<u>Needs Assessment Report</u>

Team 23
Robot Pentathlon

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ABSTRACT

This Needs Assessment Report is intended to bring to light the ideas and approach of the design we will be entering into the 2017 ASME Robot Pentathlon Competition. This competition requires competitors to design and assemble a robot to accomplish five distinct tasks: Sprint, Throw, Climb, Hit, and Lift. While accomplishing these tasks, our robot design is subject to a few strict specifications. First, the combined size of our robot, controller, and batteries may not exceed 50cm x 50cm x 50cm. Also, all energy storage devices such as batteries and compressed air tanks used in our robot must have the ability to return to their initial state at some unspecified point in time.

ACKNOWLEDGMENTS

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1. Introduction

The ASME Robot Pentathlon competition gives us the opportunity to design and build a multifunctional robot to compete in five specified events. Each event will be broken down individually and researched with the goal of find the best design to perform each task. The first event is the sprint where the robot will have to travel down a straight path of 10 meters, touch a fixed wall, and then return to the starting box. The second event, named the lift, will require the robot to lift an object with a weight of our choice as high as possible and hold it in this position. The third event, the throw, calls for the robot to throw a tennis ball as far as possible while remaining in a throwing area of dimensions 1 meter x 1 meter. The fourth event, the climb, requires the robot to climb three steps and back down to return to the starting area at the base of the steps within a period of two minutes. The fifth and final event is the hit which requires the robot to hit a stationary golf ball placed on the ground as far as possible. Combining all of these tasks into a singular robot will produce a well-rounded machine as desired by the nature of the pentathlon competition.

2. Background and Literature Review

2.1 The Lift

The lift portion of the competition is scored based on the weight lifted, and the height lifted. The score is calculated using the formula:

$$Score = (Height - Maximum\ Height) * Mass \qquad \text{Eq. 1}$$

One of the most efficient ways to lift the weight is a scissor mechanism that extends when the ends of the bottom links are pushed toward each other. We are exploring the use of a pneumatic system in order to provide the force to lift the weight. The geometry of the condensed scissor lift is one of the main issues with this design due to the lack of mechanical advantage when the angle of the link compared to the ground is relatively small. This can be corrected by changing the direction of the force input to a more vertical orientation.

Figure 1a: A small scissor lift demonstrating the large height gain that can be achieved from a small initial state

Figure 1b: A pneumatically-powered scissor lift using a vertically oriented input piston

We are also exploring the possibility of lifting an extremely heavy weight using only pneumatic pistons on the four corners of the robot that will extend upward and downward in order to lift the weight a maximum of approximately 80 cm. The main benefit of this design is the significantly increased amount of weight that can be lifted. Some initial back-of-the-envelope calculations based on available and affordable air compressors result very high weight that can be lifted. For example, assuming we used a compressor rated for 150 psi to lift a 50 cm x 50 cm plate of unknown thickness and material, we could theoretically lift a maximum weight of ~58000lbs, calculated using Equation 2.

$$150\frac{lbf}{in^2} * 2500cm^2 * \frac{0.155in^2}{1cm^2} = 58{,}125lbf \qquad \text{Eq. 2}$$

This design is also much more mechanically simple, and doesn't rely on the linkages between large numbers of links which increase the opportunity for catastrophic mechanical failure. This simplicity also lends itself to a lower cost. The amount of material and linkages required for a scissor lift are large, heavy, and costly. As long as pistons can be acquired for a reasonable price we will save on cost, weight, and complexity using this approach. The redistribution of cost here will allow us to use a larger air compressor and tank, which we can also use to benefit other events, such as the golf hit, and the tennis throw.

2.2 The Sprint

The rules of the sprint state that the robot must leave the starting box completely, touch a wall 10 meters away, and return to the box. These rules leave a glaring loophole, in that the robot is allowed to expand from its original configuration throughout the course of the event. We intend to exploit this by using a projectile on a retractable tether in order to contact the wall and quickly return to the initial position. The robot will only need to move about half a meter forwards and back, and the projectile can reach the wall virtually instantly. The scoring system of the sprint is not explicitly specified other than that it will be calculated solely off of the time it takes the robot to complete the event.

