Design Details Document

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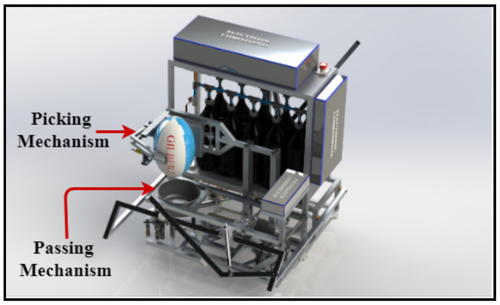
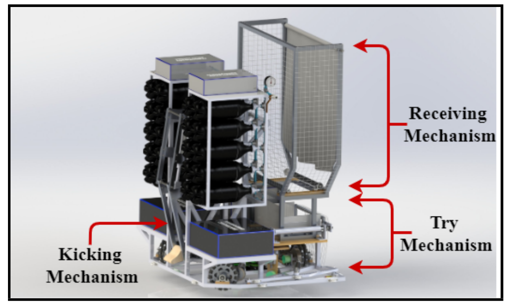
The theme of ABU ROBOCON 2020 - "ROBO RUGBY 7s" is the game of two robots collaborating to score Try and Goal Kick, avoiding five obstacles. Both the robots are having reliable and long-ranged communication to share their real-time position and the task they are performing, with each other. All mechanisms are designed abiding by the rulebook to accomplish the tasks. After considering various possible strategies, the kicking process is done by the Try Robot, and a team member manually places the Kick Ball. At first, the TR travels to the required position in the Receiving Zone to receive the Try Ball. Meanwhile, the PR travels towards the Ball Rack and picks up the first Try Ball. After the TR reaches the required position, it signals the PR to pass the Try Ball. On a successful receive of the Try Ball, the TR travels to the desired Try Spot avoiding the obstacles using a Path Planning Algorithm. Further, the TR places the Try Ball in the Try Spot. After a successful Try, a team member places a Kick Ball in the Kicking Zone, and then the TR proceeds to kick the Ball.



PASS ROBOT



TRY ROBOT

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1 Picking and Passing Mechanism

1.1 Overview

The Picking and Passing Mechanism consists of an Active Gripper[1], a Double Crank Mechanism, and a Leverage Mechanism. The Gripper is mounted on Double Crank Mechanism such that the Try Ball can be positioned directly above the Passing Mechanism.

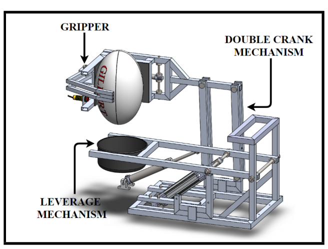

Fig.1.1 Picking and Passing Mechanism

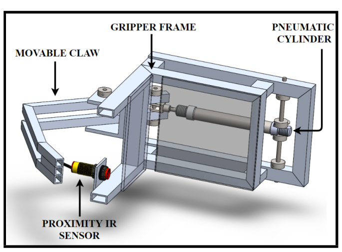

Fig.1.2 Gripper

1.2 Mechanisms

1.2.1 Gripper

The Gripper consists of a Movable Claw, a Gripper Frame, a pneumatic cylinder (Bore Diameter: 16mm, Stroke Length: 80mm), and a Proximity IR sensor; as shown in Fig.1.2. To grip the Try Ball firmly, the Claw is made up of links, rigidly connected at specific angles. Angular motion is provided to the Claw by a pneumatic cylinder.

1.2.2 Double Crank Mechanism

After gripping, the Double Crank Mechanism (Parallelogram Linkage) elevates the Try Ball exactly above the Throwing Base. It is a special case of Grashof's Law in which $s+l = p+q$ (refer Fig.1.3). The motion of the cranks is controlled using a pneumatic cylinder (Bore Diameter: 25mm, Stroke Length: 100mm) to obtain the desired path of the gripped Try Ball.

