AC 2010-583: R2D2 AS A MOTIVATOR IN ENGINEERING EDUCATION

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R2D2 as a Motivator in Engineering Education

The use of robotic system applications continues to grow as a learning tool in electrical and computer engineering, but basic designs and projects have been well investigated and advances in the field are becoming increasingly complex. Many new and interesting systems are beyond the scope of what undergraduates can tackle as a capstone project. As a result, capstone design projects usually either require a massive learning curve to build on previous systems or are relegated to relatively simple designs, many of which are repeated year after year. This paper describes the educational experience gained through design and construction of an R2D2 replica from the Star Wars™ movies. The initial project incorporates basic radio control as well as simple autonomous navigation and limited user interface with the capability for future expansion. The modular design is intended to allow future capstone groups to add innovative new features as well as novel applications of well established technologies. In addition to being a motivational project for senior-level engineering students, it is also a marketing tool for future electrical and computer engineering majors. It was anticipated that the novelty and expected publicity that this project would receive would motivate even a below average team of students to work above and beyond their peers. Unfortunately this was only partially true as half of the group performed as hoped, with a mix of stronger and weaker students performing above what was expecetd and the other half performing below what was expected.

Introduction

It is well documented that the use of robots stimulates the learning process in an educational environment. One of the benefits of using robots in a design context is that it forces the students to consider multiple cross-disciplinary subsystems. Systems engineering is, by default, a critical part of the design as students must address the interfaces between digital, analog, and mechanical subsystems. Considering that ABET requires curricula to integrate cross-disciplinary teams with a focus on projects, robots are an ideal platform. Additionally, overcoming these integration issues help satisfy the goal of the United State Air Force Academy's senior design capstone course of enabling "students to learn to solve multidisciplinary problems by integrating knowledge and skills from previous disciplinary engineering courses and employing the design and system engineering processes."[1]

Ideas for capstone projects originate from numerous avenues: professor interests, student suggestions, requests from external sources, or satisfying Air Force needs. The R2D2 project began as an independent study by several interested students. R2D2 is a well-recognized three legged droid from the Lucas Films Star Wars™ movies. In the movies, R2D2 can be observed autonomously navigating flat surfaces, interpreting situations and commands and responding with relevant beeps or whistles, recording video and playing it back via holographic projector, transitioning from three legs to two, storing a light saber and ejecting it when needed, and providing a taser-like shock. Although the students in the independent study found useful information on building a realistic R2D2 from the Astromech Builders Club website[2], their progress was limited. Since there was considerable student interest in the project despite the lack of initial progress, the R2D2 project was selected as a capstone project, knowing it had potential for several years of project upgrades.

Team Introduction

The capstone team consisted of six fourth-year students: two Computer Engineering majors, two Electrical Engineering majors, a Systems Engineering major with an Electrical emphasis, and a Systems Engineering Management (non-technical) major. The greatest challenge with this team was that they were not the top students. Collectively, they had a cumulative GPA of 2.55 and an average major's GPA of 2.38 on a 4.0 scale. The primary mentor had personally failed two of the team members in Introductory Digital Systems class earlier in their student career. The team members, however, had no negative personality issues within the group or with the mentors and were motivated.

Project Introduction

In addition to student growth and development, a key objective of the project was to create a fascinating but recognizable device that could be used to help recruit engineers. The plan was to exhibit a functional R2D2 during Major's Night, where the academic majors market their discipline to freshmen and undeclared sophomores, and possibly even at home football games. The full-sized, metal replica envisioned by the team was to be a far cry from the 15" plastic model with simple voice recognition which can be purchased for slightly over $100. The goal was to produce a facsimile of the R2D2 droid which was as close to movie quality as possible. The independent study had yielded a partially painted shell with legs and a partially functional radio control (RC) interface mated to a Motorola HC12 microcontroller. None of the parts had been integrated into the physical shell, the RC subsystem was partially functional and sitting on a lab bench, and the droid remained immobile with no drive wheels. Although part vendors had been identified and risk-reduction research had been done, there was little that could be used for the capstone project.

Due to time constraints, tradeoffs had to be made and the scope of the capstone R2D2 project was necessarily limited. The capstone design project consists of a 3 credit hour course for the two semesters of the student's senior year. The requirements set forth for the capstone group was to produce an R2D2 robot which could move on flat surfaces via remote control, autonomous navigation, and a combined mode where manual remote control would be augmented by collision avoidance capability. In the latter two modes, obstacles were to be sensed and avoided, regardless of travel speed. Walls, objects and barriers were to be mapped and displayed on a retractable color screen on the R2 unit. In autonomous mode, those obstacles were to be navigated around. The unit was to make appropriate sounds consistent with those made by the R2D2 in the movies. A battery lifetime of 1 hour between charges and a maximum speed of 5 mph were expected. Kill switches were to be mounted at three locations for emergency power-down.

