DD ROBOCON 2019, INDIA Preliminary Design Detail Report

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ABSTRACT

This report outlines the design and development process of the Robots, being developed by the Team Vector for DD-ROBOCON 2019, in a nutshell. It covers various aspects of the Robots including Mechanisms, CAD Designs, Calculations, Dimensions, Electronics subsystem. The main objective of the team was to satisfy and accomplish various tasks as-per the gameplay while meeting the ABU's rules and regulations with special consideration given to Safety.

INTRODUCTION

This report contains the technical aspects of the two robots being developed by our team that will compete at DD ROBOCON 2019, India.
This document has been subdivided into 3 Sections i.e. Manual Robot (MR1), Automatic Quadruped Robot (MR2) and Electronics subsystem. Every subsection tries to cover the various aspects and also gives a brief idea about the Mechanisms of Base Drive of the Manual Robot, Walking of the Automatic robot, Gerege Holding, Passing and Raising, Shagai Loading and Throwing. Further this document highlights the strategy with which we are approaching the 2019 theme and also various calculations that we have performed for our mechanisms. Some subsections also cover the additional aspects that we are implementing to gain a performance boost.

MANUAL ROBOT (MR1)

The Manual Robot known as Messenger Robot 1(MR1) has to primarily perform two Tasks – Passing the Gerege and Throwing the Shagai. Our team proposes to build MR1 as an Efficient, Sturdy, Accurate and Rapid Robot. Various subsections of the MR1 such as Base Drive, Gerege Holding and Passing Mechanism, Shagai Loading and Throwing Mechanism have been covered under this section.

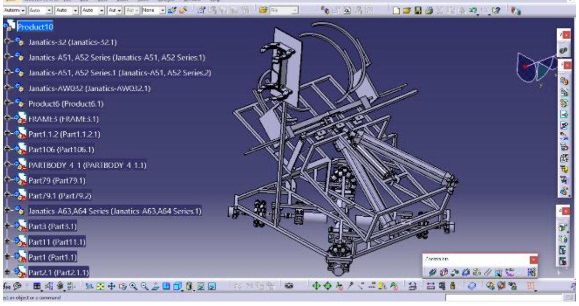

Figure 1: Manual Robot Final CAD Design

BASE DRIVE

We are using Holonomic Drive, where the controllable degree of freedom is equal to the total degree of freedom which enables us to move the robot in any direction with the help of force vector and manipulating speed and direction of each wheel. The base drive of our robot is built using Omni-wheels aligned at an angle of 45 degrees. The biggest advantage of this drive is that we can move the robot in Zigzag manner quickly, while it passes through forest region.
We are using an Optical Rotary Encoder as a feedback mechanism, for implementing a PID approach to automatically correct the path of MR1. We consider this feedback and correct the control signal sent to the DC motor according to the error.
The manual operator will guide MR1 through the desired path. After MR1 has cleared 9/10th of the given path, the microcontroller will initiate the PID loop.
The error is fed as an input to the PID algorithm which then determines the appropriate control signal and the direction of rotation of the motor shaft.
Once the desired setpoint is achieved, the PID loop will terminate and the operator will resume with further functioning of MR1.