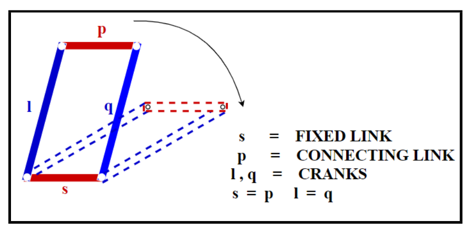

Fig.1.3 Double Crank Mechanism

1.2.3 Passing Mechanism

The Passing Mechanism is based on Third Class Lever. Here, the Try Ball acts as the load, the force applied by the pneumatic cylinder(Bore Diameter: 32mm, Stroke Length: 100mm) acts as the effort, and the pivot acts as the fulcrum as shown in Fig.1.4. The Throwing Base is used to hold the Try Ball. There are two major factors which affect the trajectory of the Try Ball, the force applied by the pneumatic cylinder and the orientation of the Try Ball in the Throwing Base.

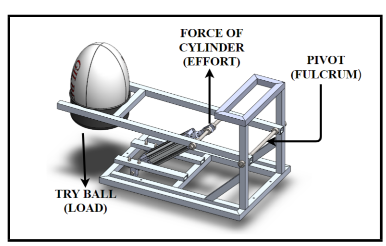

Fig.1.4 Third Class Lever

1.3 Justification

1.3.1 Gripper

When the Try Ball is gripped, it is supported by the Gripper Frame on two sides and by the Claw on the third side. This increases points of contact between the Gripper and the Try Ball, thereby reducing the force per contact.

1.3.2 Double Crank Mechanism

Due to the Parallelogram Linkage Mechanism, the Connecting Link of the Mechanism always remains horizontal. Thus, the orientation of the Try Ball is retained as shown in Fig.1.5, which is required for successful passing. The crank lengths are selected such that the Gripper does not touch the Ball Rack, and the gripped Try Ball remains at the desired height to prevent its bouncing off the Throwing Base when dropped.

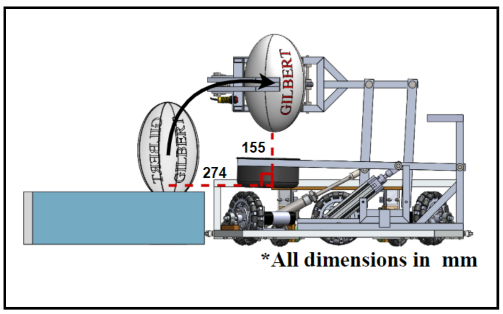

Fig.1.5 Unaltered Try Ball orientation

1.3.3 Passing Mechanism

The effort of the Passing Mechanism can be changed by changing the pressure supplied to the pneumatic cylinder. By simulating the Passing Mechanism at the same orientation of the Try Ball and different values of pressure supplied to the cylinder, different trajectories of the Try Ball are obtained. After analyzing these trajectories, an optimum value of pressure is selected, as shown in Fig.1.6. A Proportional Pressure Regulator maintains this required pressure.

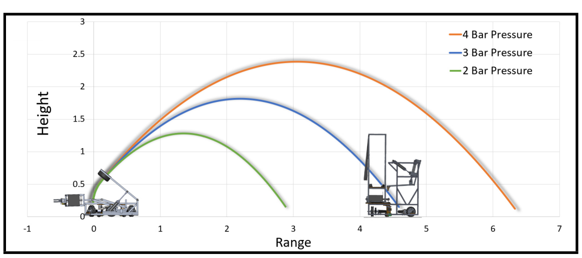

Fig.1.6 Height v/s Range at different pressure

1.4 Task Objective

The PR moves along the Ball Rack until it detects a Try Ball, using a Proximity IR sensor. The Gripper is actuated using a pneumatic cylinder, which rotates the Claw about its hinge, gripping the Try Ball against the Gripper Frame. The Gripper is elevated by the Double Crank Mechanism positioning the Try Ball exactly above the Throwing Base. The Try Ball is then dropped in the Throwing Base. Using the Third Class Lever, the Try Ball is eventually passed to the Receiving Cage of the TR.

