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SMALL-SCALE PHYSICAL MODELING AND TESTING OF A VEHICLE TRAILER WITH ONBOARD POWER SUPPLY

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ABSTRACT

In typical towing situations, all of the power needed to move the towing vehicle and the towed vehicle (trailer) is supplied by the towing vehicle. This dictates that a person who wishes to tow a trailer must have a vehicle capable of providing enough power to move both the vehicle and the trailer; if they only occasionally tow a trailer, then they either need to rent an appropriately sized vehicle or buy a larger vehicle than is dictated by their everyday needs, which has both financial and environmental consequences. However, if the trailer can provide sufficient power itself to move, then the demands on the towing vehicle are reduced. Such a trailer would be guided by the towing vehicle, but the vehicle would provide very little power to the trailer, and therefore a small car could be used for the towing task, removing the requirement to buy or rent a larger vehicle for occasional towing. This concept has been previously explored theoretically, and was found to be feasible based on dynamic models of the trailer, with the trailer powered by a DC motor; in this paper, it is investigated experimentally, on a small scale. The experiment was conducted on a 1:18 scale remote controlled (RC) car and similarly scaled powered trailer that was constructed for it. The project included the design of an appropriate trailer, integration of a load cell into the trailer hitch, and the design of an appropriate controller. The controller was implemented using National Instruments' LabVIEW software, running on the NI myRIO controller. The LabVIEW program also saved data from the force sensor and two accelerometers, as well as the controller output to the system, for later analysis. The car was driven around with the assistance of the trailer while data was collected by the affixed sensors. The tests were conducted with different drivers, with the car driven on varying paths that included both straight driving and turns, all on a standard hard indoor floor surface. The goal of this project was to prove out the concept on a small scale, after its feasibility had been shown through modeling and theoretical calculations. The results showed that the concept is feasible and will work in practice on this small scale, although some challenges were seen. Some of these challenges were caused by the limitations of the test setup, such as limited battery capacity and limited space to mount sensors. The success of this test setup, despite these limitations, suggests that a larger-scale model should be constructed and tested, and that in practice the concept will be feasible.

1. INTRODUCTION

Individuals who occasionally need to tow a trailer currently have two main choices: they can purchase a sufficiently powerful vehicle to tow the trailer, regardless of their normal daily needs, or they can rent a large vehicle for occasional use. Either choice has financial implications; the purchase of a larger vehicle than a person needs for their usual driving tasks also has an environmental impact. If the trailer can provide sufficient power to move itself, however, then a relatively small vehicle can tow it, without the financial and environmental impacts necessitated by a larger vehicle. In order to work, this trailer must also include some form of sensing and control, to ensure that the proper amount of power is supplied by the trailer. Such a trailer is the object of investigation in this paper, with a load-sensing trailer hitch and a simple control system.

This paper is organized as follows: in Section 2, a short summary of unique trailer designs and trailer hitches is given. Section 3 covers the mechanical design of the trailer and trailer hitch; Section 4 covers the data acquisition and control design. Results of the testing are given in Section 5, and Section 6 gives the conclusions and discusses future work.

2. BACKGROUND

There are a number of trailer designs with unique features, such as a steerable trailer proposed by Ryu et al. [1], and the trailer with individual powered wheels proposed by Sheidler &

Anderson [2]. The concept of a load-sensing hitch has also been used at times, such as in the detection of problems with alignment or provision of shock absorption [3-6]. Modeling of other trailer systems has also been done, as discussed in [1, 7, 10], and control systems have been designed to incorporate braking as a safety feature [11]. Controls have also been investigated for various types of trailers, including controllers for docking maneuvers [12] and the control of trailer-like robotic systems [13, 14]. The concept of the on-board power supply, load-sensing hitch, and control system was proposed and modeled in [15], and showed that this concept is in fact feasible.

3. MECHANICAL DESIGN

The realization of the model was created using a stock remote control (RC) car, the National Instruments myRIO controller, a Shenzhen DC motor, an accelerometer, the load cell, and the trailer. The trailer was primarily constructed out of one-eighth inch plywood to create the bed, wheels from a Pinecar Racer®, and finally an assortment of hardware to create the trailer hitch. An overall view of the system is shown in Figure 1.