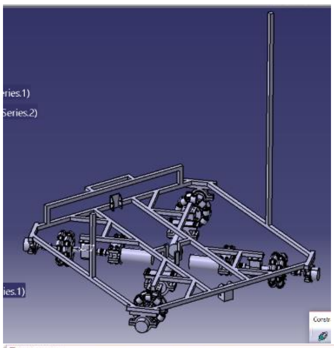

Figure 2: Holonomic Base Drive Assembly

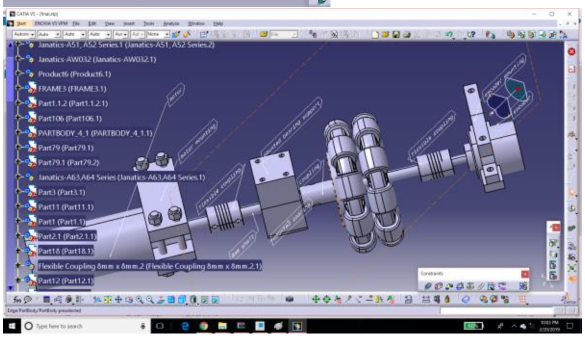

Figure 3: Motor + Wheel + Encoder including Mountings and Couplings

GEREGE HOLDING MECHANISM

We are using Servo based Grippers for holding the Gerege in MR 1. The locking and releasing of the Gerege is carried out by gripping arms fastened using nylon thread controlled using the Servo motor. The approx. weight of this mechanism including the Gerege is 250gm which is within the tolerance limit of the Servo Motor (FUTABA S3003) that we are using, having the Maximum Torque bearing capacity of 4.1 kg-cm.

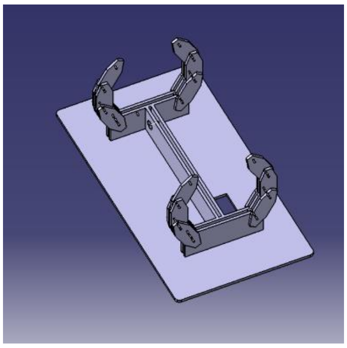

Figure 4: GEREGE HOLDING GRIPPER

GEREGE PASSING MECHANISM

The Gerege Passing mechanism is quite straightforward. It involves a stationary Arm which possesses Gerege Holding Gripper at its uppermost Part. The Gerege gripper in MR1 grasps the Gerege until the Gripper on MR2 holds the Gerege sturdily. Thereafter, the operator releases the Gerege Gripper of MR1 and the Gerege Passing is completed.

SHAGAI LOADING MECHANISM

Shagai throwing holds the key-points for the progression of MR2 over the Mountain Area. Hence this mechanism plays a vital role in achieving 'UUKHAI'. So, our team has prioritised Rapid and Accurate motion by the use of Pneumatics. We are using 4 Pneumatic cylinders of 2 types for Grabbing, Raising and Placing the Shagai.

*Figure 5: Magnetic Injection Pneumatic Cylinder (**P2**)*
Model No- A520121600

*Figure 6: Double acting Pneumatic Cylinder (**P1**)*
Model No- SU32X300-S

The Idea for Grabbing and Placing the Shagai on the Throwing base is as follows-

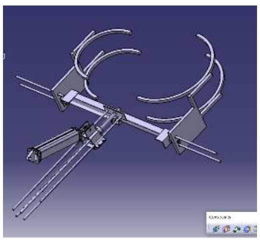

Figure 7: Shagai Gripper

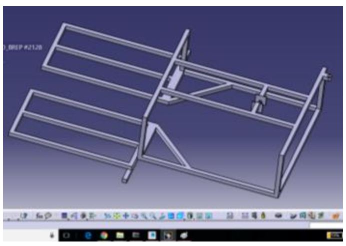

Figure 8: Inclined Shagai Base

Initially the Shagai Grabbing Arm is extended using P1, Then the Shagai is Grabbed by the Shagai Gripper using Injection Pneumatics(P2). Then the Shagai Gripper is raised to a required angle using the Magnetic Injection Pneumatic(P2). Then the P1 Pneumatic is Retracted such that the Shagai is placed on the Inclined platform. And Finally,the Gripper releases the Shagai, which enables the Shagai to be precisely thrown from the inclined throwing base.

SHAGAI THROWING MECHANISM

After the Shagai is placed on throwing base, and the Automatic Robot reaches the Mountain Urtuu, the Operator is allowed to throw the Shagai from the Throwing Zone. The team must score 50 points in an order to progress. To improve accuracy,time and to score 50 points in one throw, Our team proposes the following mechanism by which the Shagai is thrown and lands with Yellow Face upwards with negligible chances of failure.
Class 3 Lever has been used to reduce the output force while maximising the velocity which in turn increases Shagai's momentum. The Shagai is thrown parallel to the inclined base. After the Shagai is placed on the Inclined throwing base using our Shagai Loading and Placing Mechanism, the operator then pilots the MR1 to the Throwing Zone. With the help of precise pneumatic system, the throwing arm is actuated and its Angular momentum is then transferred to the Shagai. This Angular momentum then makes the Shagai to follow the desired path i.e. Making it land in the Landing Zone with its Yellow side facing upwards. The main advantage of our Shagai Throwing Mechanism is that the Shagai never topples during the course of its flight and enables us to score 50 points in only one throw.