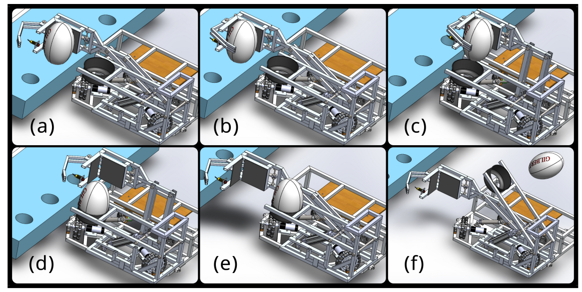

Fig.1.7 Picking and Passing task completion

2 Receiving Mechanism

2.1 Overview

The Receiving Mechanism consists of a Damping System and an Aligning System. The Damping System consists of a Damping Cloth and a Square Pattern Net. The Aligning System consists of two parallel Rollers, which are located at the base of the Receiving Mechanism.

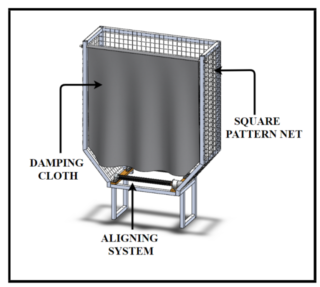

Fig.2.1 Receiving Mechanism

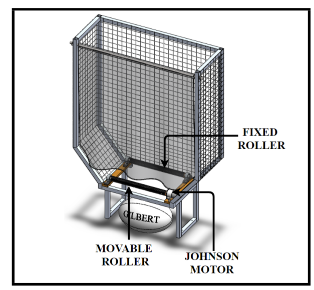

Fig.2.2 Aligning System

2.2 Mechanisms

2.2.1 Damping System

The Damping Cloth is made from a Thick Fabric and is of dimensions 650 × 620 mm^2. It is suspended from an aluminium rod fixed across the top of the Receiving Mechanism. It forms the front side of the Receiving Mechanism, and the other three sides are covered by a Square Pattern Nylon Net, loosely fixed around aluminium bars. An inward slope is provided to the aluminium bars just above the Aligning System, as shown in Fig.2.1.

2.2.2 Aligning System

The Aligning System consists of two horizontal Rollers parallel to each other and are placed 165 mm apart. Movable Roller is powered by a $12V$, 100 RPM Johnson Motor, and the other Roller is kept fixed, as shown in Fig.2.2.

2.3 Justification

2.3.1 Damping System

In the receiving process, the Try Ball first encounters the Damping Cloth which significantly reduces its momentum. Due to its reduced momentum and the loosely attached net, it is ensured that the Try Ball is constrained within the Damping System and does not rebound out of it. The slope provided at the bottom of the Damping System ensures that the Try Ball is directed towards the Aligning System without getting stuck.

2.3.2 Aligning System

The Try Mechanism requires the Try Ball to be dropped in it in a specific orientation. This orientation is achieved by using the Aligning System. The gap between the two Rollers is 165 *mm* which is slightly less than the Try Ball's width (170 *mm*). When the Roller starts rotating, the Try Ball gets aligned as shown in Fig.2.3(a),(b). If the other Roller is allowed to rotate freely, it provides an opposing motion to the motion provided by the Movable Roller. Hence it is kept fixed. The Movable Roller is initially rotated in one direction with high rotational speed, so that the Try Ball quickly gets aligned on both the Rollers. Then the Movable Roller is rotated in opposite direction with low rotational speed so that the Try Ball slips into the Try Mechanism smoothly as shown in Fig.2.3(c).

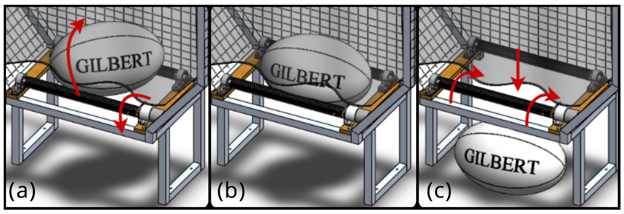

Fig.2.3 Aligning Process

2.4 Task Objective

The Try Ball first encounters the Damping Cloth and looses its momentum. After that, it falls on the Aligning System and gets aligned in the desired orientation. Then the Try Ball slips into the Try Mechanism. While the aligning process happens, the TR starts moving towards the desired Try Spot.