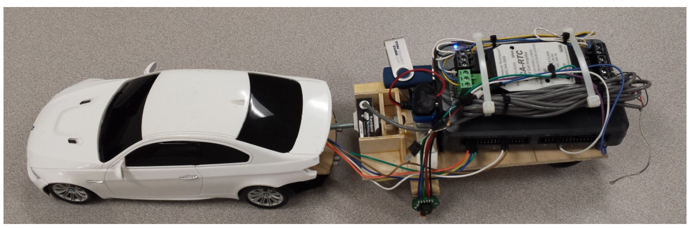

Figure 1: RC Car and Self-Powered Trailer: Overall View

The trailer itself was held together by wood glue with the addition of Command™ Strips to hold on the NI myRIO controller while allowing for easy removal. The load cell was bolted into a frame on the trailer to keep it still and secure allowing for better quality of data, as shown in Figure 2. Data was saved to a flash drive plugged into the myRIO, as discussed in Section 3.

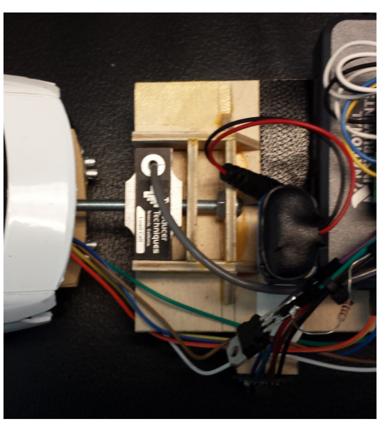

Figure 2: Load Cell Mounting

The motor was mounted on the underside of the trailer with the drive wheel in the exact center of the trailer. A single drive wheel was used in order to avoid the need for a differential, with its added complexity and space requirements. Two additional idler wheels were mounted to the back end of the trailer, one on either side.

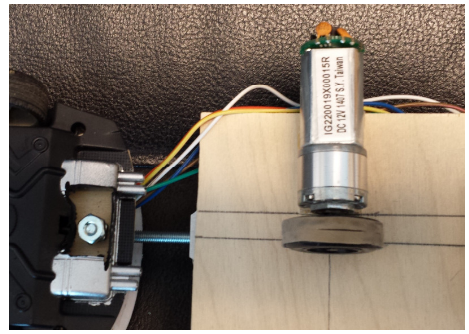

Figure 3: Bottom View of Trailer: Motor Mounting

The placement of the drive motor caused the trailer to have a weight bias to the left side; the NI myRIO controller was then moved to the right to compensate for this, in order to avoid destabilizing the system. In addition to the accelerometer in the NI myRIO on the trailer, an accelerometer was also mounted above the rear axle of the remote controlled car, as discussed in Section 3. Finally, the trailer was securely attached to the car using a configuration of hardware which provided the necessary degrees of freedom without allowing any unnecessary movement in the linkage which might cause problems in the system or add additional disturbances to the measured signals.

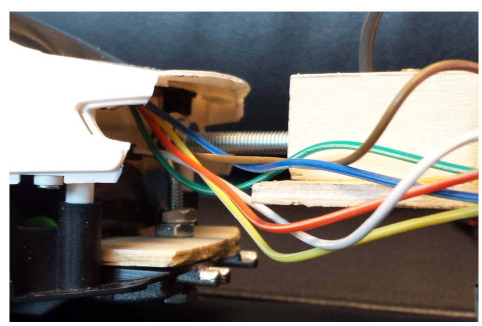

Figure 4: Trailer Hitch

4. DATA ACQUISITION AND CONTROL

In this system, there were three sensors and a single actuator. These sensors were a load cell and two accelerometers, one on the car and one on the trailer. Information about the sensors is given in Table 1. The actuator was a DC motor, which was coupled to the drive wheel on the trailer, as explained in Section 3. Data acquisition and control tasks were carried out using LabVIEW, deployed to the National Instruments myRIO controller.

Table 1: Sensors and Actuators Used

Sensor or Actuator	Purpose	Manufacturer	Part Number
Load Cell	Measure force between car and trailer	Transducer Techniques	MLP-10
Amplifier	Amplify force sensor signal	Transducer Techniques	LCA-RTC
Accelerometer	Measure acceleration of the car	Adafruit	ADXL345
Accelerometer	Measure acceleration of the trailer	National Instruments	N/A (internal to myRIO)
DC Motor	Provide motive power to the trailer	Shenzhen Power Motor Industrial Co. Ltd.	IG220019X00015R

The overall structure of the closed-loop control system is given in Figure 5. The front panel of the LabVIEW VI is shown in Figure 6. The basic control scheme was a simple proportional controller, with the load cell's output as the input to the controller and the duty cycle of the DC motor as the controller output.