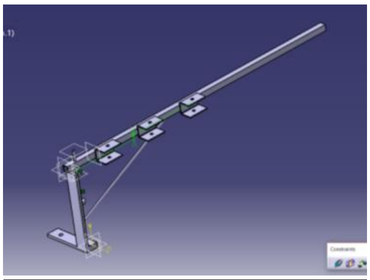

Figure 9: Shagai Throwing Arm

CALCULATIONS

F_1: Force exerted by pneumatic
F_2: Force at the point of contact of Shagai
F: Force in the direction perpendicular in the point of contact
F_R: Resultant force
$\emptyset$: Normal angle
θ: Angle of inclination
μ_k: Coefficient of kinetic friction
u: Velocity of projection
R: Range of projectile
m: Mass of Shagai
M: Total mass
t: Time of contact
$\emptyset = 33.5°$

$$F = F_2 \cos \emptyset = 53.035\ N$$
$$F_R = F - \mu_k mg \cos\theta \quad \ldots (N)$$
$$u = \frac{F_R t}{m} \ldots (ms^{-1})$$
$$R = \frac{u^2 \sin 2\theta}{g} \ldots (m)$$
$put\ R = 2.5m$(Expected Landing Distance)

$$\frac{{F_R}^2 t^2 \sin 2\theta}{m^2 g} = 2.5$$

$$\sin 2\theta\, {F_R}^2 t^2 = 2.5m^2 g$$

$$\boxed{\textbf{\underline{Therefore,}}\ \boldsymbol{\theta = 22.067°}}$$

Hence, with the above calculation and further refinement on actual Prototype, we observed a successful Shagai Throw with a distance traversed in a range of 2.1-2.5m (By Varying the Pressure to the pneumatic)

Automatic Quadruped Robot (MR2)

The Automatic Quadruped robot knows as Messenger Robot 2(MR2) emphasises on carrying the Gerege from the start to the Uukhai Zone. We focused on designing and manufacturing a Stable and Swift Quadruped. Various subsections of the MR2 such as Gerege Holding and Raising mechanism, Gait Analysis, Kinematics, Trajectory Optimisation have been covered in this section.

Figure 10: Final CAD Design for MR2

Gerege Holding Mechanism

Here, we have designed a Servo actuated Gripper similar to the Gerege Holding Gripper in MR1 with addition of a base support.
The passing of Gerege from MR1 to MR2 takes place when the Limit switch present on the MR2 Gerege Holding Gripper is pressed by the Gerege which actuates the Servo motor to grasp the Gerege on MR2. After it grasps the Gerege the Gerege Gripper present on MR2 is lowered using the Pulley Mechanism to Hide the Gerege in the C section. The Gerege Gripping arm is inclined at an angle of 5° (*The ambiguity present in Rule 1.5.5 suggests that the Gerege doesn't have to Visible or Vertical. So, if the ambiguity is resolved the hiding C section will be detached and the inclination of 5° will be removed*).