2.3 The Climb

This portion of the competition requires our robot to climb up and down a set of three stairs within a period of two minutes. Although the actual step heights are not known, it is stated in the rules that each landing height will be no less than 8 cm and no greater than 15 cm. There is also a possibility that each successive landing may be of the same or a different height of the landing that precedes it. It is also stated that each landing will be a minimum of 50 cm in length, which is also the maximum allowable length of the robot. Another caveat of this event is that the landing finish is unknown, meaning that the stairs may be rough or smooth, painted or unpainted. All that is certain is that the stairs will be made of wood. We will be given two attempts to climb the stairs in under two minutes.

Our plan is to utilize well researched locomotion techniques, like treads, that will allow for traversing the possible range of stair heights and provides a sufficient level of friction as to not slip when attempting the climb in the event a landing does happen to be smooth. One proposed method of this is to use articulated treads which would be mounted on four independently rotating arms as seen in Figure 2.

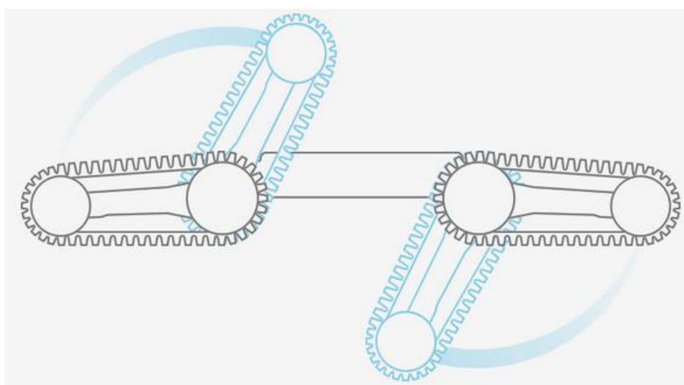

Figure 2: Revolving tracked arms

An alternative method would be to mount our robot on a rocker-bogie style chassis. This style of chassis utilizes six wheels with the sets of wheels on each side on an independent axis of rotation. In addition, the front two wheels on each side are hinged together, this link pair rotates with respect to the rear wheel and allows for a high degrees of mobility. The rocker-bogie system allows for great mobility, especially on uneven terrain, because each side can adapt to different surface conditions. Rocker-bogie systems are popular in space exploration vehicles as well as experimental stair-climbing robots. An illustration of this mechanism is shown in Figure 3. The scoring system for this event is also not explicitly described except that it is calculated directly from the time it takes to complete the event.

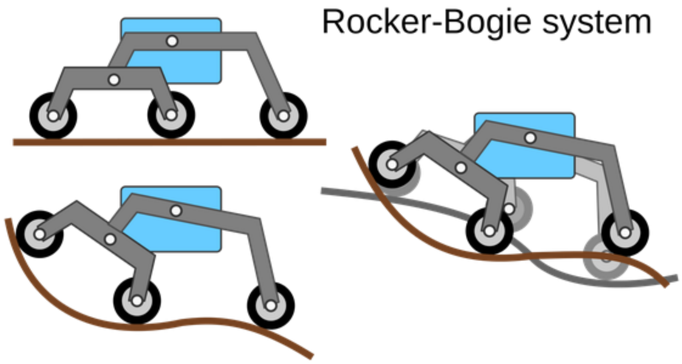

Figure 32: Example of a rocker-bogie system

2.4 The Throw

The rules of this category require us to throw a standard tennis ball as far as possible in a specified direction. Total distance, including post-bounce, is taken into account however, only the distance in the specified direction is counted. This means that our distance score is equal to the product of the total distance of the ball and the cosine of the angle of our error (Ɛ).

$$D_{score} = D_{total} * cos(\varepsilon) \qquad \text{Eq. 3}$$

Our approach to this event is to minimize our error angle as much as possible while maximizing the distance of the ball. The rules of this event state that the ball must be "thrown", though they do not state that the ball cannot be "launched". We plan on implementing a compressed air cannon to launch the ball directly forward with as little error as possible. Using this approach, the ball will travel virtually *exactly* where we desire it to while giving us the freedom to add backspin and orient its initial velocity at the optimum angle of attack.

