Design Details of MR1 and MR2 robots for ROBOCON 2019

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I. Introduction

This report states the details about the functionality of robots i.e. Messenger Robot 1 (MR1) and Messenger Robot 2 (MR2) on the basis of structure, mechanisms, control methodology and control systems for completing all the tasks of the Robocon 2019 theme in less time with low probability of failures. All the designs and the approach mentioned in this report have been analysed and they keep a check on competitive variables, such as match play time and ease for the operator in mind.

II. Messenger Robot 1 (MR1)

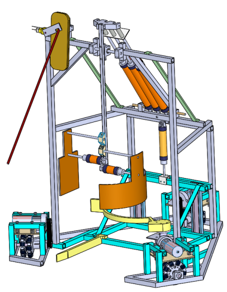

Fig. 1. MR1

The MR1 is a 3-wheeled holonomic drive which uses Omni wheels resulting in high maneuverability which is useful while crossing the forest area. It consists of high torque and high RPM motors for the drive. The robot holds the Gerege through the hole and is passed to MR2 by sliding it on a smooth rod which results in saving the time and multiple actuations while transferring. The transfer is such that the position of the MR2 robot is not disturbed. The robot grabs the Shagai by a DC motor actuated gripping mechanism and raises the Shagai vertically upwards, with the help of a pneumatic cylinder, which is further grabbed by the gripper mounted on the throwing arm. Finally the Shagai is thrown, using a class-1 lever mechanism actuated by pneumatic cylinders, from a long distance in order to minimize the time and grab the next Shagai at the earliest if needed.

A. Dimensions and weight

The overall dimensions of the robot are 985x900x978mm [LxWxH] and weighs 25kg.

B. Materials

- Chassis - Aluminium
- All mounts (Shagai gripper, motor mounts, sensor mounts) - 3D printed PLA
- Gerege Slider - Polypropylene rod
- Throwing arm - Stainless steel

C. Type of drive

Belt transmission has been used in-order to increase the area to pick up the Shagai (as shown in the fig 2). Timing belts and pulleys have been used for positive transmission.

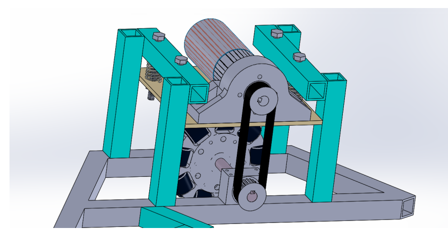

Fig. 2. Drive

D. Mechanisms and their functioning

1) Wheel configuration: In triangular configuration the required torque is higher than 4-wheeled configurations. The torque is calculated considering the entire load being only on 2 motors which turns out to be 8.33 kg-cm. The motors we selected for this were – **Mabuchi^{TM} RS-775WC** as base motor with a gearbox of **1:23** reduction ratio which gives us a neat **750 RPM** at a rated torque of **39 kg-cm.** These cost the same and are the best in class.

2) Gerege holding and passing: The mechanism has been designed keeping in mind the basic theme rules. The hole provided on the Gerege is used to hold it over a rod with the help of a flap actuated by a BO Motor. When BO motor is actuated, the flap opens and the Gerege slides over the rod fixed on the MR1 at a certain angle **which saves time and actuation**. (As shown in fig 3).

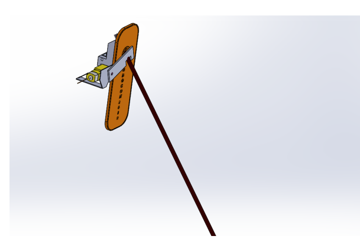

Fig. 3. Gerege holding and passing

3) Shagai picking and throwing: We have used a gripper having the shape of Shagai curve for holding it properly Considering the all the forces and the moment of inertia of the claw, the minimum required torque is 6 kg-cm. The motor we selected to actuate the gripper is Johnson motor.The mechanism also lifts the Shagai with the help of a Pneumatic cylinder of 150mm stroke and 16mm bore and passes it on the throwing arm using a 5/3 solenoid operated DCV, all the while robot reaches the throwing zone hence **saving time.** A contact limit switchis triggered when the Shagai reaches the throwing arm. This signals the micro-controller to actuate the Gripper of the throwing arm and thereafter release the lifting gripper. The throwing arm gripper uses 2 pneumatic cylinders and a 5/2 solenoid actuated DCV to grab the Shagai. Shooting action is initiated through remote control. Air Pressure used is 5 bars and is stored in PET bottles.