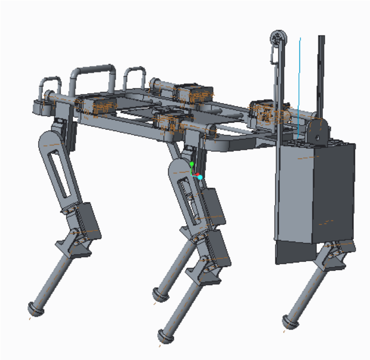

Figure 11: Gerege Hidden after collecting Gerege

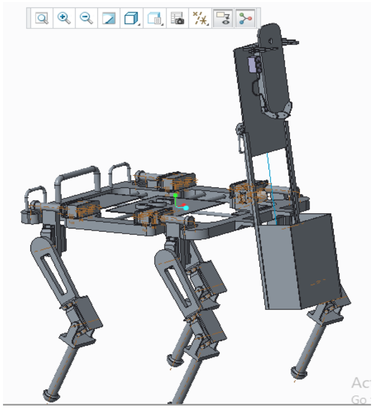

Figure 12: Gerege at Raised position at Uukhai Zone

Gait Analysis

There are mainly two Quadruped Gaits – Creep Gait and Trot Gait. The basic alternating diagonal walk, called the Creep – sometimes is known as the Crawl or Static stable gait. In this Gait, only one leg is lifted from the ground at a time, while the other 3 maintain a stable tripod stance. Although it seems promising in concept, it's not practical to use the Creep Mechanism in a Quadruped robot because if the legs are too short with respect to its body length, they don't travel too far, don't co-ordinate well and may not form a stable tripod at all times. Comparatively, this Gait pattern is slow as compared to Trot Gait.
In Trot Gait, two diagonal legs swings forward while the other two support the body and move backward (as if the body is moving forward). It's one of the quickest gait because two of its legs are lifted at one time.
The diagonal gait pattern allows the legs to be raised before the other diagonal pair of legs would touch the ground with suspension of all four feet's. The sequence of trot gait is left front (LF) + right hind (RH) legs with 1st beat, whereas, the 2nd step footfall is Right Front(RF)+ Left Hind(LH) legs

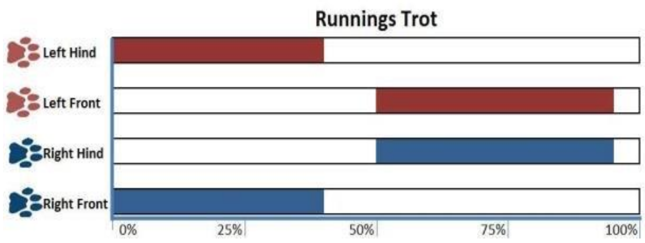

Figure 13:Sequential Diagram of Trot Gait

KINEMATICS

The Kinematic Analysis of the MR2 is described in this section. This quadruped robot is a robotic system that consists of a rigid body and four legs with three degrees of freedom (each leg has the same structure). The links of legs are connected to each other by rotary joints.

Length of Robot	L=550[mm]
Width of Robot	W=450[mm]
Length of Side Swing Joint	L_1=110[mm]
Length of Hip joint	L_2=250[mm]
Length of Knee joint	L_3=250[mm]
The Coordinate System of Centre of body	[x_m, y_m, z_m]
The Main Coordinate System of Each leg	[x_0, y_0, z_0]
The Coordinate System of Side Swing Joint	[x_1, y_1, z_1]
The Coordinate System of Hip Joint	[x_2, y_2, z_2]
The Coordinate System of Knee Joint	[x_3, y_3, z_3]
The Coordinate System of Endpoint of Leg	[x_4, y_4, z_4]
The Yaw Angle of Robot	Φ
The Pitch Angle of Robot	Ψ
The Roll Angle of Robot	Ω
The Angle of Side Swing Joint	θ1
The Angle of Hip Joint	θ2
The Angle of Knee Joint	θ3

Table 1: Physical Parameters of MR2

Depending on the leg coordinates, the robot body can have different configurations. For this reason, the kinematic equation between the rotational movements (φ, ψ, ω) around the Centre of body's coordinate system (X_m, Y_m, Z_m) and the coordinate system of each endpoint of leg (X_4, Y_4, Z_4) is investigated. Initially, to determine the position and orientation of the robot Centre of body in the workspace, the transformation matrix is obtained.
The positions and orientations of each leg can be calculated according to the position and orientation of the robot's body.