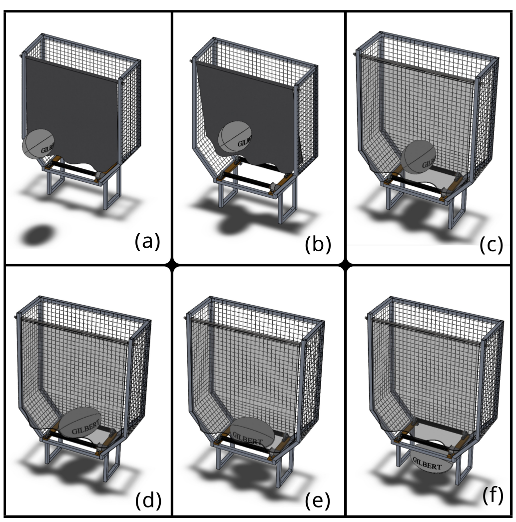

Fig.2.4 Receiving task completion

3 Try Mechanism

3.1 Overview

The Try Mechanism is located directly below the Receiving Mechanism. It consists of an Aluminium Structure, a Drawer Channel, a pneumatic cylinder, and Cable Ties as shown in Fig.3.1. A wooden plank forms the base for this system.

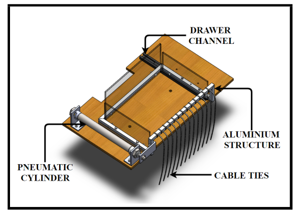

Fig.3.1 Try Mechanism

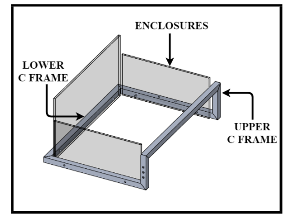

Fig.3.2 Aluminium Structure

3.2 Mechanism

The Aluminium Structure is made up of two mutually perpendicular C-shaped frames, as shown in Fig.3.2. The Lower C-shaped Frame has Enclosures on its three sides. It is mounted on the Drawer Channel. Multiple Cable Ties are suspended from the top of the Upper C-shaped Frame and also from the front of the wooden plank. The pneumatic cylinder (Bore Diameter: 25 *mm*, Stroke Length: 200 *mm*) provides linear motion to the structure, directing it outwards from the TR, to place the Try Ball.

3.3 Justification

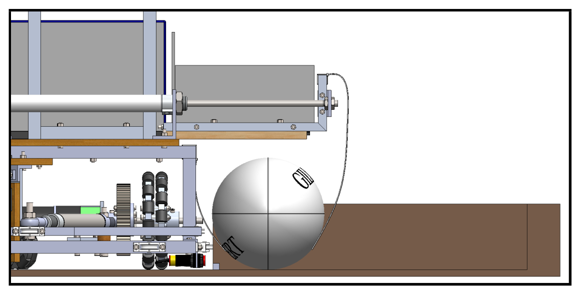

Fig.3.3 Try Ball in contact with the TR (Cable Ties) and Try Spot

When the Try Ball is received in the Try Mechanism, its motion is constrained by the Enclosures on three sides and the Upper C-shaped Frame on the remaining side. The dimension of the Try Ball along the motion of the Aluminium Structure is 170 *mm*, hence a pneumatic cylinder of 200 *mm* stroke length is used to ensure that the Try Ball is completely pushed out of the Try Mechanism. The ground clearance of this Mechanism is kept 208 *mm* to prevent the Try Ball from bouncing out of the Try Spot when it is being placed. To satisfy rule 19 (a) of the rule book, Cable Ties are used supported by FAQ (0-19-3). Thus, when the Try Ball touches the game field for the first time while it is being placed in the Try Spot, it is also in contact with the Cable Ties (TR).

