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Final Design Report: The CARTer IV

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EXECUTIVE SUMMARY

This report begins by going into a detailed introduction of the problem. The Trinity Coates Library has old carts that are difficult to push, loud, and slightly dangerous when loaded with books. The main objective of this design project was to build a library cart that was safer, quieter, and easier to navigate around the library.

The design of our cart is broken down into several essential subsystems: the frame, mobile shelving, motor-assisted propulsion, control system and steering system. After the introduction, this report goes into detailed explanations of each component, including the descriptions and requirements of each subsection of the design. Following the descriptions, we go into detail about the initial prototype, as well as the testing and results of the physical prototype.

The initial prototype constructed is a simple circuit designed as a basic proof-of-concept of the carts control system. The prototype demonstrates basic motor functions such as forward and reverse control, speed control, and braking. We also made proof-of-concept calculations on the bolts used to support our shelves, proving that the load can be supported over long periods of time.

Our test plan included tests on the linear actuators, motor, battery, control system, steering system and the overall noise level of the cart in motion. We managed to conduct successful load tests on our actuators and control tests on the motor. Due to time constraints, the remaining motor tests, the noise tests, the battery tests, and the control system tests were delayed. However, the report goes in detail on how we intend to perform each test, the acceptance criteria and the tests will be conducted by the presentation. The results of these tests will be discussed in said presentation.

INTRODUCTION

The library has used antiquated and ineffective library carts for at least 17 years. These current carts are loud, heavy, cumbersome, and dangerous. Along with stiff wheels, the cart becomes extremely top-heavy and difficult for student workers and library staff of various ages and physical strengths to maneuver. This can create problems when loading, unloading, and navigating around the library, especially at the elevator. Our objective is to design, prototype, and test a cart to transport library books and small supplies more effectively than the current design. This process will be used to create a safer, more user friendly cart for students and staff in the time frame of 9 months. The new cart will emit less than 86 decibels of sound in hopes of adhering to the quiet atmosphere of the library. It will also eliminate safety concerns caused by the weight of the cart and the depth of the shelves. The cart should have an improved turn radius so it can easily maneuver through the narrow aisles.

OVERVIEW OF THE DESIGN AS TESTED

The main parts of the cart design are as follows: the frame, the mobile shelving, the motor-assisted propulsion and control system, and the steering. The frame and shelves were initially going to be made out of aluminum, but due to budget constraints, the material had to be changed. We determined the mobile shelving should be made out of wood with a lifting mechanism composed of two electrically controlled linear actuators. Wood will be suitable for the shelves given the constraint of the weight of the books being at least 50 pounds, and the linear actuators will be suitable for the upward and downward motion required, while also supporting at least 100 pounds.

The controls sub-system includes the battery, the motor, the linear actuators, and the Arduino board. The battery will power all of the electrical components in the cart including the Arduino, the motor, and the linear actuators. The Arduino will control the motor and the linear actuators. The motor will push the cart forwards or backwards, and the linear actuators will raise and lower the shelves of the cart.

The steering system consists of a welded metal frame underneath the cart. Attached to the frame are two spindle brackets in the front and a rear axle in the back. The rear axle holds the two wheels and the gear that is powered by the motor. The spindle brackets are each connected directly to the wheels and indirectly to each other through tie rods and a servo motor that turns the wheels left and right.

Most of the design process was centered on cost, noise level, safety, and functionality. The budget was an important factor to keep in mind when deciding on materials and which specific products to purchase. There is no extra money if we were to go over budget, and we needed to leave a cushion in case we needed to order more parts or an idea failed. As the cart will be used in the library, noise was also an important consideration. Lastly, functionality and safety were top factors for choosing parts.

PROTOTYPE TESTS

This section will discuss all the tests our team performed on our prototype and sub-systems, along with an evaluation of the results.

Linear Actuator Load Tests

Test Overview and Objectives

The purpose of this test is to ensure that the shelves are capable of supporting at least 25 lbs of books each. Additionally, to ensure that the linear actuators are able to lift the shelves to about 10 inches with a full book load of 50 pounds.

Test Scope and Test Plan

The battery was used to power the linear actuators while weights of 10 lbs were added to the shelves to simulate the load. A stopwatch was used to measure the time it took the linear actuators to reach full extension. The first test included no load so the linear actuators lifted just the shelves up to full extension and then back down. The following tests added 10 lbs each until 50 lbs was reached, which is the average load of the cart.

A digital multimeter was used to measure the current required by the linear actuators to lift the shelves up to full extension. As previously discussed, a stopwatch was used to measure the time it took to lift the shelves to full extension, and 10 pound weights were used to provide the loads.

The data for this test included the weight in pounds of the loads that were placed on the linear actuators. Additionally, the time it took to get the shelves to maximum height was recorded. Finally, the current the actuators required was measured. The results of this test can be seen in Figure 1.

Acceptance Criteria

The requirement for the cart is that the shelves should hold books with an approximate weight of 50 pounds. Moreover, the linear actuators should lift the shelves to about 10 inches without retracting under load.