ROTATION MATRICES ANALYSIS

$$T_{RB} = T_M * \begin{bmatrix} C90 & 0 & S90 & -L/2 \\ 0 & 1 & 0 & 0 \\ -S90 & 0 & C90 & W/2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_{RF} = T_M * \begin{bmatrix} C90 & 0 & S90 & L/2 \\ 0 & 1 & 0 & 0 \\ -S90 & 0 & C90 & W/2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{LF} = T_M * \begin{bmatrix} C90 & 0 & S90 & L/2 \\ 0 & 1 & 0 & 1 \\ -S90 & 0 & C90 & -W/2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_{LB} = T_M * \begin{bmatrix} C90 & 0 & S90 & -L/2 \\ 0 & 1 & 0 & 0 \\ -S90 & 0 & C90 & -W/2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

T_{LB}= Position of Left Hind leg; T_{LF}= Position of Left Front leg; T_{RB}= Position of Right Hind leg; T_{RF}= Position of Right Front leg; T_M= Position of Body.

Forward kinematics of robot, deals with the relationship between the positions, velocities and accelerations of the robot links. The Denavit–Hartenberg(DH) parameters are the four parameters associated with a particular convention for attaching reference frames to the links of a spatial kinematic chain, or robot manipulator.
Inverse kinematics is the process of finding the values of the joint variables according to the positions and orientations data of the endpoint of robot. In other words, in order to move the robot endpoint to the desired position, it is necessary to determine the rotational values of the joints with inverse kinematic analysis.
After doing the Inverse Kinematic analysis and by the use of D.H. Parameters, the equations we got for the angles as mentioned in Table 1.

$$\theta_1 = -\tan^{-1}2(-y_4, x_4) - \tan^{-1}2(\sqrt{x_4^2 + y_4^2 - L_1^2}, -L_1)$$

$$\theta_2 = \tan^{-1}2(z_4, \sqrt{x_4^2 + y_4^2 - L_1^2}) - \tan^{-1}2(L_3 * \sin\theta_3, L_2 + L_3 * \cos\theta_3)$$

$\theta_3 = \tan^{-1}2(-\sqrt{1-D^2}, D)$ ----------------------------> For RF, LH leg

$\theta_3 = \tan^{-1}2(\sqrt{1-D^2}, D)$ ----------------------------> For LF, RH leg

Where, $D = \dfrac{(x_4^2 + y_4^2 - L_1^2 + z_4^2 - L_2^2 - L_3^2)}{2L_2 * L_3}$

MOTION PLANNING

This inverse kinematic analysis helps us to obtain joint angles which can be used to define individual gait motion of each leg. These angles are helpful in planning of the foot trajectory. For the path to be traversed by the MR2, we know that a single gait pattern is insufficient for the stable walking of the quadruped. Therefore, 4 Different trajectories (Normal Walking, Sand dune, Tussock and the Mountain Area) are to be obtained which can be used for each type of terrain. Now, how to obtain the trajectory is answered by the Inverse Kinematics equations. Angles of the links at a particular point on the ground are obtained by giving coordinates of end effectors. So we can get the angles of links on starting point of the gait as well as end point of Gait. Also, if we place a third point on the trajectory in air we can obtain a full gait pattern.

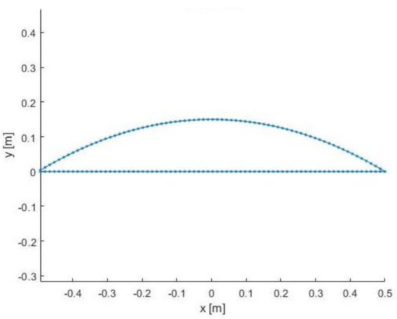

Figure 14: FOOT GAIT TRAJECTORY

But this gait pattern obtained depends on the third point on trajectory and also just 3 points make the trajectory quite rigid and linear. This problem is solved with the help of **Cubic Spline Interpolation Method**. We have used this method for conversion of the rigid trajectory to a smoother spectrum. This smoothness allows the actuators to move without jerks incorporating non-aggressive behavior to torque fluctuations.