3.4 Task Objective

As the TR receives the Try Ball, it starts moving towards the desired Try Spot. After the TR stops in front of the Try Spot, the Aluminium Structure moves out of the TR by the actuation of a pneumatic cylinder. Once the Try Ball is placed in the Try Spot, the Aluminium Structure is retracted, and the TR proceeds for the next task.

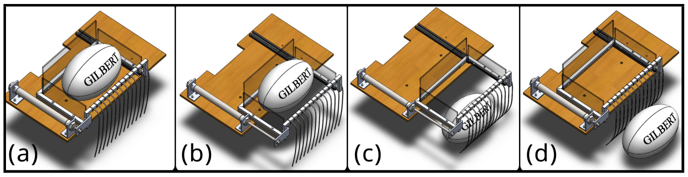

Fig.3.4 Scoring a Try

4 Kicking Mechanism

4.1 Overview

The Kicking Mechanism is inspired by a human leg. It mimics the motion of the leg, kicking a ball. For the same, an aluminium skeleton, a Wooden Shoe, and two pneumatic cylinders are used in this mechanism.

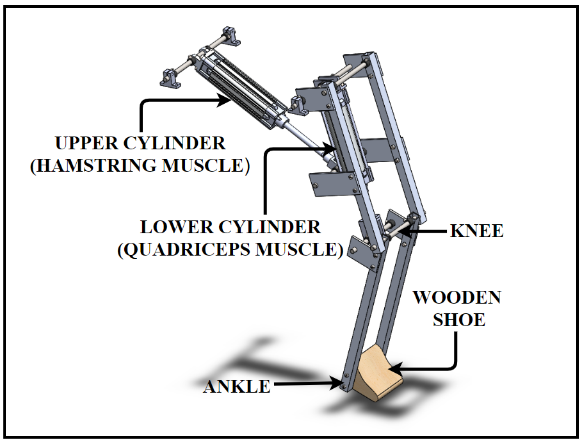

Fig.4.1 Kicking Mechanism

4.2 Mechanism

Pneumatic cylinders are used to actuate the aluminium skeleton. The Upper Cylinder (Bore Diameter: 32 mm, Stroke Length: 100 mm) resembles *Hamstring muscle* and the Lower Cylinder (Bore Diameter: 40 mm, Stroke Length: 100 mm) resembles *Quadriceps muscle*. Both pneumatic cylinders operate under very sensitive timing constraints so that the Shoe can achieve maximum speed at the instant of the impact. A quick exhaust valve is used to increase the speed of forward stroke of the pneumatic cylinders. In this system, the Shoe is fixed to the ankle. The arc formed by the Shoe, while kicking, depends upon the lengths of the links, the pressure at which the cylinders are operated, and the delay between the actuation of two cylinders.

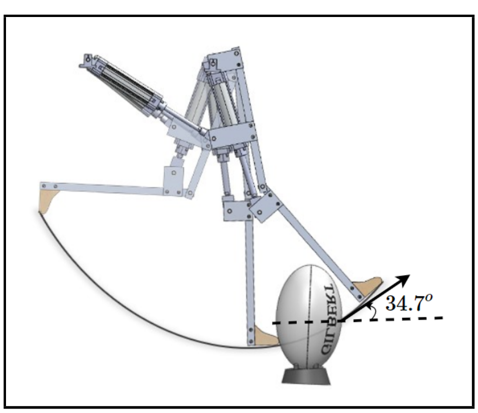

Fig.4.2 Kicking Arc

4.3 Justification

A particular angle and velocity of the Shoe is required, at the time of kicking. The optimum arc of the Shoe is determined by detailed motion analysis of the leg in *SolidWorks* software, as shown in Fig.4.2. The maximum velocity of the Shoe, when it comes in contact with the ball is observed to be 16.87 m/s in simulation.
Using this velocity of the Shoe, the velocity of the Kick Ball can be determined by the equation :

$$V_{ball} = \frac{I}{I + M_b R^2} \times (1 + e) \times V_{foot} \qquad [2]$$

Here, R is the distance of the Shoe from the uppermost hinge point i.e., 780 mm. The moment of inertia of the leg, I is obtained using *SolidWorks* i.e., 0.293 $Kg.m^2$ and the mass of the ball, M_b is measured to be 0.325 Kg. The coefficient of restitution, e is assumed to be 0.5 [3], the maximum velocity achieved by the ball at the time of the impact comes out to be 15.11 m/s using the above equation. Using this velocity, the maximum range under ideal conditions, of the Kick Ball is calculated to be 21.8 m.
The efficiency of this Humanoid Kicking Mechanism mainly depends on two major factors.

