Robocon 2019
Design Report
RoboManipal, MIT Manipal

1.General Overview:

The Robocon 2019 problem statement is a more exciting and complex challenge as compared to the previous years. Over multiple brainstorming sessions, simulations and proof-of-concept tests, the following solutions were conceived of, and narrowed down by our team for the challenges posed by the rulebook.

Design Challenge	**Proposed Solution**
Navigation of Forest and Bridge zones by MR1	A semi-autonomous hybrid MR1 design, with a manual wireless controller assisted with autonomous line-following with a holonomic 4 wheel base
Loading and Tossing of the *Shagai*	Pneumatically operated 2-prong mechanism and catapult/paddle mechanism
Passing of the *Gerege* by MR1	Envelope and trapdoor mechanism (Cassette player mechanism)
Receiving and storage of *Gerege* by MR2	Funnel and Basket mechanism
Fundamental Design of Quadruped	Design with low CG for mammalian locomotion using legs with 3 DOFs
Navigation of Sand dune and *Tussock* zones by MR2	Computer aided vision and proximity sensors on hooves
Signal for ascent of Mountain zone to MR2	Unique non-contact IR assisted interrupt

2.Semi-Autonomous Hybrid MR1:

The following section describes our research, design and analysis process for MR1.

2.1 Base Movement and Sensing

The base of MR1 is an aluminum chassis measuring 900mm x 900mm. The holonomic drive consists of 4 Omni wheels attached to planetary-geared DC motors, placed in an 'X' configuration. This wheel configuration was chosen to attain optimal speeds while retaining agility. The base motor assembly consists of 24V DC IG-45 Cytron motors, bearing blocks, motor shafts and motor mounts. The motor shafts and bearing blocks were designed and crafted in our machine shop as per our requirements. Learning from past design failures, each motor has two sets of bearings and blocks to compensate for torsion applied by the motor and a bending effect due to the offset between the two axes. A pair of Cytron MDD10A motor drivers control the motors allowing up to 4A per motor giving MR1 the necessary acceleration. Also, they support an anti-phase locked mode that aids in faster braking.

The wheel assemblies were tested on the basis of their immediate response to variations from the controller to avoid any drift during an impulsive acceleration as well as to ensure on point rotation. The base was manufactured from aluminum to counteract the impact loads from the piston actuated paddle mechanism. The load is equally distributed on all four wheels.

The MR1 is a semi-autonomous robot that operates autonomously in the Forest and Bridge zones. It achieves this by taking inputs from 3 Cytron LSA08 (Line Sensing Arrays) sensors. It is maneuvered using a wireless PS2 controller in the other regions.

Because no-onboard computation was required, the Arduino platform was chosen for MR1. An Arduino Mega 2560 along with a PCB interface shield designed by the Electronics team is the main controller on the bot. The PCB is designed within the IPC 2221 standards and works on an 8V level while powering and interfacing all the sensors of MR1.

2.2 Shagai Loading Mechanism

This loading mechanism consists of two stages; gripping and pivoting.The gripper consists of two prongs, one of which is 3d-printed to conform to the contour of the Shagai to provide grip. The other, is fixed and patterned as a fork to eliminate the moment produced while holding and gripping onto the Shagai. The end effector is hinged at the edge of the bot. The gripper is actuated with the help of a Johnson motor (with gear reduction 60:1). A four bar linkage is used to pivot and load the Shagai onto the paddle.

2.3 Air Reservoir Array

The connectors are sealed with silicon paste which allow for more expansion tolerance at the pneumatic connectors. The bottle hoisters are made from laser-cut acrylic and are padded with isocyanate foam to compensate for expansion tolerance and firmly constrict the bottles to the reservoir assembly. There are two reservoirs on the sides, called cartridges, and two such structures hold the required amount of pressure for the entire duration of the game.