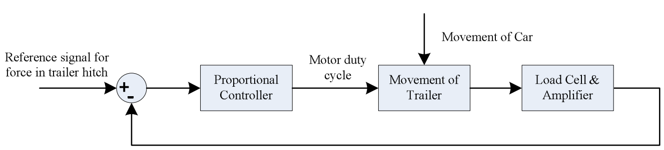

Figure 5: Block Diagram of System

Note that, while in LabVIEW it is possible to change parameters through the front panel, this functionality is not available when deploying to the myRIO. Since the myRIO is used to run the trailer when it is not connected to the computer, no input values can be changed or graphs or charts viewed while the trailer is running.

Prior to selecting the controller gain, preliminary testing was carried out using the trailer with no motor attached, and the force required to pull the unpowered trailer was measured. Three different test runs were conducted, with the car stopping, starting, reversing, and turning in a random fashion, to determine what the range of forces seen would be. Results of this testing are shown in Figure 7. It can be seen that, while the data varied considerably, the force never exceeded 0.8 N or was less than -0.6 N. This data was used to select the initial value of the controller gain, with the final value selected through empirical tuning over a large number of test runs.

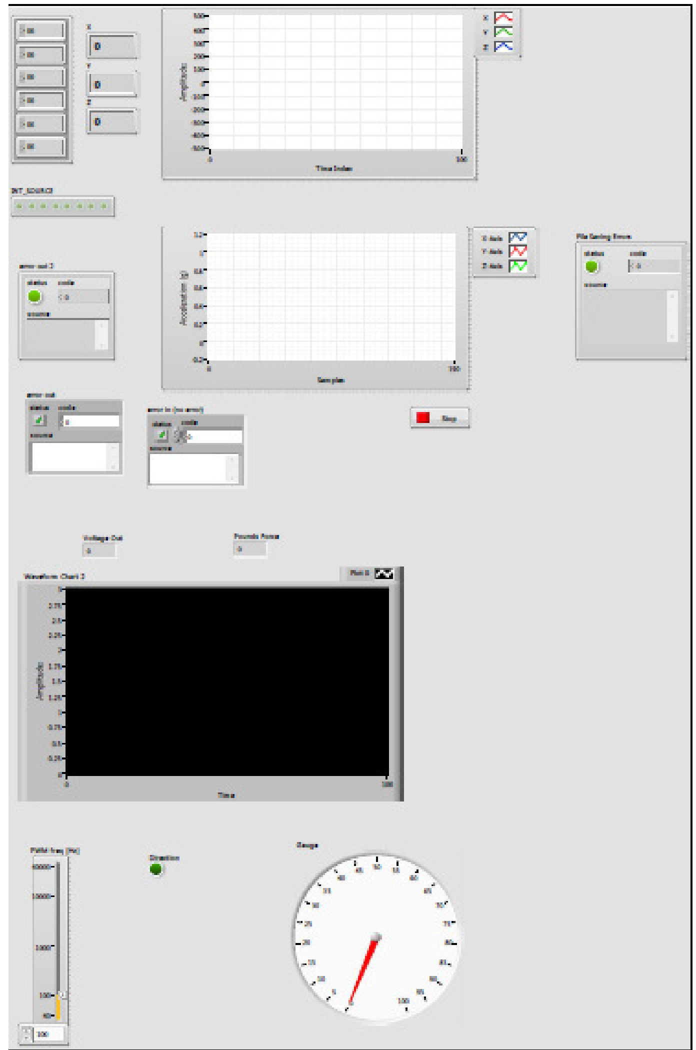

Figure 6: Front Panel of LabVIEW Code

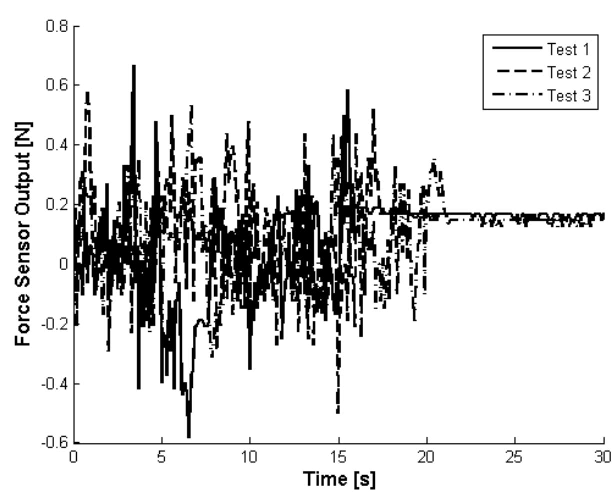

Figure 7: Force Output for Unpowered Trailer

5. RESULTS

Prior to testing the trailer with the car, a bench test was carried out to ensure that the controller would respond appropriately to the input from the load cell. In this test, the load cell was manually actuated, and the controller sent a signal to the motor, which was disconnected from the trailer. Both the load cell output and the signal sent to the motor were saved to a *.csv file for analysis. The results of the bench test are shown in Figure 8, and these results demonstrate that the controller was functioning as planned. It is noted that the actuator saturated at a value less than 2 N; however, this was not anticipated to be a problem, based on the results shown in Figure 7.

Testing was then carried out with the full system assembled and operational. A total of five test runs were conducted, with the car being driven in various different trajectories. The comparisons of the force and motor signals for each test run are shown in Figures 9 – 13. It should be noted that the conditions for the test included a varying level of charge in the 9 V battery used to power the myRIO and, through it, the motor, as it drained rapidly over the course of testing. The battery ran extremely low at the end of Test 4, and a loss of some data is seen in that test.