The trajectory range of the ball can be found by solving the equations of motion where α is the angle of attack and g is the earth's gravity. These were solved to be:

$$D = {v^2}_0 * sin(2 * \alpha) \div g \qquad \text{Eq. 4}$$

Of course, this is a simplified version of the actual system and does not account for lift and drag. The optimum angle of attack is actually somewhere between 35 and 40 degrees [1] and we plan on determining this angle experimentally.

2.5 The Hit

This event requires our robot to hit a stationary ball off of the ground as far as we can manage. In this event, the ball must also travel along a specified path but distance after a bounce is not included in the score. The penalty for angular error is also far greater than in the "Throw" event. In this event, the distance the ball travels *away* from the specified direction is subtracted from the straight-line distance of the ball. This means that the score is calculated using the equation:

$$D_{score} = D_{total} * cos(\mathcal{E}) - D_{total} * sin(\mathcal{E}) \quad \text{Eq. 5}$$

Because we will be penalized twice for any angular error in our hit, precision is paramount on all components pertaining to this event. We plan on using an actual golf club head to make contact with the ball. The reasoning behind this is that the engineering behind golf clubs has been refined over hundreds of years. Any golf club on the market today is undoubtedly superior to any substitute that we could come up with during the course of senior design.

We plan on actuating the club with compressed air as well. Because we already plan on utilizing a pneumatic system for other events, it is both resourceful and cost-effective to apply that infrastructure here as well. The type of club to be used is still to be determined. We plan on building a test rig with our pneumatic system in order to determine the optimum type of club and club pitch for this event.

3. Need Statement

The objective of Team 23 is to design and build a remote controlled robot that can sprint in a straight line, lift a weight, throw a tennis ball, climb a set of three stairs, and hit a golf ball. Additionally, the robot must meet the rules and constraints of the competition. The robot will be designed with the intention of winning the 2017 ASME Robot Pentathlon Competition.

4. Constraints

4.1 Spatial and Energy Constraints

- The entire system (robot, batteries, controller, weight) must fit within a sizing box with dimensions of 50 cm x 50 cm x 50 cm
- The robot must begin every event from the configuration in which it was removed from the box
- All non-renewable energy for the device must be supplied by rechargeable batteries
- All energy storage devices (compressed springs or gas) must be returned to their initial state
- All replacement batteries must fit within sizing box
- Flying devices are not permitted

4.2 The Sprint

- Robots which touch the sideline incur a five-second time penalty for each touch
- Robots which fully cross the sideline are disqualified from the event and are awarded last place
- There is a maximum one-minute time limit for this event

4.3 The Lift

- Weight must remain stationary at the maximum height in order to be measured
- The weight must be in the shape of a rectangular prism
- The weight must have smooth sides with no gripping or holding features

4.4 The Throw

- Robot must remain within a 1 m^2 throwing box during the event
- The robot must throw a standard, unmodified tennis ball

4.5 The Climb

- Robot must begin in a 1 m^2 starting box
- If the robot is touched by a team member while competing, or falls off of the side or back of the steps, the robot is disqualified and the team receives last place for the event

4.6 The Hit

- Golf ball must initially rest on the ground
- Device must remain in a fixed location during the event
- Golf ball must not be modified in any way
- Robot must be controlled remotely during this event

5. Conclusion

The goal of this project is to develop a remote controlled robot to complete specific tasks within a competition. So far, we have the needed equations for the swing and cannon shot within a controlled environment. For the weight lift, our robot will utilize a scissor lift, array of pneumatic pistons, or a combination of these methods to get maximum height with respect to weight for best performance. The stair climb event will utilize a revolute-tracked drive system to move up and down the stairs effectively without having to add any peripherals to the robot to move it upwards. For the 10 meter sprint, we plan on designing our robot to move past the starting line and fire a tethered projectile to contact the wall and quickly retract.

Importantly, these ideas are all subject to change. While we currently believe the implementation of the methods outlined in this report are sufficient for victory, we also understand that there are many practical limitations to all of these approaches and we anticipate modifying our design to compensate for these.

6. References

[1] Maximum projectile range with drag and lift, with particular application to golf. Herman Erlichson, *American Journal of Physics* 51:4 (1983), pp. 357-362.

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