2.4 Shagai launching mechanism

The launching mechanism comprises of 3 invariable links and a piston cylinder arrangement as its fourth link. The placement of jointed pairs is such that the mechanism makes the most of mechanical leverage to quickly launch the Shagai. The paddle is made with a wooden platform along with an aluminum frame with variable positions for placing the fork pivot. This allows us to experiment and obtain the optimal range of throwing. The launching is controlled by two solenoid 5x2 valves with a plumbing design that helps keep a consistent range of inlet pressure. However, on further trials, it was noticed that 6 bar of pressure was insufficient to achieve our throwing range. Ergo, an alternative plumbing design was envisioned to attain a gauge pressure greater than absolute pressure in the piston during the launch.

2.5 Gerege Passing Mechanism

The Gerege is initially held in a 3D printed envelope. The envelope has provision for a 9g servo that actuates a slot at the bottom. The design minimizes lateral movement while facilitating a smooth transfer. The structure holding the Gerege consists of a central pillar with a square cross section, and is supported by 4 ribs in all directions that prevent bending, torsion and provide a rigid structure. This actuator minimizes chance of error.

3.Autonomous Quadruped MR2:

To design a successful four legged robot was a challenging task. However, modularizing our process and functioning as efficiently as possible made this as the MR2 is not a conventional wheeled robot, its subsystem breakout is more extensive. The following section describes the research we performed, our design and analysis process for MR2

3.1 Basic design outline and chassis

The design team explored the following options for designing the quadruped:

- a spider-like mechanism with the chassis of the bot much lower to the ground
- a horse-like mechanism with both the hip and knee joints active
- a horse-like structure with only the hip being active

The design team did not want a robot having degrees of freedom lesser than the minimum number, so as to not being able to perform any of the tasks in the problem scope. However, we did not even want to make a quadruped that had extra mobility because it would cause complexity in control. The spider mechanism and horse mechanism without an active knee joint would not be able to provide us with the required gait. Various simulations on Gazebo and RoboAnalyzer of the spider-like mechanism further validated our choice to draw inspirations from well-known four-legged robots.

Upon extensive research to find the optimum length to breadth to height ratio of the robot, we began our first iteration with a ratio of 5:2:1 with the shortest length (height) being 150mm.

3.2 Movement, Control and Sensing

As the motion of a functional quadruped is the product of many interdependent variables, this section is further divided into the following subsystems.

3.2.1 Actuation

The next stage of design included choosing from the various forms of actuation we could employ. Below are few of the options that were considered:

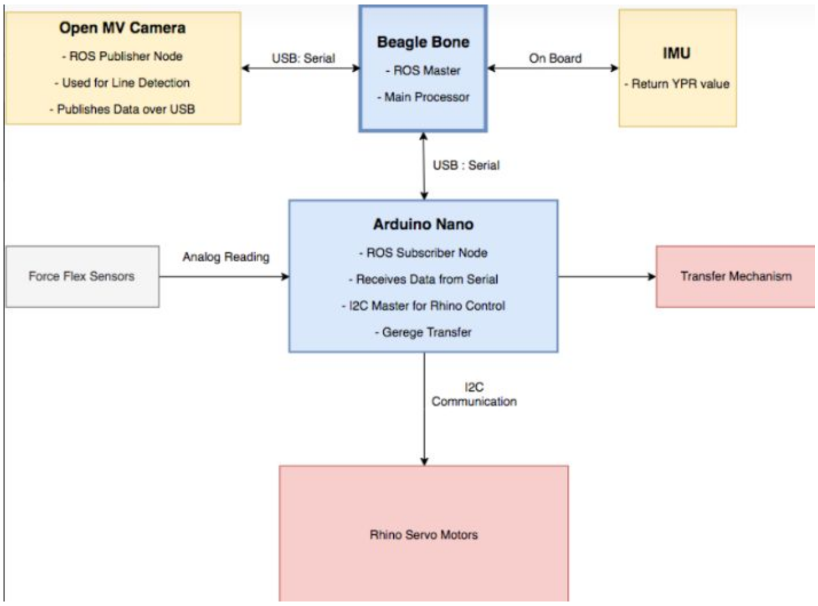
Using two motors at the hip joint and one on the knee

Using two motors at the hip joint but pneumatic controlled piston at the knee joint