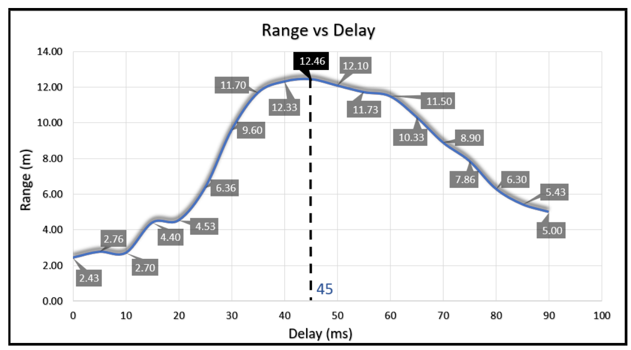

Fig.4.3 Range v/s Delay between the actuation of cylinders

- Time Delay: By changing the delay between the actuation of the two pneumatic cylinders, the arc of the Shoe can be changed. Even a variation of 5 milliseconds in the delay would change the knee angle at the point of impact, causing the foot to strike the ball slightly above or below the desired point of contact, with profound effects on the trajectory [4]. Hence an optimum delay is set to obtain the required arc made by the Shoe. This delay is calculated by experimental analysis; observations of the same are shown in Fig.4.3.
  *The distance of the Tee from the TR was kept constant (23.5 cm) throughout the experiment.

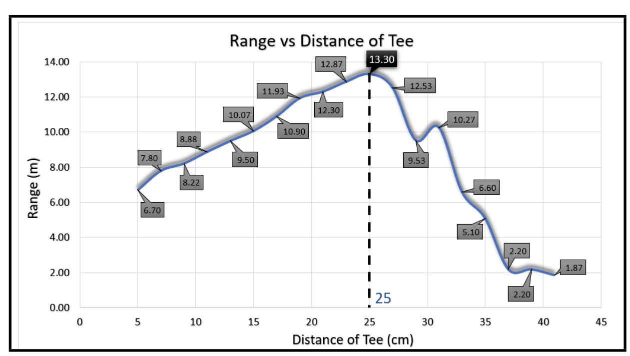

Fig.4.4 Range v/s Distance of Tee from the TR

- Position of Tee: For the time delay (45 ms) obtained in the above experiment, an optimum arc of the Shoe is generated. Depending on the distance of the Tee from the TR, the tip of the Shoe can hit anywhere on the Kick Ball, which is placed vertically on the Tee. Hence an optimum Tee position is required to obtain the desired trajectory. Required Tee position is found by experimental analysis, observations of which are shown in the Fig.4.4.

4.4 Task Objective

Tee and Kick Ball are placed manually in the kicking zone. The TR aligns itself in a specific orientation w.r.t the Tee. At first, the Upper Cylinder is actuated, and after a delay of 45 ms, the Lower Cylinder is actuated to obtain the desired arc of the shoe resulting in a successful kick.

