


Figure 10: (A) Kicking leg DC high torque motor (B) Gate operation DC motor

International Journal of Science and Engineering Applications
Volume 12-Issue 11, 26 – 35, 2023, ISSN:- 2319 - 7560
DOI: 10.7753/IJSEA1211.1008

4.2 Sensors

A wide range of sensors are used to offer critical feedback data in order to ensure perfect operation and movement of the passing and kicking robot. The various kinds of sensors used include:

- Wheel Encoders: These devices offer valuable feedback regarding the rotation of each omni wheel, enabling precise calculation of the robot's position and facilitating adjustments in its movements. Wheel encoders play a pivotal role in implementing closed-loop control, ensuring the robot adheres to its intended path.
- IMU (Inertial Measurement Unit): An IMU amalgamates accelerometers, gyroscopes, and, at times, magnetometers to gauge the robot's acceleration, angular velocity, and magnetic field. Processing data from these sensors enables the controller to determine the robot's orientation, detecting alterations in direction or inclination.
- Proximity and Obstacle Detection Sensors: Utilizing sound waves, ultrasonic sensors measure distances to nearby objects. These sensors are instrumental in detecting obstacles within short to medium ranges, allowing the robot to maintain a secure distance from objects.
- Wheel Odometry: Although not a conventional sensor, tracking wheel odometry data (i.e., the distance traveled by each wheel) is indispensable for estimating the robot's position accurately. This data, when integrated with inputs from other sensors, enhances navigation accuracy.
- Wireless Communication Modules: For control and communication, Zigbee modules are employed. Zigbee, operating within the 2.4 GHz ISM band, facilitates low-power, short-range communication between devices, making it ideal for applications demanding energy efficiency, low data rates, and secure communication within confined spaces.
- Battery Voltage and Current Sensors: Monitoring the power supply's voltage and current consumption is pivotal for preventing over-discharge and ensuring the robot maintains adequate power levels for safe operation.

4.3 Motor Controller and Battery Management

Both the MR1 and MR2 robots are equipped with a sophisticated control system, centered around the Arduino Mega 2560 microcontroller board [20]. This advanced microcontroller features a comprehensive array of components, including 54 digital input/output pins, a 16-MHz crystal oscillator, 15 PWM output pins, 16 analog input pins, a USB connection, a power socket, and an ICSP header. Integrated seamlessly with the Arduino Mega 2560 is the Embedded Module Series (EMS) 30 A H-Bridge, a critical component capable of facilitating a two-way drive for three and four planetary DC motors for MR1 and MR2. This H-Bridge operates within a voltage range spanning 4 to 16 volts and sustains a continuous current of up to 30 A. To enhance control precision, the module is equipped with a load current sensor circuit, providing essential inputs to the controller.

Furthermore, each robot operates on an independent 24 V Lithium Polymer (LiPo) battery, meticulously managed by a specialized battery protection circuit. This circuit plays a pivotal role in monitoring the battery voltage, automatically disconnecting the load when the Li-Ion battery's voltage descends below the predetermined lockout threshold. This meticulous approach prevents over-discharge, ensuring the longevity and efficiency of the power supply system. For a comprehensive visual representation of the H-bridge driver and the Arduino controller, refer to Figure 11.

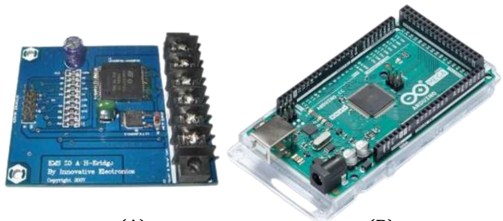

(A) (B)

Figure 11: (A) Embedded Module Series (EMS) 30 A H-Bridge driver (B) Arduino Mega 2560

5. CENTRAL CONTROLLER FOR MOTOR MOTION CONTROL SYSTEM

Figure 12 illustrates the comprehensive real-time omni-wheel motor control system implemented for both MR1 and MR2, as presented in the block diagram. This integrated system orchestrates various real-time tasks critical to the robots' functionality, including robot kinematics, interpolations, battery management, odometry computations, sensor data processing, charging control, and error detection mechanisms. The embedded system's central objective lies in facilitating precise motor movements, responding dynamically to user inputs.

The control system is equipped with essential features such as USB connectivity and a Controller Area Network (CAN) bus, a standardized vehicle bus designed to enable seamless communication between microcontrollers and other devices, without relying on a host computer. The CAN bus interfaces with DC servo amplifiers, managing communication between the robot and the controller, as well as facilitating additional data transfer. Notably, the robots incorporate ultrasonic distance sensors to facilitate obstacle avoidance. Detection and management of errors such as follow error, overcurrent, or under-voltage lockout are meticulously handled by the servo diagnostics subsystem.

Within this intricate framework, the navigation task takes precedence, involving tasks such as interpolation and servo driver referencing. The controller assumes a pivotal role in overseeing these aspects, ensuring precise and efficient motor control, thereby enhancing the overall operational efficiency of the robotic systems.