TRAJECTORY OPTIMISATION

The trajectory obtained, even though it is smooth and perfect, it lacks the basic desired quality and that is it should work on minimum needs. That is, it must include less use of battery, quickest path along with the shortest path. These all qualities give the trajectory an upper edge over basic requirements. Therefore, we have tried to incorporate this in our trajectory optimization. Hence we have decided to optimize the following parameters:

1. Shortest time for motion
2. Shortest displacement of end-effector
3. Maximizing number of way-points in a single trajectory
4. Creating non-aggressive torque profile for smooth motion

This optimization is done with the help of MATLAB’s Deep Learning Toolbox. This Deep Learning Toolbox helps us to simulate the quadruped. It enables us to get deep insight into the trajectory path of each leg.

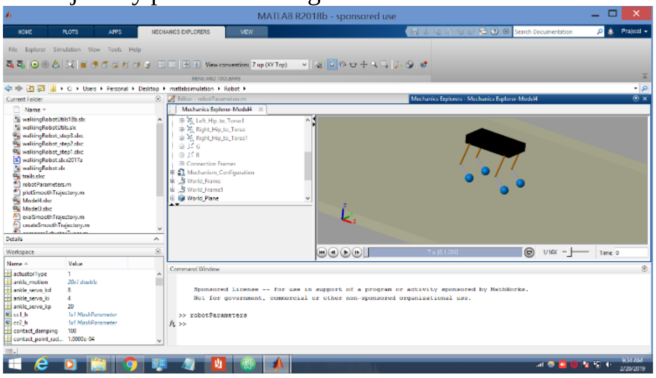

Figure 15: Walking Quadruped Simulation and Path Optimisation on MATLAB

We are doing it by using the Cost-Function on SIMULINK Model, which helps the simulation model to learn how to walk. This Cost Function consists of the calculation of what is correct and what is not. Therefore we add points for Positive Rewards i.e. when the simulation does desired motion while Negative Rewards reduces the total point score and also gives us the idea about the parameter which hinders the motion of the

Thus the trajectory can be optimized using the MATLAB’s Deep Learning Toolbox which will be used for Gaits of different paths. Giving more Dynamic approach to this, we are adding MPU, Gyro and Accelerometer feedback to make it dynamically stable and prevent the Bot from toppling.

ELECTRONICS OVERVIEW

PCB

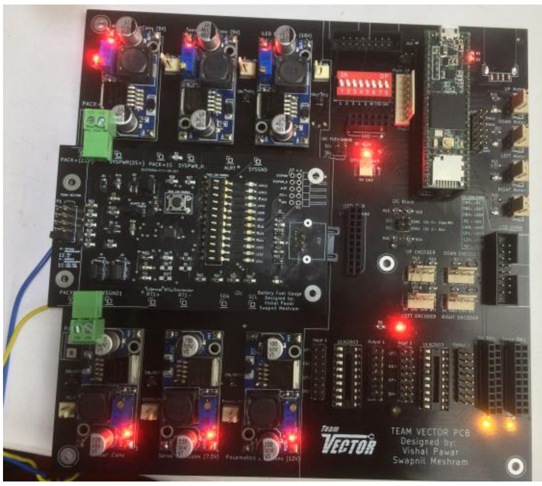

Figure 15: PCB for MR1 and MR2

BATTERY MONITORING SYSTEM

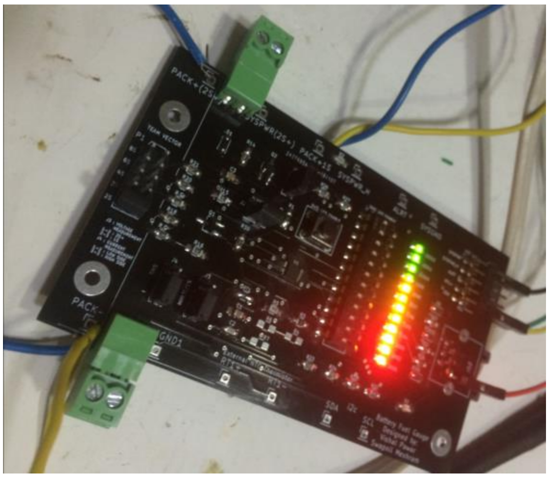

Figure 16: Battery Monitoring System

LCD & RELAY BREAKOUT BOARD

Figure 17: LCD Breakout Board