Test Results and Evaluation

The linear actuators lifted weights of 50 pounds in around 10 seconds, as expected. The full results of these tests can be found in Fig. 1 of the appendix. The linear actuators met the acceptance criteria and are working as expected. The results of this test were successful and proved the linear actuators and shelving system are compatible for the maximum load.

Motor Tests

Test Overview and Objectives

The tests done on the motor will determine the operating characteristics of the main motor used to rotate the rear axle and drive the cart forward or backwards. The objectives of this test are to obtain values for the current required to drive the motor under various load conditions. This will determine the power consumption of the motor and contribute to calculating the theoretical battery life. In addition to the current ratings, speed and acceleration measurements determined what control limits need to be placed on the motor via the control system. These tests will examine the prototype's ability to propel both forward and backward without the aid of the user and determine the maximum ratings of the motor.

Test Scope and Test Plan

The cart will be operating in an open room, in similar conditions as the library. There will be no shelves in the area as testing the steering features of the cart is out of the scope of these specific tests. The 12V battery will be wired to the motor and a potentiometer will be used to vary the voltage to the motor and, therefore, the speed. Books will be stacked onto the cart throughout the test to measure the performance of the cart with different loads.

This test will require the use of a DMM (Digital Multimeter) to measure the current and voltage of the battery and the motor, and well as the resistances of the potentiometer(s) and the motor and the overall system. We will need a scale to measure the weight of the books that we are adding to cart to obtain the average and maximum load the cart can handle. We will need a stopwatch and a tape measure in order to measure the speed of the cart.

We will use basic electrical circuit theory to determine the power consumed by the battery, the current flowing through various electrical components such as Ohm's law and the power equation. Furthermore, kinematics with the tape measure and the stopwatch will be used to calculate the speed and acceleration of the cart. Mechatronic theory will be used to calculate the torque of the motor.

Current and resistance measurements were taken to determine the power consumption of the motor. Additionally, the time it took the cart to travel a certain distance with a certain load was determined to verify the speed of the cart.

Acceptance Criteria

The acceptance criteria for these test include the ability of the motor to push the cart with an external load of at least 50 lbs. The motor must be able to propel forward at the average walking speed and no faster than 3.5 mph (a brisk walking speed). The power consumption of the motor should not be so that it drives the battery life down.

Test Results and Evaluation

The measured no-load current of the motor is around 0.55 A at 12V. However, this voltage is way too high for applications in this project. At 3 V, the no-load current was measured to be around 0.38 A. We were unable to mount the motor as of the time the report was written, as the mount for it is not quite finished. We plan on fully testing and having the results by the time of the presentation on May 9th.

As of now, it is difficult to evaluate the results of these tests due to the fact that there is little data to back up our claims. Again, we will address this issue by the day of the presentation since we will have a finished product.

Noise Test (tires, motors, linear actuators)

Test Overview and Objectives

The purpose of this test is to ensure the noise level remains under 86 decibels while the cart is moving and while the shelves move up and down. A constraint of the cart was that it remained under 86 decibels to comply with the quiet atmosphere of the library. We will also ensure the cart remains quiet as it drives over the uneven brick areas of the library.

Test Scope and Test Plan

As mentioned earlier, the cart must remain under 86 decibels of noise at all times of use. Obstacles will include the uneven terrain and the noise of the motor and linear actuators. The test will take place in a quiet environment so there is no external noise that skews the results.

Instruments used to perform this test include an application called Decibel X. This application is a noise meter app that has pre-calibrated measurements that turn any iOS device into a professional sound level meter.

Acceptance Criteria

The sound produced by the motor and linear actuators should be less than 86 decibels in order to allow a quiet library environment. The cart should also remain at a noise level less than 86 decibels while moving over the uneven brick floor of the library.

Test Results and Evaluation

Due to a delay in receiving a part for our axel, we are not able to perform the test at this time. We will have completed the test and the results come presentation time.

Battery Tests

Test Overview and Objectives

These tests are used to determine the performance of the battery that is used to power all of the electrical systems in this design. The objectives of these tests are to determine the battery life of the battery under normal cart load conditions, the fail voltage of the battery, and the time it takes to recharge the battery from drained to full. These tests should show that the battery can provide reliable power to the cart and last through the workday.

Test Scope and Test Plan

The battery will be tested by using the cart in normal operation to see how long the battery lasts. This operation includes the use of the linear actuators, the drive motor and other exterior electronic devices that will drain the battery. Load conditions will be varied from no load to the average load of 50 lbs to assess the effects weight has on the battery life. Additionally, the battery will be charged with the charger that we will provide the user to maintain battery life.

A 12 V battery charger will be used to charge the battery. A digital multimeter (DMM) will measure the voltage of the battery and determine the charge. A timer will measure how long the battery lasts and how long it takes for the battery to charge in practical situations. Simple mathematics will be used to evaluate the theoretical lifetime of a battery under a given load against the measured battery life under said load.