Using hydraulics to actuate both joints

The final choice after various PoC test runs was to use 3 sets of motors on each joint for maximum range of

motion and a reasonable speed. The motors for a such an application needed to have a provision for high torque, minimal play, accurate speed control and precision feedback, preferably on a suitable serial communication protocol. After a market survey of all the motors available and analysis of torque, RPM and feedback required, Rhino High Torque Encoder DC Servo Motors were finalized for the MR2 design. They allow us to give commands on an I2C line thus simplifying communication. Also, an in-built 0.2-degree resolution quadrature optical encoder provides precision feedback for speed and position control.
The ROS master monitors the motion based on the feedback received from the Arduino, and sends control signals back to it using inverse kinematics to compute the joint motion. An Arduino, acting as a subscriber node on the ROS network acts as the I2C master for Rhino motor assemblies.



3.2.2 Choice of Gaits

Upon various exhaustive simulations in RVIZ and Gazebo, taking into account the inertial properties as well as the collision properties, we arrived at various stable and reliable gait patterns including the creep and walking trot gaits, for our design. The singularity analysis of closed-chain kinematics pointed out the configurations that should be used or avoided for a desired behavior of the robot. In quadrupedal trot-walking, robot feet are diagonally paired i.e. front left is paired with back right and front right is paired with back left, and these pairs move simultaneously.
In continuous trot walking, there are three phases:

1. Left front, right hind stance phase;
2. 4 legs stance phase,
3. Right front, left hind stance phase.

We can create an analogy for an equivalent planar biped model, considering the particular trot-walking motion, where the left foot of biped is the middle point of left front - right hind couple. Hence it can be interpreted as:

i) left foot single support phase,
ii) double support phase,
iii) right foot single support phase.

It's one of the quickest gait because two of its legs are lifted at one time. The stability of the body is directly proportional to the frequency of the legs being lifted and placed.

While the alternating diagonal walk has dynamic stability (Trot Gait), the creep has "static" stability. Only one leg is ever lifted from the ground at a time, while the other three maintain a stable tripod stance. The grounded legs are maintained in a geometry that keeps the center-of-mass of the body inside the triangle formed by the three points at all times. As the suspended leg moves forward, the three legs shift the body forward in synchrony, so that a new stable tripod can be formed when the suspended leg comes down. The steady mechanism maintains static stability at all times.

The climb up the slope can be achieved by using the same gaits as in case of the walking, i.e. the Trot gait or the Creep gait. The difference here will be the height of each step which is achieved by modifying the ellipsoid workspace equations in which a leg moves. By increasing the height of the step, an increased slope can be traversed without compromising the static / dynamic stability achieved by the above mentioned gaits.

As for climbing, our hoof is designed such that it can climb any slope up to an incline of 20 degrees. It has a spherical bottom providing point contact with the ground, allowing a tangent (the slope) to be scribed. This also allows us to eliminate the degree of freedom on the ankle joint. The issue of traversing the Tussock was resolved because we already had one degree of freedom each at the knee as well as two at the hip.

3.2.3 Control systems and Sensing

The control system aka our locomotion module, draws inspiration from animal neural system and uses adaptive Central Pattern Generators (CPGs). Such a system provides characteristics like synchronization, entrainment and allows the quadruped to be modulated by external signals. The walking period and step length are set as constants, while the foot trajectories are changed on different terrain. The CPG model possesses several advantages:

1) It produces periodic signals without sensory inputs (sensor inputs can be supplemented to modulate the output of the CPG).
2) Provides distributed control, where each unit of the CPG controls one joint and upon modulating network parameters, we achieve different phase relationships
3)Adaptive to the different terrains on the Arena. The sensory feedback adds robustness to the CPG, further stabilizing limit cycles and limiting perturbations.

While most CPG models (e.g. the Kuramato, the Matsuoka, and the Van der Pol models) are restricted to sine or quasi-sine signals, which may work well for snake-like (serpentine) motion, they are pessimal for walking patterns of legged robots. A series CPG model is suited to achieve robust and dynamic trot and creep gaits. Our proposed CPG model is expected to learn A_i (DC component) and $iwt+\varphi_i$ to represent any periodic motion using Fourier Transforms. We build a CPG model that can produce any periodic signal and adjust its phase online. We control the 12 joints using 12 such CPG models, through adjusting phase difference for each CPG. We would require a maximum of 4-5 harmonics for the CPG to learn the gait and reproduce it.