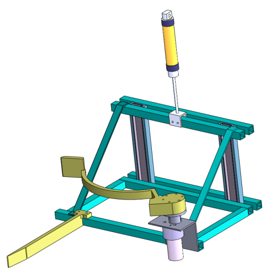

Fig. 4. Shagai picking and lifting

2 IR switches are mounted on the Pneumatic cylinder which actuates the throwing arm using a 5/3 solenoid actuated DCV and a plate is mounted at the end of the rod which is detected by the IR switches which are calibrated to trigger at the required positions. Throwing is done by considering Shagai as a projectile. After the throwing action is completed, the arm retracts itself to the starting position.

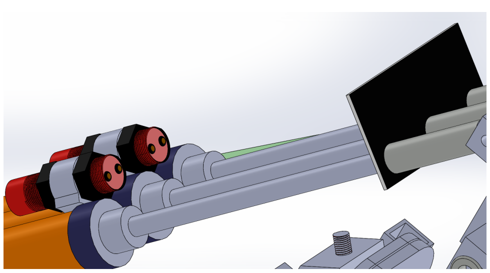

Fig. 5. Position of IR switches and plate

Robot throws the Shagai at a distance of 4m from the landing zone. If the Shagai lands 40 or 20 it would **require less time to pick another Shagai** which helps in **completing the tasks swiftly.**

4) Actuators:

- Mega torque motor with Mabuchi RS-775WC 750 RPM and 39 kg-cm torque (Motors used in drives)
- 3 Pneumatic cylinders - Bore: 25mm, Stroke: 200mm (for throwing arm).
- 2 pneumatic cylinders - Bore: 20mm, Stroke: 50mm (gripper on throwing arm).

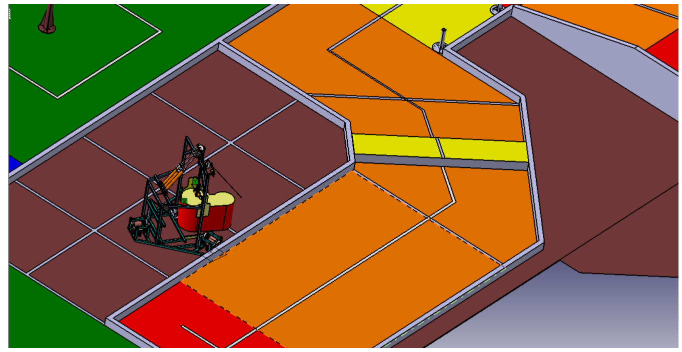

Fig. 6. ACTUAL POSITION OF MR1 ON ARENA

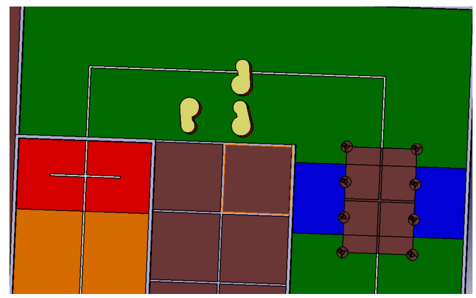

Fig. 7. PLACEMENT OF SHAGAI ON KHANGAI AREA

- Pneumatic cylinder – Bore: 16mm, Stroke: 150mm (Shagai lifting).

5) Integration of components: The integration of all the sub-systems is done through a central PCB with Arduino MEGA 2560and the remote controller used is a XBOX 360 controller.The 2.4 GHz receiver is connected to thee Arduino using a USB host shield. The board design of the PCB is shown in the figure on the right.

