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Design of a BattleBot System to Maximize the Probability of Winning the Competition

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Abstract: BattleBots is a competition that pits robots against each other. The winner either disables the opponent or generates the highest number of points determined by a panel of judges. A detailed analysis of knock-out competition dynamics and an attack and defense mechanisms resulted in the design of mid/under cutter and identified a novel strategy in a tail-spin attack to whip a round and lash at the enemy. The front of the bot has armor plating minimizing damage taken while we keep our weapon far away from the opponent to give it time to spin up to speed. The design of individual components was conducted using CAD and Finite Element Analysis including the design of impact resistant drive train. The design has 120 components. Any damaged part of the design can be replaced and reassembled in a mean of 15 minutes (St deviation 5 mins). A 12lb version of the bot was constructed and took 3rd place in the Norwalk Havoc Robot League Competition in Connecticut on May 26nd, 2022.

Keywords: Combat Robotics, BattleBots, Tournament, Modular Design

1. Introduction

We are Team Thagomizer, a rookie Battle Bots team on a mission to win in our first year. Building a combat robot with little experience requires systems engineering and the analysis of the competition in its entirety. We need to find the best type of robot to build supported by a strategy that the competition has never seen. Our decision to use a horizontal spinner is backed by competitor analysis and the competition enterprise. Our decisions over this course of time will focus on maximizing our winning potential.

The BattleBots competition relies on viewership, and we need to put on a good show. Everything leads back to the concept of fans being the driving force behind the money of the competition. With $48,000 dollars on the table there is motivation for the 60+ teams to give their all. Only one team can be the winner and take home the trophy, the Giant Nut. 53 of the 61 robots in last year's competition were veterans; no rookie team has ever won the competition in their first year. While this raises the question of whether this endeavor is at all possible, the systems engineering approach enabled us to analyze the mistakes and successes of previous robot teams in unprecedented depth, and develop a novel and effective design that has the highest chance of winning the competition.

1.1 Context Analysis

BattleBots is an American robot-combat television series that hosts an international tournament in which heavily armored remote-controlled robots fight to the death in a bulletproof arena [1]. The tournament is seen world-wide as the highest-level of competition in the combat robotics scene. The show consists of two parts: "Fight Night" qualifying rounds, and a single elimination tournament. Once accepted and competing, teams fight each other in the Fight Night qualifying rounds in the hope of impressing the selection committee in order to make it into the final tournament.

Fights consist of three-minute bouts in a 48'x48' arena filled with saws, pneumatic hammers, and other hazards which robots can use to their advantage in a fight. Robots are free to smash, cut, rip, and tear at each other in the hope of immobilizing or destroying the other robot. Three minutes fights are decided by judges who score the robots on damage, aggression, and control.

Figure 1. Two BattleBots fighting in the arena

1.2 BattleBots Rules

BattleBots has two rulebooks, one for defining tournament proceedings and one that governs the design of combat robots. Tournament rules delineate the definitions and proceedings of the tournament. This includes but is not limited to Pit and Preparation Area Rules, Safety/Technical Compliance, and Tournament Format. Design rules describe the requirements for any team building a robot to compete within the show. The rules aim to be as unrestrictive as possible while still encouraging fairness and safety. These rules have all been incorporated into the requirements of this project.

1.3 Match Winning Criteria

One-on-One Match Winner: At the conclusion of each One-on-One Match, the winner will be decided by the winner criteria. Judges determine the winner of a match, if it does not end in a knockout, using the criteria of damage, aggression and control where points are awarded based on performance for each for maximum points. (one-on-one match winner). [3]

1.4 Robot Basics

Combat robots primarily spin large blades at thousands of revolutions per minute that they use to disable their opponents. They are battery powered and use electric motors to move and spin their weapons [4].
There are many types of robots, however the most popular and destructive are the aptly named horizontal and vertical spinners. The robots are controlled by human operators using RC technology [5].

1.5 Problem and Need Statement

1.5.1 Problem Statement

Combat Robotics teams struggle to win BattleBot matches with a probability of 90% (compared to an average of 50% winning each match) because of the following reasons:

- Quality – Teams design robots in an ad-hoc manner without researching the competition, strategy or tactics.
- Schedule – Teams fail to schedule properly, leading to a lack of testing and entering half-functional robots into competitions.
- Cost – Teams lack fundraising and sponsorship to cover the costs of their robot.

1.5.2 Need Statement

A system needs to be designed that can compete and win the BattleBot competition and maximize winning probability with the following characteristics:

- Quality – Sport analytics shall be utilized to design a competitive robot that utilizes the latest strategies and tactics to give it the greatest advantage over the competition.
- Schedule – Robot assembly shall be completed early enough to allow for comprehensive validation and verification testing.
- Cost – The robot shall be fully sponsored, requiring no out-of-pocket expenses.