Student Motivation

One of the primary reasons for faculty to select this project was the additional motivation they hoped to see from a below-average team. The opportunity to use the completed product as a marketing tool was a nice by-product, but the desire was to use the novelty and interest coupled with the possibility of significant public exposure to create self-motivation within students to perform well above their previous level. Additionally, the R2D2 project was anticipated to be a baseline platform that future capstone groups would augment with more advanced features and technologies. The result was mixed, and clear conclusions cannot be drawn from their performance.

The students were clearly motivated at the design reviews and in discussions with mentors. They had grand visions of what they were going to create. However, when it came to actually doing the work, several of them put in the minimum expected time or less. Being a three-hour class with forty meeting periods, it was expected the student would put in at least 120 hours over the course of a semester. Realistically, with an eager group, 160-200 hours is common. In the first semester, the time invested ranged from 90 hours to 162 hours. The results reflected this investment as those who put in 150+ hours made great strides toward completing their subsystems. Those with less than 100 hours had little design or engineering work to show.

Surprisingly, the two students with the lowest major's GPAs (1.9) were at the two ends of the spectrum. The Systems Engineer put considerable work into a computer aided design of the physical structure of the robot, shown in Figure 1, including redesigning and personally fabricating the legs to make them lighter than those created by the independent study team. His design was solid and went above the requirements, developing a motorized system to raise the primary distance sensor (a laser rangefinder) from the top of R2's head.