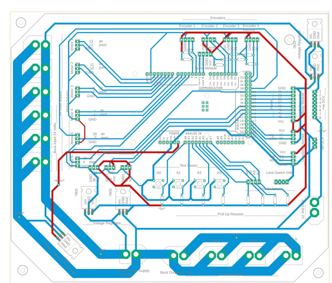

Fig. 8. PCB design - MR1

III. MESSENGER ROBOT 2 (MR2)

The **Messenger Robot-2** is a **quadrupedal robot** where each leg is a **5-bar linkage mechanism**, or as we name it the **V-Leg**. Since the end effector and manipulator are in direct contact, this design can be classified as a parallel manipulator (as shown in the fig 10). It has a Gerege receiving mechanism wherein the Gerege is received without disturbing the stability of the MR2 while standing. Each leg comprises of 2 motors beside each other facing the same direction. This particular orientation of legs helps in obtaining any type of gait for

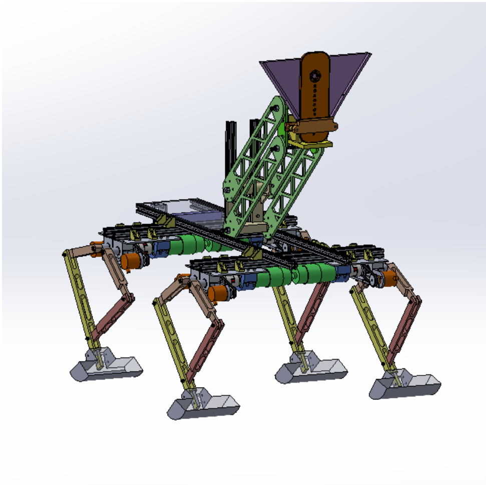

Fig. 9. MR2

overcoming all the obstacles. After reaching the mountain, it raises the Gerege using a four bar mechanism. **We have implemented a modular design where we can change the mountings as per the test results and desired values.** Various types of Polymers and 3D printed components have been used in the manufacturing of MR2 to reduce its weight.

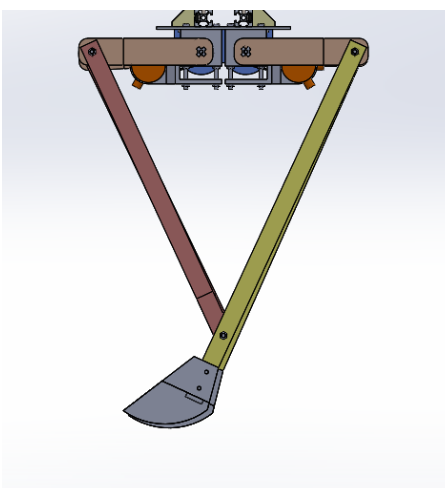

Fig. 10. Leg design

A. Dimensions

The overall dimensions of the robot are 831x680x740mm and weighs 20kg.

B. Materials

- Chassis - Aluminium T slot extrusions
- Legs - Aluminium
- All mounts (motor, servo, camera, Gripper, sensor mounts)- 3D printed PLA
- Foot - 3D printed ABS

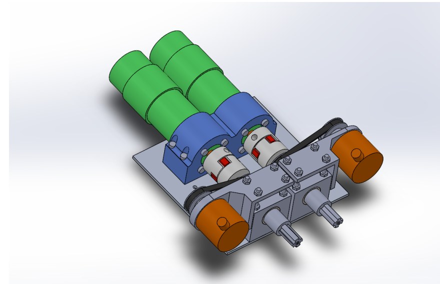

Fig. 11. Drive

C. Drive and control methodology

The torque is calculated considering the entire load being beared on 3 legs for walking gait or 2 legs for trotting gait which turns out to be 42 kg-cm. The motors we selected for this were – **Mabuchi$^{\text{TM}}$ RS-775WC** as base motor with a gearbox of **1:181** reduction ratio which gives us **100 RPM** at a rated torque of **255 kg-cm.**