We will measure the current coming out of the battery under light and heavy load conditions to derive the theoretical battery life given the 20 Ah battery capacity. Voltages will also be measured to determine when the battery is fully charged and when it is drained. Time measurements will be taken to find the actual battery life of the battery under different conditions.

Acceptance Criteria

The battery must last at least 8 hours under normal operating conditions, and at least 4 hours under constant use at the average load of 50 lbs. The battery should be able to be able to charge fully overnight, approximately 8 hours.

Test Results and Evaluation

We do not have a lot of data regarding this test as we are having the same issues as in the motor test section; the motor is not mounted so we cannot get true battery life data without the motor attached with a load. As previously stated, we will address this issue in the presentation after everything is completed and we have run the tests and accumulated data.

Control System Tests

Test Overview and Objectives

The control systems tests should confirm that the electrical systems of this design work as expected given the correct inputs. The objectives of this test are to verify that the controller can control the speed and direction of the main motor and linear actuators while receiving key input from the user such as power on, desired speed and direction.

Test Scope and Test Plan

The controller used is an Arduino Mega, which powered by 5 V voltage regulator that regulates 12 V from the main battery. There are several switches used to power the electrical systems: the on/off switch, the linear actuator up/down switch, and the motor direction switch. Additionally, there will be a speed dial to control the speed of the motor. Two LEDs will be used to indicate electrical power is on and whether motor is in forward or reverse mode.

A DMM was used to measure voltages and currents in the control circuit. Most of the control system tests were done without everything assembled onto the cart. Some tests were done of the control system individually, disconnected from the system as a whole to ensure functionality and to ease the debugging process.

Modular programming was used to help with the readability of the control program and the debugging. We used several debugging methods in order to fix errors in the control system, including LED debugging, serial printing, and piece-by-piece debugging. The whole control system was not tested as a whole at first, as this greatly increases the difficulty in fixing errors found in the program, however it was tested section by section. For example, the motor direction and speed control was tested first, then the linear actuator position control was tested, then the power switch was tested, and so on. Once everything was verified to be working correctly, the different subsystems of the control system were put together to test the system as a whole.

There was no concrete data taken in these test results. However, in order to test the systems, we went through a checklist of scenarios that proved the control system worked as expected. These scenarios include situations like changing motor speed, changing motor direction, lifting the linear actuators up, and bringing the linear actuators down. The motor direction switch changed the direction of the motor, and the speed knob increased and decreased the speed.

Acceptance Criteria

The control system should control the speed and direction of the motor, the position of the linear actuators and the shelves, and the power of the system. If these things are met, the control system designed is seen as acceptable.

Test Results and Evaluation

The control system met all of its requirements and is working as designed. These tests were done without the full construction of the cart completed, therefore it is not known if these systems will be affected once applied to the full cart. These tests will be performed shortly and their results will be discussed in the upcoming presentation.

CONCLUSIONS

The cart has proven capable of withstanding a full load of books and lifting them to a more manageable unloading height. The control system performs the necessary functions of changing motor speed and direction, shelf height, and system power. As of this point, several tests were not completed due to construction delays. These tests include the motor full load tests, the battery life full load tests, the noise tests, and the fully integrated control system tests. These tests will be completed prior to the presentation, and the results will be addressed then.

APPENDICES

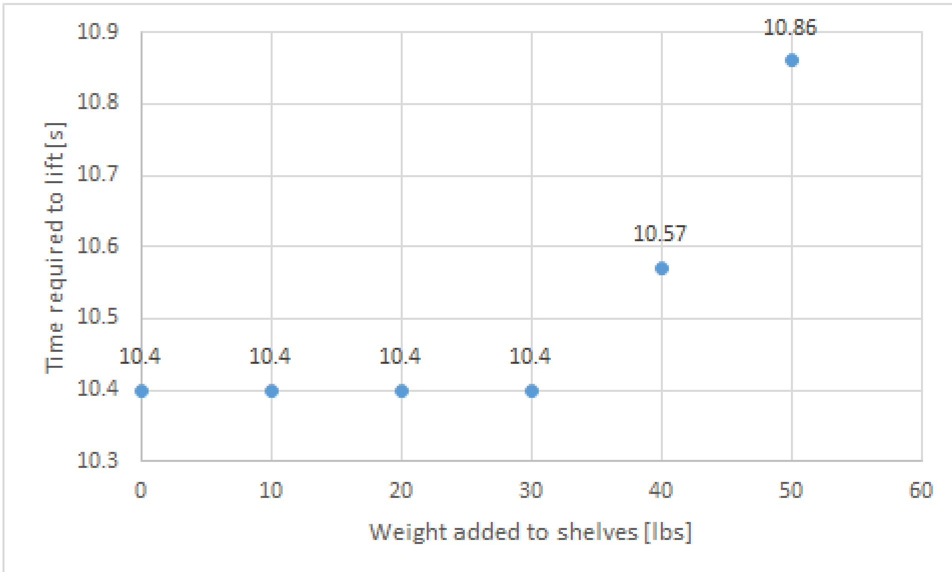

Figure 1: Lifting times for various weighted loads