F.I.R.S.T. Robotic Drive Base

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Abstract
F.I.R.S.T. is an organization dedicated to inspiring and teaching high school students to be leaders in science and technology. F.I.R.S.T. organizes annual robotics competitions where students in grades 9-12 participate in games using robots to complete specific tasks. These robots are designed, manufactured, and assembled by the high school students and their mentors. NUtrons at Northeastern University is a robotics team which competes annually and features NU students mentoring local high school students. This team can be more successful by implementing greater continuity in year-to-year robot designs. One way to effectively increase continuity is to introduce a universal robotic drive base which is designed to be competitive in most F.I.R.S.T. games and can evolve every year with small modifications. A robotic drive base includes the frame, propulsion motors, transmission, wheels, and chains/belts needed to make the robot mobile. This Capstone group will deliver a design for an 8-wheeled, two-speed, tank-drive drive base that is fast, strong, lightweight, and simple.
The Need for Project

A universal drivebase that can be used in competition every year will simplify the design process and save time for the NUtrons.

The NUtrons traditional method of designing a new drive base every year for annual F.I.R.S.T competitions wastes time and effort in an already tight schedule. Most playing field characteristics remain the same every year, and only several different obstacles have been used throughout F.I.R.S.T.’s history. Because this is the case, a universal drive base can be designed that will be competitive in nearly every foreseeable future competition. The result of a universal drive base design will be no time required for drive base design in future years. Also, a repeatable design will allow for a simplified build process, fewer mistakes, and predictability in the resulting performance.

The Design Project Objectives and Requirements

The goal of this project was to design and build a competitive robotic drive base with both high speed and pushing power.

Design Objectives

The drive base of a FIRST robot requires several key characteristics to be successful in any given game. All design objectives are based on improving scoring efficiency. A high top speed will allow the robot to traverse the field quicker, thus minimizing time between scores. A high pushing force will deliver the ability to move a defending robot out of the way. The drive base also must be able to maneuver over all field elements to make available the most direct routes between game objects and scoring locations. While meeting these three performance objectives: fast, powerful, and all terrain; the drive base must also be weight conscious to leave more room in the total weight budget for superstructure and end-effector elements.

Design Requirements

Through our research, competition data shows a top speed of approximately 14 fps for 75% of robots in the final matches of the world championship. This number, accompanied by a competitive acceleration, is the design requirement we have set for velocity. The pushing power required for our drive base is approximately 190 lbs. This is calculated from the force required to push a robot at full competition weight (150 lb) with a coefficient of friction of 1.3. The drive base geometry has been designed to allow clearance of a 6” step and a 45° ramp. The goal weight of the drive base is 30 lb. This is a very aggressive number compared to previous NUtrons drive bases (25-30% lighter), however it will be a very beneficial exercise to build weight saving knowledge and experience for future drive bases.
Design Concepts Considered

Alternative design options were considered for each subcategory of the drive base design.

Propulsion Methods

Research on propulsion methods used in F.I.R.S.T. competitions resulted in both omni-directional and linear motion drive designs being considered. Omni-directional propulsion designs (swerve, holonomic, mecanum, and ball drives) were found to be inadequate due to their high costs, complex designs, and inefficient propulsion. A tank-drive design was selected over the other linear motion design, Ackerman steering, because of the superior mobility and simplicity.

Frame

6061-T6 aluminum was selected as a frame material because of its excellent strength to weight ratio, low cost, and availability. Different frame geometries were considered, including designs where wheels are “sandwiched” between two plates, contained inside box tubing, and cantilevered a short distance from box tubing. Ultimately the cantilevered design was implemented based on weight and strength analysis.

Wheels

Six different wheels were selected for consideration in a way which maximized variation in the following characteristics: diameter, width, tread pattern, tread material, and solid/pneumatic. Wheels were selected based on traction, weight, and cost. The 2”-wide pneumatic wheels selected were heavy compared to other alternatives, however offered the best traction and second lowest price of the six considered.

Transmissions

Both commercial off-the-shelf (COTS) and custom transmissions were considered for the drive base design. The most commonly used COTS transmissions are sold by AndyMark and range from 3.5-4.0 lbs in weight and $350-360 in price. Custom options are generally cheaper and lighter, and included a modified DeWalt drill transmission, a ball-shifting design, and a custom planetary transmission. Ultimately a custom ball-shifting transmission was selected because of its low cost and ease of both fabrication and integration.