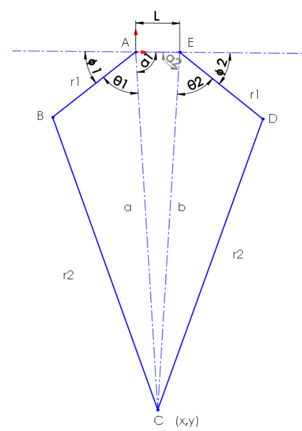

Fig. 12. V-Leg

Motors are connected with optical quadrature encoders with belt and timing pulley arrangement for the angular position of the crank. The desired position of the cranks are thus obtained from the given (X, Y) co-ordinates through derived inverse-kinematic equations. These equations are described below:

The origin is assumed at the midpoint of segment $\overline{AE}$ for (X,Y)

$$\therefore\ a = \sqrt{(X - \frac{L}{2})^2 + Y^2}$$

$$b = \sqrt{(X + \frac{L}{2})^2 + Y^2}$$

Using cosine rule,

$$r_2^2 = r_1^2 + a^2 - 2r_1\cos(\theta_1)$$

$$2r_1\cos(\theta_1) = r_1^2 + a^2 - r_2^2$$

$$\therefore\ \theta_1 = \cos^{-1}\left(\frac{r_1^2 + a^2 - r_2^2}{2r_1 a}\right)$$

Similarly for θ_2 ,

$$\theta_2 = \cos^{-1}\left(\frac{r_1^2 + b^2 - r_2^2}{2r_1 b}\right)$$

Using cosine rule,

$$b^2 = L^2 + a^2 - 2La\cos(\alpha_1)$$

$$a^2 = L^2 + b^2 - 2Lb\cos(\alpha_1)$$

Hence,

$$\alpha_1 = \cos^{-1}\left(\frac{a^2 + L^2 - b^2}{2La}\right)$$

$$\alpha_2 = \cos^{-1}\left(\frac{b^2 + L^2 - a^2}{2Lb}\right)$$

$$\therefore\ \phi_1 = \pi - (\theta_1 + \alpha_1)$$

$$\phi_2 = \pi - (\theta_2 + \alpha_2)$$

The angular velocity of the motors to cover the angular distance is inferred from the graph shown in Fig. 12. The gait of each leg is divided into two phases:

1) Stride phase: In the stride phase, the leg is in contact with the ground, driving MR2 forward. A smaller stride gives us more stability while other legs are in their flight phase. The graph of encoder pulses vs. X given below shows a near linear change in ticks as it progresses through the stride phase. This near linear change in pulses with respect to X on stride is the result of a larger minimum length of the leg with respect to the stride covered, as it resembles a shaft creating a near linear path when covering a relatively minuscule arc with respect to a rather large radius. The leg covers stride uniformly i.e in a non-accelerating manner, we can assume that change in X on stride with respect to time is constant, hence, it covers equal slices of the stride in equal slices of time.

From this inference, we make the assumption that $dX = dt$, further using the following assumption:

$$\frac{d\theta}{dt} = const$$

2) Flight phase: The flight phase is where the leg makes no contact with the ground. We've implemented a triangular flight end-effector trajectory due to simplicity and ease of implementation. We implement the Trotting gait, where the duration of the stride and flight phase are equal and contralateral legs are in phase i.e both legs are in flight/stride phase simultaneously and ipsilateral legs are in opposite phases i.e if one is in stride, the other executes flight simultaneously.