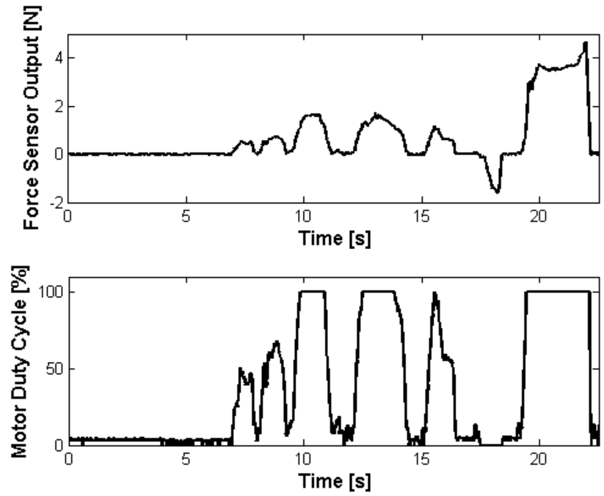

Figure 8: Results of Bench Test of Force Sensor and Controller

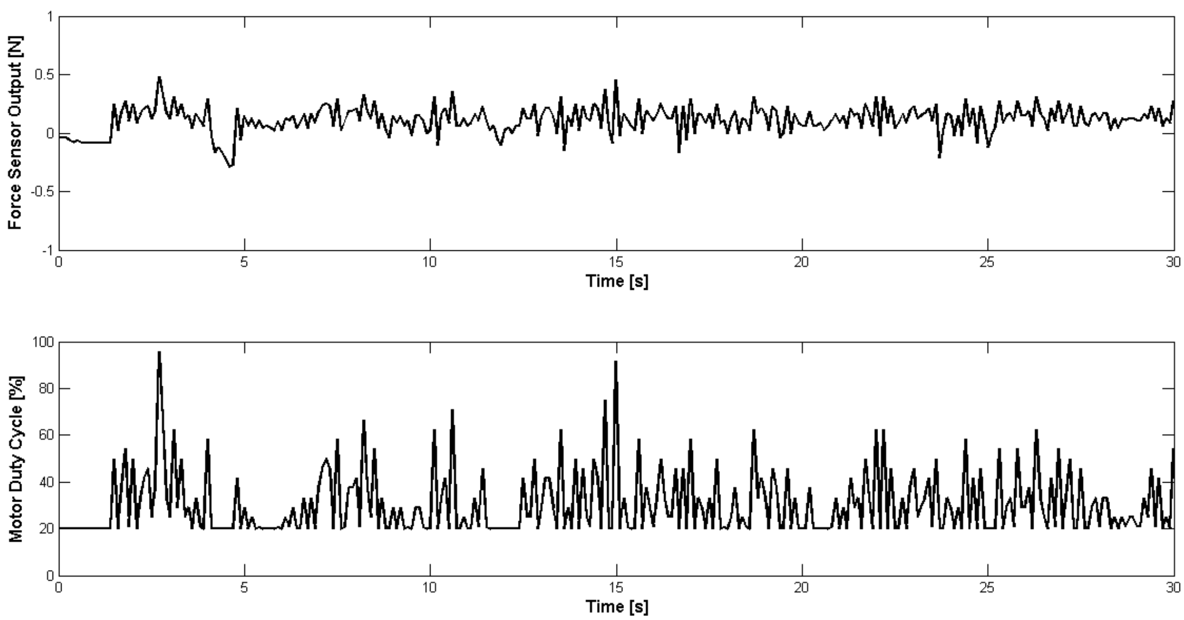

Figure 9: Force and Duty Cycle for Test 1

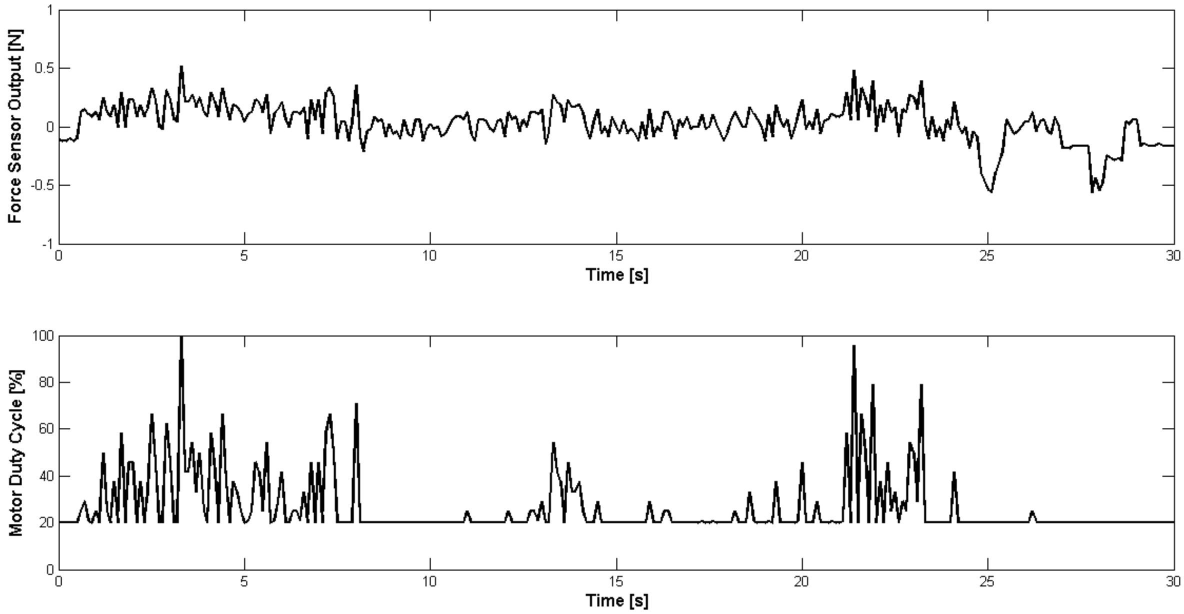

Figure 10: Force and Duty Cycle for Test 2

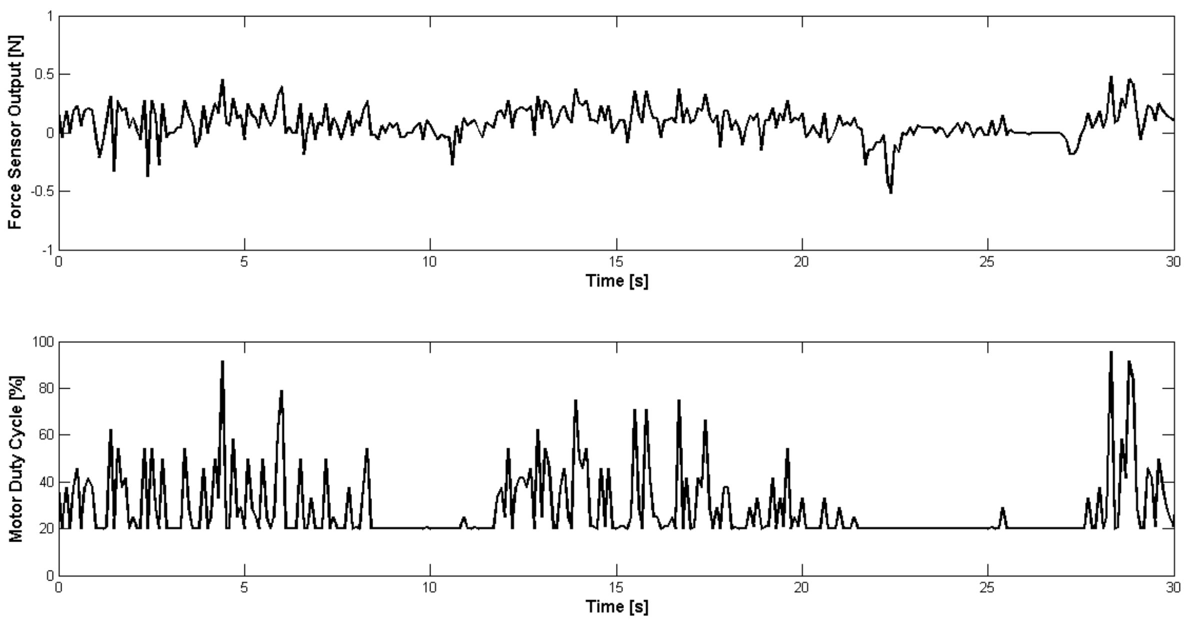