2. Requirements

Two sets of requirements were created. The first are requirements based on the BattleBots rulebook and criteria to participate in and compete at BattleBots. Secondly the design requirements are based on the capabilities needed to create a competitive combat robot based on our own analysis

2.1 BattleBots Rules Requirements

The rules requirements for the system comprehensively cover the BattleBots Rulebook [3]. Some examples of these requirements are as follows:
1.1.3 - The BattleBot shall be capable of moving at a speed of 4mph or faster.
1.2.1 - The BattleBot system shall be remotely controlled.
1.3.1 - The BattleBot shall have one independently powered weapon that is intended to disable the operation of another bot.
2.1.1 - The BattleBot system shall not weigh more than 250 pounds
3.4.1 - The system shall be incapable of moving or operating its weapons when the bot is deactivated.

2.2 BattleBots Rules Requirements

The design requirements for the system were derived from our analysis on what the optimal robot design is. Some examples include:
1.1 - Weapon System Requirements - Robots shall have a horizontal spinning weapon.
1.1.2.2 - Weapon Material - Weapon blade shall be made out of AR500 steel
1.1.5.4 - Shock Resistance - Weapon motors shall be shock-mounted.

2.3 Method of Analysis

Robots are identified by their type of offensive and defensive components. A robot's strategy will be centered around their components. Certain components are more effective against some components and less effective against others. These relationships were analyzed and compiled into an Attack/Defense matrix [3]. This matrix is created on a few assumptions. 1) that every robot is built to the best of their ability. 2) That each robot doesn't damage itself. 3) That every robot has equally skilled drivers.

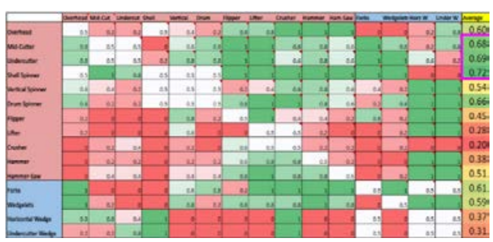

Figure 2. Attack/Defense Matrix

A 1 signifies that a robot with the left configuration will almost always win against an opponent of the top configuration. A 0 means that this robot will almost never win against its opponent. A .5 means that both robots have an equal chance of winning. This matrix was created by analyzing hundreds of matches to identify trends among robot archetypes in order to assist our decisions in the creation of our own robot.

In our analysis we discovered that the Shell Spinner design had the highest single-attachment average score. However, this did not account for robots being able to mount multiple attachments. Further analysis discovered that multiple attachments were able to "counter" a greater portion of the competition than a single attachment, especially when mounted on opposite sides of the robot to allow for selection of which attachment to point at the opponent. The combination of the undercutter and wedge attachments was found to have the highest two-attachment score, which was selected as the basis of our design.

3. Design

3.1 Attack and Defense Mechanism

Through our Attack/Defense matrix we selected an undercutter as our optimal design. As the AD matrix identified wedges as being this weapon's greatest counter, we developed a novel strategy in a tail-spin attack to whip around and lash at the enemy. By placing the spinner at the end of an elongated tail, the weapon is able to strike at the sides of wedges, placing their mountings under tensile instead of compressive stress and increasing our chances of ripping away their defenses. Our frontal side has an armored wedge, minimizing damage taken while we keep our weapon far away from the opponent to give time to spin up to speed. Once it is at speed this maneuver is used to strike at the more vulnerable sides of the opponent. Additionally, we identified an opportunity to make our weapon system modular, allowing us to adopt an optional overhead spinner configuration against robots identified as being weak to these attacks in the AD matrix.

Identified in the AD matrix the horizontal wedge gives us the best all-round advantage when paired with the undercutter spinner. However against specific opponents different attachments might be more effective. To that end our robot's front side is interchangeable in the defensive components it can mount to give the best chance at beating every robot type. For example, mounting wedgelets to the front increases our chances of defeating the common vertical spinners found in competition.

3.2 Drive Train

A combat robot with a strong drivetrain can maintain aggression, control, and push around their opponent, and respond faster to the input commands of the operator. To mitigate the traction-limitation of conventional bots the downforce on the wheels will be further supplemented through electromagnets. The drive motor-module is shock-mounted to limit the chance of damage. The robot is able to drive even when inverted, eliminating the need for a self-righting mechanism.

3.3 Modular Design

Using our Attack-Defense matrix to support our decision making we decided on a robot capable of mounting a horizontal spinner as well as interchangeable wedges. Two types of wedges shall provide protection from all types of spinners. The weapon blades can be mounted on top or below the robot, granting the ability to change the impact-height.