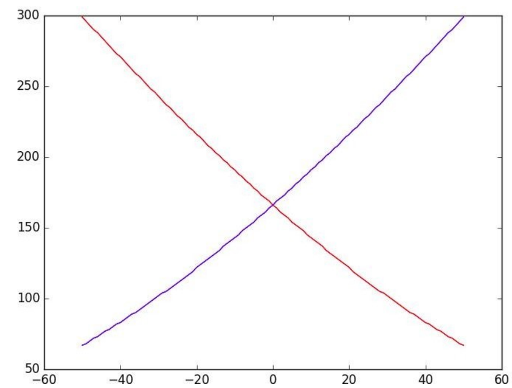

Fig. 13. Pulses vs. X for Stride = 100mm, Distance between motors = 50mm, minimum stretch of leg during stride = 200mm, length of crank = 100mm, length of coupler = 200mm

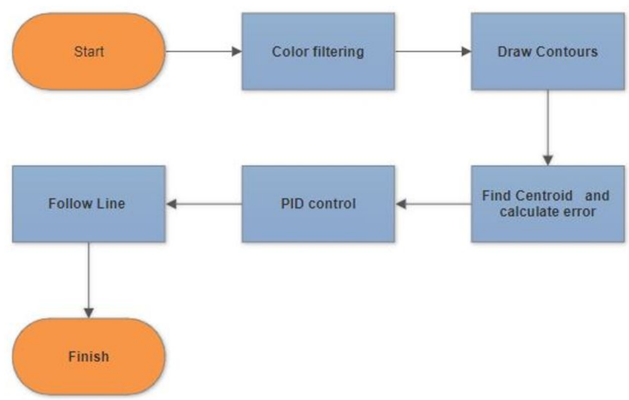

Fig. 14. Path planning

3) Path Planning: For processing visual inputs from the camera, we use OpenCV (open-source computer vision) library. Algorithm for path / motion planning of the MR2 proceeds in the figure mentioned below.

4) Stabilization of MR2: The gyroscopic values (pitch and roll) acquired by the IMU will be used to maintain the dynamic stability of the robot while walking through the sand dune, tussock and mountain. IMU will be placed at the centre of mass of the bot. These values will be filtered to mitigate noises.

According to the roll and pitch values, the stretch of the corresponding legs is adjusted.

D. Gerege Holding and Raising

Gerege, from the MR1, is received by sliding it over the rod and touches the funnel shaped part on the MR2. Gerege slides in the funnel shaped part and reaches the linear screw gripper actuated by a DC motor. This mechanism is mounted on a four bar linkage mechanism which is used to raise the Gerege after MR2 reaches the mountain.

E. Actuators and Sensors

- Mega torque motor with Mabuchi RS775WC 100 RPM and 255 kg-cm torque(used in leg mechanism)
- 600PPR Encoders are used for the feedback of leg motors.

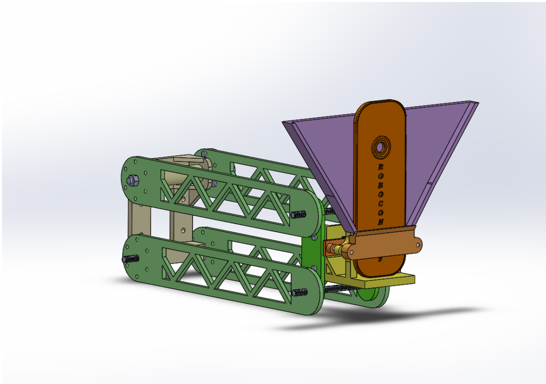

Fig. 15. Gerege holding and raising with four bar mechanism

- 5V Servo motor -Provides pitch motion to the camera.
- IR switch - senses whether the Gerege has been received or not.
- IMU - for robot stabilization.
- SharpIR sensor -placed at the front leg for detecting the sand dune.

F. Integration of components

The integration of all the sub-systems is done through a central PCB with Udoo Quad board.

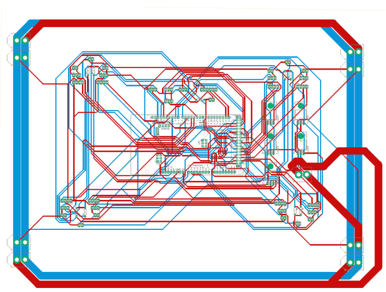

Fig. 16. PCB design of MR2