Figure 11: Force and Duty Cycle for Test 3

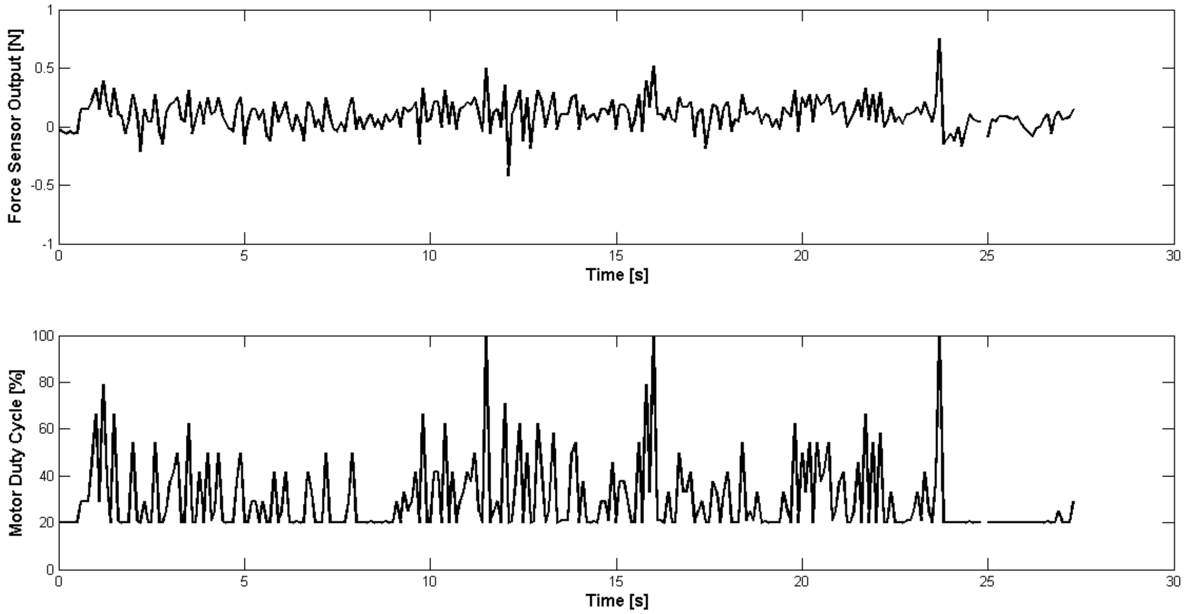

Figure 12: Force and Duty Cycle for Test 4

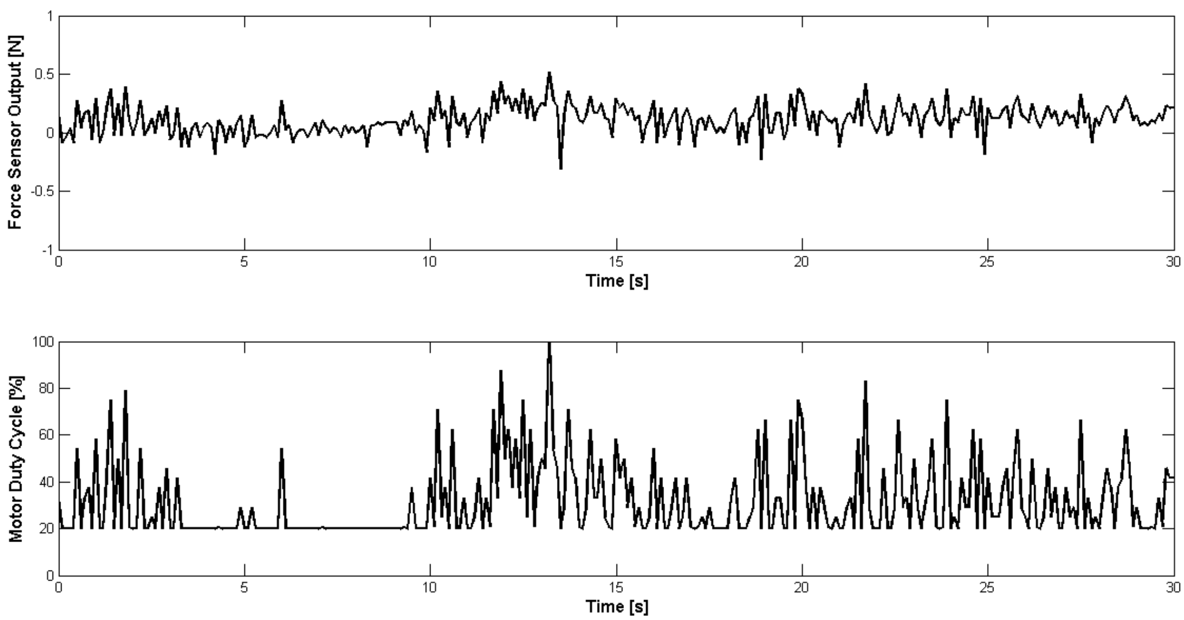

Figure 13: Force and Duty Cycle for Test 5

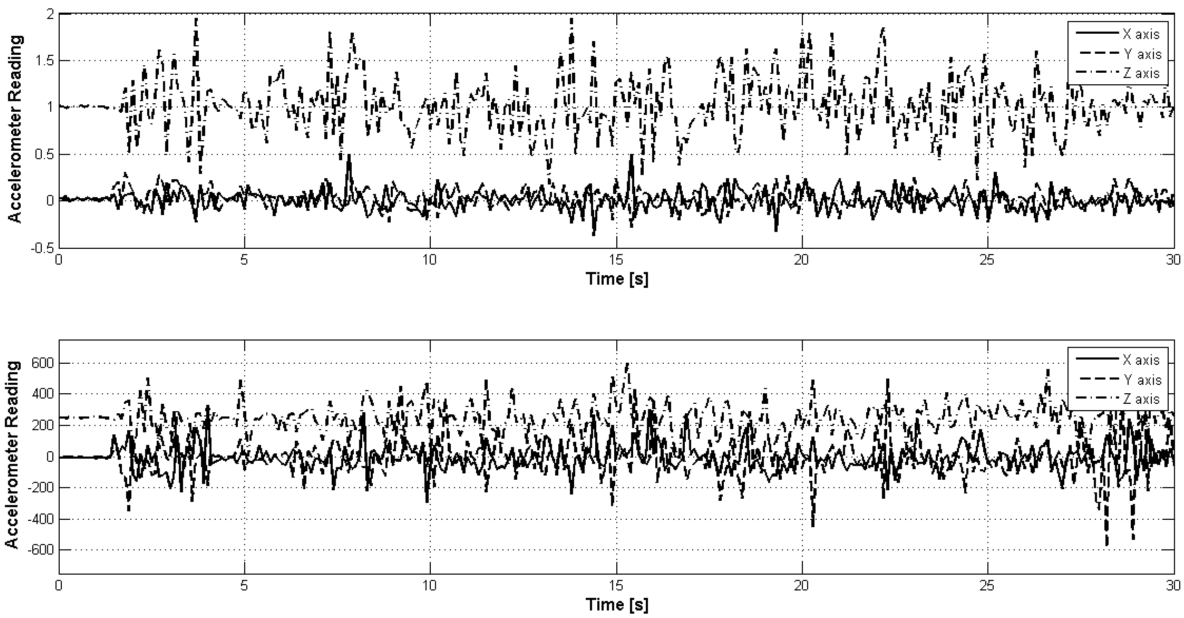

Figure 14: Accelerometer Data for Test 1

It can be seen that the trailer did respond to the force sensor by providing a considerable amount of power, in order to effectively move under the guidance of the car's movement. The sensor data shows a great deal of variation, however, which results in large, rapid changes in the output from the motor. This could be alleviated either by implementing a filter within the controller, to remove higher frequencies, or by implementing some form of mechanical damping, or possibly both. In the original concept for this type of trailer, as proposed in [15], the trailer hitch did include both a spring and a damper; however, it was not possible to implement them on the 1:18 scale model due to space constraints.