3.4 Maintainability

Particular emphasis was put on the maintainability of the system. From interviewing BattleBot teams we learned that most rookie teams struggled with repairing their robots in between fights. This led us to proactively design our robot to be as maintainable as possible. Both the drive and weapon system are designed as removable modules that allow for quick swaps if a part is damaged. The system is designed around two large plates that run the length of the robot, with additional access panels for localized maintenance. The battery compartment and the drive pods are "hot swappable" to facilitate maintenance by allowing the entire module to be removed and replaced at once.

4. Implementation

4.1 Equations

To give us a rough idea of the forces involved in the competition, we used physics equations to determine the impulses that the system would be subjected to from attacks by our opponent and our own weapon. This gave us a rough range of materials that are suitable for our application and helped us understand the magnitude of the forces we were dealing with.

4.2 Computer Aided Design

To ensure that our digital twin simulations are accurate we developed a sub-scale prototype. To ensure the model was as applicable as possible we used construction practices typically used in 250lb robots, instead of the 12lbs weightclass. The

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entire assembly was designed in the Fusion 360 CAD package, which allows us to visualize how parts fit together and perform preliminary verification testing by ensuring that all requirements were traced to the modeled components.

4.2.1 Drive System

The drive system was identified as the most critical subsystem, as loss of drive is the most common way for robots to get knocked out. The entire drive module is removable in order to ensure ease of maintenance. The motor is connected to the wheel through a two-stage reduction, the first stage is a pulley to mitigate shock, and the external second stage is a hardened pinion and gear for maximum durability. The wheel itself, being the most vulnerable part of the drive was constructed out of a durable urethane outer coating with a nylon core. The pocketed nature of the core meant that urethane could flow into gaps during casting, preventing the urethane from falling off even if large chunks of the wheel were removed.

4.2.2 Weapon System

Our weapon system was designed to be fully invertible, allowing the spinning weapon to run above or below the chassis. The weapon motor direct-drives the spinning blade through a rubber gear to mitigate shock.

4.3 Simulation

The result of the impulse equations were inputted into the Fusion 360 Finite Element Analysis tool. This software allows us to simulate loads on the structure of a digital-twin of our robot, allowing us to test the system before physical assembly. Successive iterations of parts were tested to identify how various geometries reacted to simulated forces. This process ensures that the robot is capable of withstanding expected loads with an acceptable factor of safety, while assisting in the identification of overengineered parts, ensuring the best balance of performance to weight.

5. Verification and Validation

5.1 Verification

We ran multiple verification tests on the Robot's overall condition and separate subsystems (Drive System, Weapon System, Controller). Some examples are described here.

Shock Resistance: The weapon was run at full speed and tested against wooden and metal targets. The shock-absorbing materials protected the sensitive electronics and no damage to the weapon system or electronics was sustained.

Maintainability: The time to replace parts on the robot was measured. The minimum time between matches is 30 minutes, so every part on the robot should be replaceable within this window. For this test, tools were used to disassemble the robot to access the internal components, subsystems were replaced, the robot was put back together, and the time was recorded. Due to the focus on maintainability during design every part was found to be replaceable 15 minutes with a standard deviation of 5 minutes.

Verification of Metal Parts: All metal and welded parts were individually inspected to find possible defects and malfunctions. Early in the process the drive pod was struck with a hammer and found to bend easily. This indicated insufficient strength, which resulted in the 4130 Chromoly parts being sent for heat treatment. After being quenched and tempered at 1000f the parts were struck again and were unable to be bent.

Overall Results: Though not all of our verification test passed immediately, they identified important vulnerabilities and allowed us to resolve them before our validation testing.

Figure 3. The Finished Robot: Minimizer

Figure 4. Minimizer Performing an Attack

5.2 Validation

5.2.1 Prototype Validation

To validate that the high-level design works a 12-pound scaled-down prototype of the robot was assembled and entered into the Norwalk Havoc Robot Combat competition in Norwalk, CT. This event is smaller than BattleBots, however it provided the opportunity to identify early issues with the design as well as test multiple versions of our robot's modular design before entering the 250lb competition. At the event our robot took 3rd place out of 15, beating out many veteran teams and qualifying for a spot in the competition's December Finals.

The novel strategy that we employed in our tail-whip attack surprised both our opponents and the announcers and allowed us to make a deep run into the tournament. The further we got into the competition the more important our ability to repair became. Despite parts failing in unexpected ways, the redundant nature of the system allowed us to keep going. Every step of the competition was documented for later research.

5.2.2 Validation Results

Despite performing well in the competition, there are still many ways the robot can be improved. We identified 24 shortcomings in design and developed potential solutions.

6. Conclusions

The systems engineering process proved to be a valuable and effective tool in enhancing the capabilities of engineering teams in a competitive setting. Analysis of the interactions between existing robot archetypes identified a novel design that could outperform the competition. The careful application of this research led to the development of a digital twin for the robot which could be tested in a simulated environment before physical testing. Verification testing ensured that the system was capable of desired performance before the competition, and the system was validated through a podium finish for a rookie team.

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