Recommended Design Concept

This 8-wheel tank drive design implements a custom ball-shifting transmission. The designed transmission is a 2 speed shift on the fly (SOTF).
transmission, 2"-wide 6" pneumatic wheels, and a cantilevered frame design. It is stronger, faster, lighter, and simpler than nearly all other NUtrons drive base designs.

The transmission uses spherical ball bearings engaged via pneumatic cylinder, to protrude outside of the shaft’s circumference to engage one of 2 different gears that are side by side. The ball bearings engage in detents cut into the inner diameter of the shifting gears that match the radial location and diameter of the ball bearings. To save space, and reduce weight and cost in bearings, a coaxial combination input/output shaft is used with the true input gears being rotationally isolated from the true output shaft on a common roller bearing. These features yield a transmission that at 40in³, 2.25lb, and $170 is 56% of the weight, 64% of the volume, and 47% of the cost of the leading off-the-shelf competitor. Because the transmission is a custom design, the gear ratios are specifically tailored to the motors selected.

The CIM-brand motors are the optimal drive base motor available from the allowed motors. Given the assumption of 196 Watts/CIM motor a top speed of 14 fps will be achieved from standstill in 0.79 seconds. The gear reduction required for this is about 8:1. Also, using the published motor power curve, the torque delivered at max current draw is 100 oz-in. This will require a ratio of approximately 22:1 to deliver 190 lb pushing force on a 6” wheel. The difference between desired ratios is about 2.7:1. The final gear selection of 20 tooth and 40 tooth shifting gears in the transmission yields exactly 8:1 reduction in high gear and 22.22:1 reduction in low gear.

ANSI #25 roller chain will transmit power from the transmission to the wheels. The design features complete adjustability of tensioning for optimal chain engagement at all times.

Pneumatic wheels from Albion measuring 6” in diameter and 2” in width were selected based on experimental traction results (discussed below). Weight and cost were also factors in this decision.

The final frame design comprises of 2”x1”x0.125” rectangular tubing connected by 1/8” thick gusset plates and stainless steel rivets. This connection method allows for the drive base to be assembled without welding, a manufacturing process that requires specialized skills that the team may not have in future years. The frame members are pocketed to reduce weight.

Analytical Investigations

ANSYS finite element analysis was performed to compare the structural strength of the frame design to the minimum yield stress of
6061-T6 aluminum (240 MPa). After several design improvements, the maximum stress was found to occur in superstructure connection plates of 180 MPa, providing a minimum safety factor of 1.33.

AGMA gear stress analysis was also performed for each gear used in the transmission to predict realized stresses in each gear in both high and low speeds.

**Experimental Investigations**

Wheel traction experiments were performed to characterize the amount of torque that each of the wheels could withstand before slipping against a tight-pile carpet surface (which is the standard F.I.R.S.T. playing surface) with a radial load characteristic of the robot. These tests included all six wheels (plus additional tread materials for 4” and 6” solid AndyMark wheels). A Student’s t-test verified that the 2” wide pneumatic wheel provides significantly greater traction than the 6” AndyMark (the next best wheel) with probability P=97.1%.

**Key Advantages of Recommended Concept**

The recommended concept design offers advantages in the following areas: weight, speed, pushing force, simplicity, and cost. Past NUtrons drive bases have all been single-speed designs. Implementing a shifting transmission will allow for both a greater top speed and greater pushing force than past designs. Weight reduction considerations in nearly all areas of design result in a design that is lighter than past years, yet still strong enough to withstand any conditions that can occur during competitions.

**Financial Issues**

The cost for NUtrons to replicate the drive base design is expected to be approximately $1300. The total cost of this project was $1,399.86, however this includes items that were used in testing, but were not part of the final prototype design. An exact replica of the final drive base design would be expected to cost approximately $1,300.

**Recommended Improvements**

Custom wheel hubs can be designed for weight reduction, and superstructure attachment plates may need to be redesigned. One potential weight savings improvement to the drive base design is custom wheel hubs for the purchased wheels and tires. The current design utilizes custom machined PVC hubs that interface with the OEM steel plates provided with the wheels. Also, gusset plates that were designed and analyzed as superstructure attachment locations may be changed or added to suit the specific superstructure
requirements for any given year.