Which solution is best would depend on whether the variation is coming primarily from sensor noise or from actual variations in the force that is being sensed. Due to the quality of the data in the bench test with the force sensor, it is believed that the variation is primarily due to variations in the force being sensed, and therefore a mechanical change to the system would alleviate much of this issue.

The data from the accelerometers, likewise, showed a great deal of variation. A sample of the raw accelerometer data from the first test run is given in Figure 14. It can be seen that the data would need to be appropriately normalized, since the accelerometers clearly are measuring in different units, in order to be of any use. Due to the large amount of variation in the data, it was decided that any kind of dead-reckoning calculations of the car and trailer paths would be highly inaccurate and therefore no such calculations were carried out.

Averages were computed for the various tests, for each of the accelerometer readings as well as for the force and duty cycle, and this data is summarized in Table 2.

Table 2: Summary of Test Results

Test Number		1	2	3	4	5
Mean Force [N]		0.1088	0.0266	0.0763	0.0993	0.1084
Mean Duty Cycle [%]		29.94	26.07	28.12	29.64	30.79
Accelerometer 1	X axis	0.0023	0.0173	0.0117	0.0186	-0.0046
	Y axis	0.0284	0.0326	0.0208	0.0355	0.021
	Z axis	1.0088	0.9916	0.9842	1.0076	1.0051
Accelerometer 2	X axis	-13.033	-14.904	-10.974	-10.863	-13.735
	Y axis	-11.864	-8.149	-4.007	-8.934	3.738
	Z axis	244.669	245.841	245.742	250.541	243.656

This data shows that the results are somewhat consistent, given the level of variation in the data. The mean force, in all tests but one, is roughly 0.1 N, with a mean duty cycle that ranges between 25% and 30%. The accelerometer data varies somewhat more, based on the fact that the car was being driven on different paths, and in fact by different drivers at times. If path data was desired, then a new test setup would be desired, which would provide more effective measurements of the car's position. The initial tests carried out in this work, while they showed that the concept is feasible, provided limited data on the vehicle's performance.

6. CONCLUSIONS

As stated, the goal of this project was to experimentally validate a basic concept for a trailer that would provide its own power when needed, with the towing vehicle providing primarily guidance. The experimental design was somewhat limited by the constraints of the RC car, both in its capabilities and in the space available to mount the necessary components, but it was possible to build a working experimental setup. The trailer powered itself and increased the motor power when needed. More tuning and enhancements could have been made, but the concept was proven overall, so the project was successful in its objectives.

This experimental setup was a very simplistic version of the basic concept, which did present some challenges and limitations. From the data provided in this paper, it can be seen that the force sensor that was used provided very clean data during the bench test. However, the real data from testing showed far more variation. By using springs and dampers, as shown in the initial concept in [15], most of these issues could likely be alleviated. However, considering the scale of this project, it was not feasible to develop such a system.

The next step of the project is to develop a larger and more sophisticated version of the one exhibited in this paper. The estimated size will be comparable to that of a Go-Kart. By building a model at this scale, it will be possible to test out a more sophisticated trailer hitch, incorporating springs and dampers. Furthermore, additional types of power sources could be used, such as a small internal combustion engine (ICE). Further work could also include optimization of the system, both in the physical design and in the controller, in order to go beyond simple feasibility of the concept and into detailed design of the optimal version of the system. Naturally, such an optimization would require the definition of one or more suitable objective functions and appropriate constraints, and such an optimization can be the subject of future work.

In addition, a more sophisticated control system should be developed in future versions of the concept. In this implementation, the forward motion of the car was the only consideration; in reality, however, the issue of backing up the trailer would need to be considered. Other conditions might be important as well, and therefore a state-machine controller scheme could be developed. Such enhancements would further refine the concept, and allow for future implementation as a full-scale prototype.

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