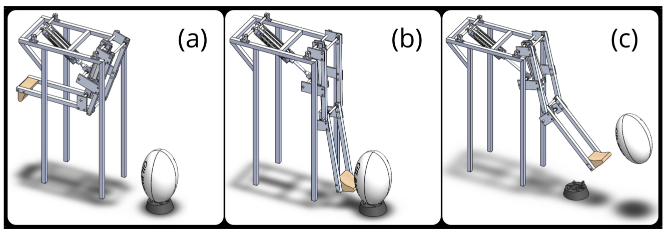

Fig.4.5 Kicking task completion

5 Drive

Three-wheeled omnidirectional drive is used for both the robots as it provides instantaneous and well-controlled motion in all directions. The robot is localised in a local environment (arena) using wheeled odometry, consisting of two Optical Incremental Rotary Encoders - mounted in a mutually perpendicular manner - and a 6-DOF IMU sensor. Given a goal pose (position and orientation), the robot plans its own path. According to the obtained path, the upper control transmits the required translational and angular velocity of robot travel to the lower control. The lower control calculates the required velocity and turn direction of each wheel using an inverse kinematic model, and maintains the same, using a PID control system. A PS3 controller is used to manually make a selection between different possible strategies at critical instances. Throughout the game, two robots collaborate with each other by continuously sharing their pose and the current task, using a XBee module.

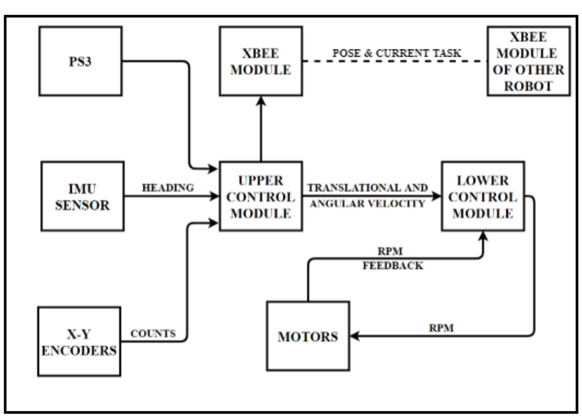

Fig.5.1 System Architecture

5.1 Path Planning

The Try robot needs to plan it's path to reach a given point avoiding five obstacles. For this, a planning algorithm is developed using Pose and given Arena (Top View), which is a variant of visibility graphs [5]. Suppose the robot is a circle of radius r. In accordance with the given work-space, the configuration space can be determined using the C-space transform as shown in Fig.5.2.

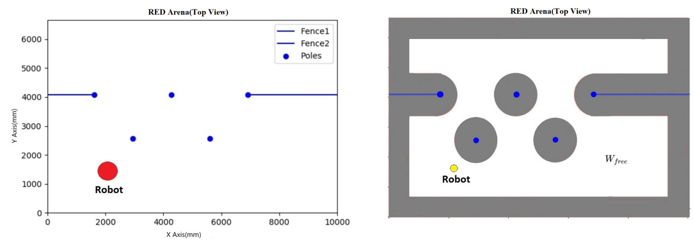

Fig.5.2 C-Space Transform

Let a goal position be assigned to the robot. Using the goal position and the current position, a rectangular window is generated. The enlarged poles contained in the rectangular window are then checked if they thwart the path of the robot, refer Fig.5.3. Once this process is completed, the robot executes a straight line motion to the tangential point(T_i) of the first enlarged pole(O_i). The robot on reaching the tangential point(T_i) checks if the current enlarged pole thwarts its path(current to goal position). If yes, the robot will circumnavigate the enlarged pole and leave at (L_i) when the enlarged pole no longer thwarts the path(current to goal position). This process is repeated until all the enlarged poles thwarting its path are avoided.

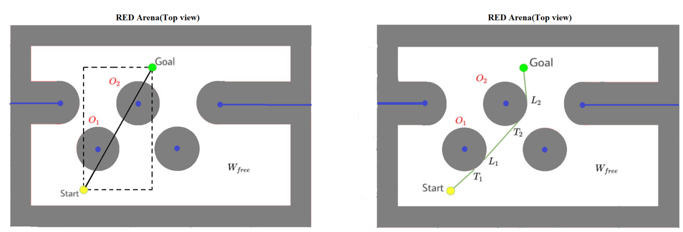

Fig.5.3 Planning the Path

References

[1] Deb SR, Deb S: Robotics Technology and Flexible Automation
[2] Bull-Andersen T, Dorge HC, Thomsen FI: Collision in Soccer Kicking. Sports Engin 1999, 2:121-126
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[5] Howie C, Kevin ML: Principles of Robot Motion, May 2005