We are using the values recorded by an IMU sensor (Inertial Measurement Unit) processed through a set of filters, to keep the body's orientation parallel to the slope of the ground. The combination of values read by the accelerometer, gyroscope and magnetometer will determine the angle at which the quadruped base is tilted. We are using a control system with a small overshoot as well as a short settling time.

Our options for control were a proportional integrator (PI) or a proportional integrator derivative (PID) control. We opted for simpler solution of a PID controller for a variety of reasons. The integrator helps our bot follow the mountain region. In contrast, the complex controllers that compensate for the non-linear components of the quadruped are processor intensive and would require a mathematical model of the quadruped which would not be feasible owing to the servo's mechanical limitations.

An OpenMV camera helps run machine learning algorithms and is a very reliable option to perform line following. A robust linear regression algorithm computes the slope between pixel pairs providing enhanced tracking control. Feedback is received in the least time to make up for the time taken by the regression algorithm. The resolution was reduced to optimize processing, not compromising on the accuracy. OpenCV conventions are followed to ensure easy debugging of the code. The two error function outputs are fed into a PID loop and the result is used to drive the motors.

The sand dune as well as the tussock region pose challenges to the maneuverability of MR2. The OpenMV camera is precisely thresholded (using Adaptive Thresholding) and calibrated at varying light conditions to differentiate the Gobi area, and the Tussock region. Otsu's binarization algorithm is apt as our image in this circumstance is bimodal due to minimal differences in the value of the pixels. MR2 takes further validation from proximity sensors placed on the fore legs. It adjusts accordingly, upon detecting the region, to avoid the edge of the sand dune as well as the rope in its next step. The IMU values obtained are very crucial in this stage to ensure that the bot does not topple while traversing the obstacles.

3.3 Gerege transfer mechanism on quadruped robot

MR1 will be transferring the gerege to MR2 at the Gobi Urttu by opening the slit using 9G servo. There will be a limit switch at the bottom of the bucket. As soon as the gerege falls in the bucket, the limit switch gets activated which gives us the feedback that the gerege has reached and the autonomous bot can respond and start moving.

For lifting the gerege at the Uukhai zone (mountain zone) MR2 will be using forklift mechanism using rack pinion. The forklift derives its power from the Johnson motor. The motor transmits the torque to the pinion which converts the rotational motion to linear vertical motion and starts lifting the bucket. It goes upward between two channels. The motor moves along the channels like a slider and pushes it up.

3.3 Material choice

Our array of choices for the manufacture of chassis included: Stainless steel rods, aluminum rods, aluminium L-Sections as well as square sections. Stainless steel was eliminated owing to its high density (2.81 g/cm^3). L sections were an impractical choice due to the high amount of twisting that they undergo. The diameter of the aluminium rods that would have to be used to provide the same strength as that of a square section would be extremely high; this would mean that the weight of the chassis would increase multifold. Hence, it left us only with one option, using aluminum square sections; this had the perfect strength to weight ratio (115 KN-kg) and also it didn't undergo as much torsion as the L sections.

We had similar choices for the legs, stainless steel rods however underwent severe slipping and twisting due to the smoothness of the surface (0.0001 microns). Hence we chose aluminum rods placed in a parallel orientation to provide resistance to bending and counteraction of twisting.

Philosophy: We are a team that believes in solving the problem efficiently and with simplicity. We minimize the components on our robots to reduce weight and power so that our robots can traverse the arena swiftly. We modularize our codes and logic into our own libraries for quick decision making and easy troubleshooting. We manufacture our own state of the art PCBs which provide the best interface between our controller and our robot while keeping compact and modular without making a mess of the wires.

This robocon is no different. We move on from frugal innovation and bring our 9 years of expertise to the arena with our solution for MR1 and MR2.