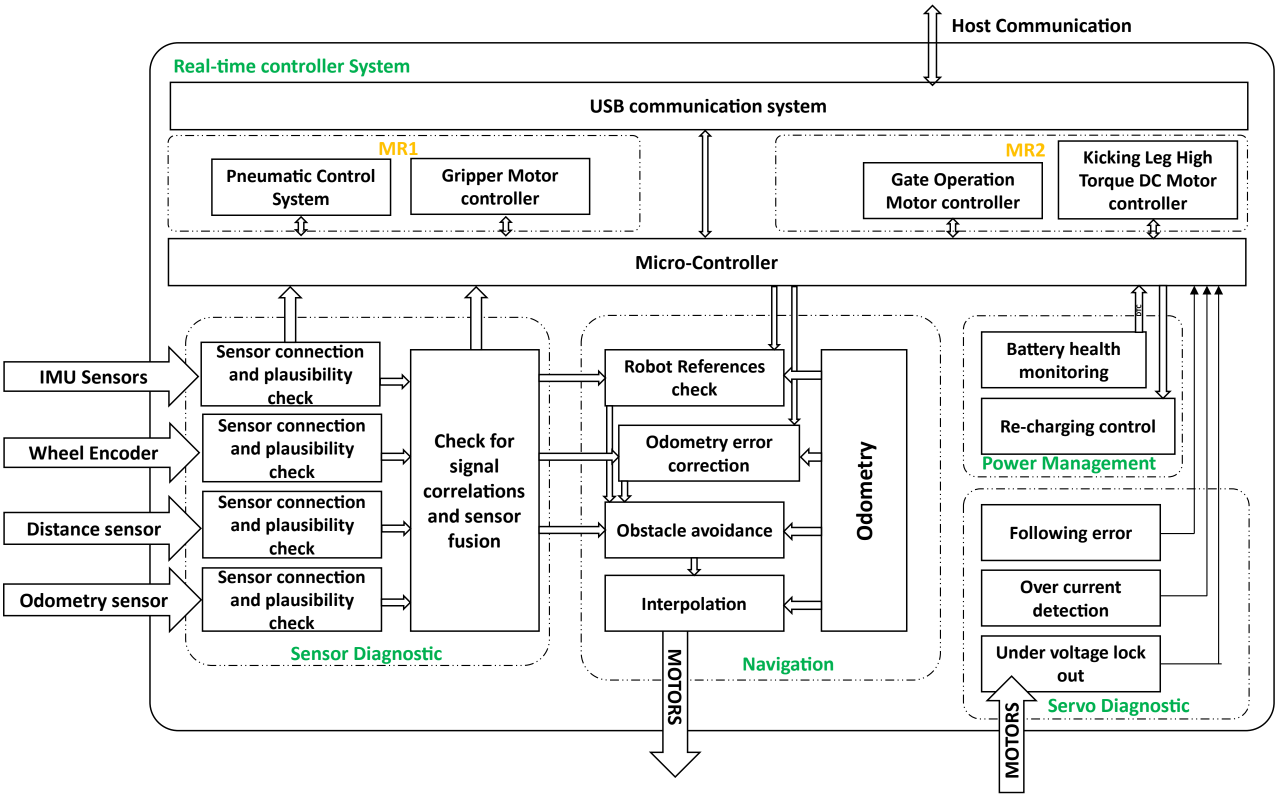


Figure 12: Block diagram of central controller system for motor motion control

6. CONCLUSION

This study stands as a pioneering effort, introducing two specialized robots, namely MR1 and MR2, meticulously crafted for the nuanced tasks of passing and kicking rugby balls, respectively. The MR1 passing robot, adorned with a holonomic omnidirectional platform, exhibits an ability to handle rugby balls deftly, achieved through a sophisticated throwing arm mechanism. Its capability to pick up the ball from the tee and execute precise passes to MR2. The robot's triangular structural configuration and intricately designed wheels facilitate seamless movement in all directions, obviating the need for intricate maneuvers. The successful amalgamation of mechanical grippers, pneumatic systems, and precise control mechanisms within the MR1 robot ensures the flawless execution of passing over a distance of 2.5 meters.

On the other hand, MR2, the kicking robot, exhibits exceptional accuracy, owing to its robust rectangular base and four-wheel holonomic omnidirectional wheels, facilitating precise ball placement and controlled propulsion. The incorporation of springs and motors in its kicking mechanism guarantees precise ball control, with the spring-loaded kicker leg mechanism generating a force of 8.41 N. This enables the robot to execute kicks with remarkable precision, propelling the ball horizontally and vertically up to 5 meters and 1.5 meters, respectively. Enhanced perception and communication abilities are achieved through sensors such as wheel encoders, IMU, proximity sensors, and wireless communication modules.

This research aims expands the horizons of robotic sports technology but also establishes an open platform for future research and development. By replicating human sports activities through robotic ingenuity, this study marks a significant stride toward the future of sports robotics, promising innovative advancements and transformative applications in various fields.

7. REFERENCES

[1] Naruse T, Masutani Y, Mitsunaga N, Nagasaka Y, Fujii T, Watanabe M, Nakagawa Y, Naito O, (2011) SSL-Humanoid RoboCup Soccer Using Humanoid Robots under the Global Vision, in RoboCup 2010: Robot Soccer World Cup XIV, Ruiz-del-Solar J, Chown E, Ploger P (Editors), Springerlink, Lecture Notes in Computer Science, 6556:60-71.

[2] Ishida T (2004) Development of a small biped entertainment robot QRIO, Micro Nanomechatronics and Human Science, 2004 and The Fourth International Symposium for Information-Based Society Proceedings, 31 October – 3 November 2004, pp 23-28.

[3] Gouaillier D, Hugel V, Blazevic P, Kilner C, Monceaux J, Lafourcade P, Marnier B, Serre J, Maisonnier B (2009) Mechatronic design of NAO humanoid, 2009 IEEE International Conference on Robotics and Automation, 12-17 May, Kobe, Japan, pp 769-774.

[4] Senoo T, Namiki A, Ishikawa M (2004) High-speed batting using a multi-jointed manipulator, Proceedings of the 2004 IEEE International Conference on Robotics and Automation, 26 April 1st May 2004, New Orleans, LA, pp 1191-1196.

[5] Nierhoff T, Kourakos O, Hirche S (2011) Playing pool with a dual-armed robot, IEEE International

Conference on Robotics and Automation (ICRA), 9-13 May 2011, Shanghai, China. pp 1-2.

[6] Kono A, Matsumoto T, Ishida Y, Sato D, Uchiyama M (2007) Drum beating and a martial art Bojutsu performed by a humanoid robot in Humanoid Robots, New Developments, de Pina Filho A (Editor), In Tech, Vienna, Austria, ISBN 978-3-902613-02-8, pp 522-530.

[7] The Economist (2012) Robot sport: Heavy hitters: Sporting robots are still slow but their inventors are making rapid strides, 21 July 2012. Available at: http://www.economist.com/node/21559391. Accessed on 13/10/2023.

[8] Holmes C, Jones R, Harland A, Ward D (2007) Development of a mechanical kicking simulator, J Sports Sci Med, Suppl. 10, O-057, pp 44-45.

[9] Fraser S, Harland A, Donovan P, O'Shea L (2012) Development of an end-effector to simulate the foot to ball interaction of an instep kick in soccer, Procedia Eng 34:284-289.

[10] Ronkainen J, El-Kati R, Fleming P, Forrester S (2010) Application of an industrial robot in the sports domain: simulating the ground contact phase of running, Proc Inst Mech Eng, Part P: Journal of Sports Engineering and Technology, 224:259-269.

[11] Moreno, Javier, Eduard Clotet, Ruben Lupiañez, Marcel Tresanchez, Dani Martínez, Tomàs Pallejà, Jordi Casanovas, and Jordi Palacín. Design, implementation and validation of the three-wheel holonomic motion system of the assistant personal robot (APR). Sensors 16, no. 10 (2016): 1658.

[12] Deepak, B. B. V. L., and Dayal R. Parhi. Kinematic analysis of wheeled mobile robot. Automation & Systems Engineering 5, no. 2 (2011): 96-111.

[13] Bemis S, Quinton B. Design development of a novel omni-directional platform. ProQuest Diss Theses [Internet]. 2009;(October):209

[14] Parmar JJ, Savant C V. Selection of Wheels in Robotics. 2014;5(10):339–43.

[15] Sani MI, Damayanti I, Ismail, Saleh MI. Vision System on Wheeled Robot Soccer. In: Indonesian Symposium on Robot Soccer Competition. 2016.

[16] Harashima, F. (1999). Kinematic Correction of Differential Drive Mobile Robot and Design for Velocity Trajectory with Acceleration Constraints on Motor Controller. Proceeding of the 1999 IEEE/RSJ.

[17] Seattle Pi: How Much Pressure Can a Two Liter Bottle Handle, By AndreaBecker. Available at: https://education.seattlepi.com/much-pressure-can-two-liter-bottle-handle-6313.html. Accessed on 13/10/2023.

[18] H. Chang, S. Wang, and P. Sun, "Omniwheel TouchdownCharacteristics and Adaptive Saturated Control for a HumanSupport Robot," IEEE Access, vol. 6, pp. 51174–51186, 2018.

[19] Rijalusalam, D.U.; Iswanto, I. Implementation Kinematics Modeling and Odometry of Four Omni Wheel Mobile Robot on the Trajectory Planning and Motion Control Based Microcontroller. *J. Robot. Control* **2021**, *2*, 448–455.

[20] Prisma Megantoro, Danar Aulia Husnan, Mian Usman Sattar, Andino Maseleno and Omar Tanane. Validation Method for Digital Flow Meter for Fuel Vendors. Journal of Robotics and Control (JRC) 1, no. 2 (2020): 44-48.