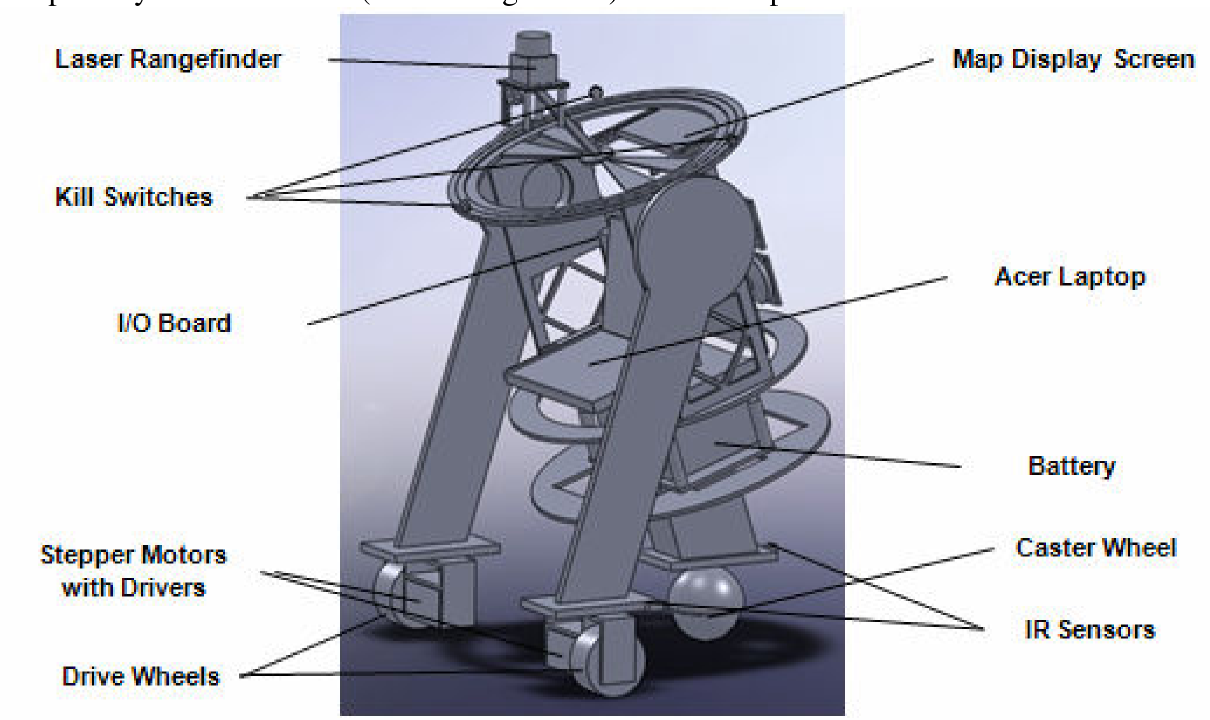

Figure 1. CAD drawing of the R2D2 structure

On the other hand, the Electrical Engineer with the lowest major's GPA put forth little effort until the final two weeks, when the mentor demanded a functional prototype of his subsystem by the end of the semester. He had done little design and had no understanding of the technical issues that he would have to deal with. Being a two-semester course, he knew he had another semester to work on it and asked "If I do it now, what am I going to do all of next semester?" He clearly did not understand the complexities of the circuit or the issues that engineers often face in integration and testing. Once he began working on the prototype it finally dawned on him the depth of the task at hand and the engineer's joy of solving ill-defined problems. At this point his attitude changed and he noted "this is the best class I've ever had." This level of effort continued into the second semester. He successfully designed a system to control the stepper motors for the systems, either by RC commands or commands from the processor during autonomous control. However, the stepper motors performed well below specifications and the design had to be modified to use DC motors with a motor driver system. As a result, he continued to be behind schedule, although he learned a vital lesson about critical paths and reliance on unproven devices.

The Computer Engineers were also very bimodal in their level of effort. The student on the team with the highest GPA (3.4) put in little effort. However, in the 95 hours he logged in the first semester, he went above the requirements and designed a system to allow the R2D2 unit's head to spin 360º. In the second semester, he stepped up his level of effort slightly but remained behind schedule on his mapping algorithms for much of the semester. On the other hand, the Computer Engineer with a mere 2.4 GPA put in 160 hours and designed a well thought-out architecture for the control software and wrote many of the modules, all while teaching himself the C# programming language. He also exceeded requirements and designed algorithms for determining the optimum path for navigation around obstacles, spacing from walls, and optimizing mapping time required. His level of effort actually increased in the second semester as he debugged undocumented errors in the laser range finder as well as attempting to find code to successfully interface the selected I/O board with C#. After 30 hours of work and little support from the vendor, he eventually was forced to purchase a different I/O board and start over. Overall he put in more than twice the expected time for the class.

The students putting in the "average" time included the Systems Engineering Manager (SEM) and the second Electrical Engineer. Both had the epiphany throughout the first semester that educators hope students have. As project leader, the SEM not only learned the difficulty in trying to motivate one's peers but also what was expected of a manager. At the beginning of the semester, he anticipated no personality conflicts and saw no issue with group member getting their inputs in on time for reviews. As a result, the System Requirements Review and Preliminary design review were incomplete, unorganized, and only marginally acceptable. However, by the Critical Design Review (the third and final design review prior to construction), he managed to pull the team together and presented one of the best capstone reviews of the semester. During the second semester, he continued to manage the team well and pushed them hard to meet their schedules, but also became knowledgeable on the technical systems. The Electrical Engineer had worked steadily, but at a lower level than hoped, throughout the semester. He realized near the end of the first semester that his Input/Output subsystem not only needed to include far more than he had realized or accounted for, but that he had not thought the interfaces out completely. When he realized his short-range sensors provided a 2.5mV analog output voltage range that he needed to supply to the digital I/O board they had already purchased, he begged to buy another board with Analog-to-Digital (A/D) converters. When denied, he then had to design a bank of A/D converters—increasing the risk to the overall project and time required. He then also realized the importance of margin-of-safety as the three lines going into the IO board suddenly sprouted to 24 lines. If the group had not purchased an I/O board with 48 extra input lines, his subsystem would have been a failure. As the I/O board and motor interface changed, the interface and control boards also had to be modified and refabricated.

Design Results

Although the emphasis and most interesting conclusions from this paper are the levels of motivation a novel project generates from students, the actual design is still of interest.

The students decided to scrap almost everything the independent study team had built. Structurally, the dome had been drilled and cut improperly for the sensors and mounts that the capstone team needed. The skin had defects and was bonded in a fashion that made it difficult to work with. The legs were solid aluminum and far too heavy to meet the 5 mph speed requirement. The motors were underpowered and difficult to control. The HC12 was feasible to use as a control mechanism but more difficult to use for the multiple required functions, and provided limited speed and expansion capabilities for future years.

As a result, the team purchased a new dome and skin. New legs were designed and manufactured by the students. A small Acer netbook was chosen as the controller and placed inside the body of the robot. Its dimensions allow users to use the screen and keyboard inside the robot body, but it can also be moved out of the body on a rolling tray. A laser range-finder rises from the top of the robot's head to provide the primary navigation data while infrared sensors are mounted along the base of the main body to detect obstacles below the laser scan height. A 7" LCD screen slides out from the top of the body to provide the visualization of the mapped areas.

One of the more difficult design decisions was whether to have the RC receiver inputs feed into the computer and have software control all motion or to have the RC signals be able to directly control the motors. Although more difficult, the latter allows motion without the main control software running. Therefore, a switchable signal interface board interfaces the motors with the Acer computer and the RC receiver. A motorcycle battery provides 12 volts to the entire system. A socket on the skin of the robot allows the battery to be charged via a normal120VAC wall outlet. The overall system diagram is shown in Figure 2.

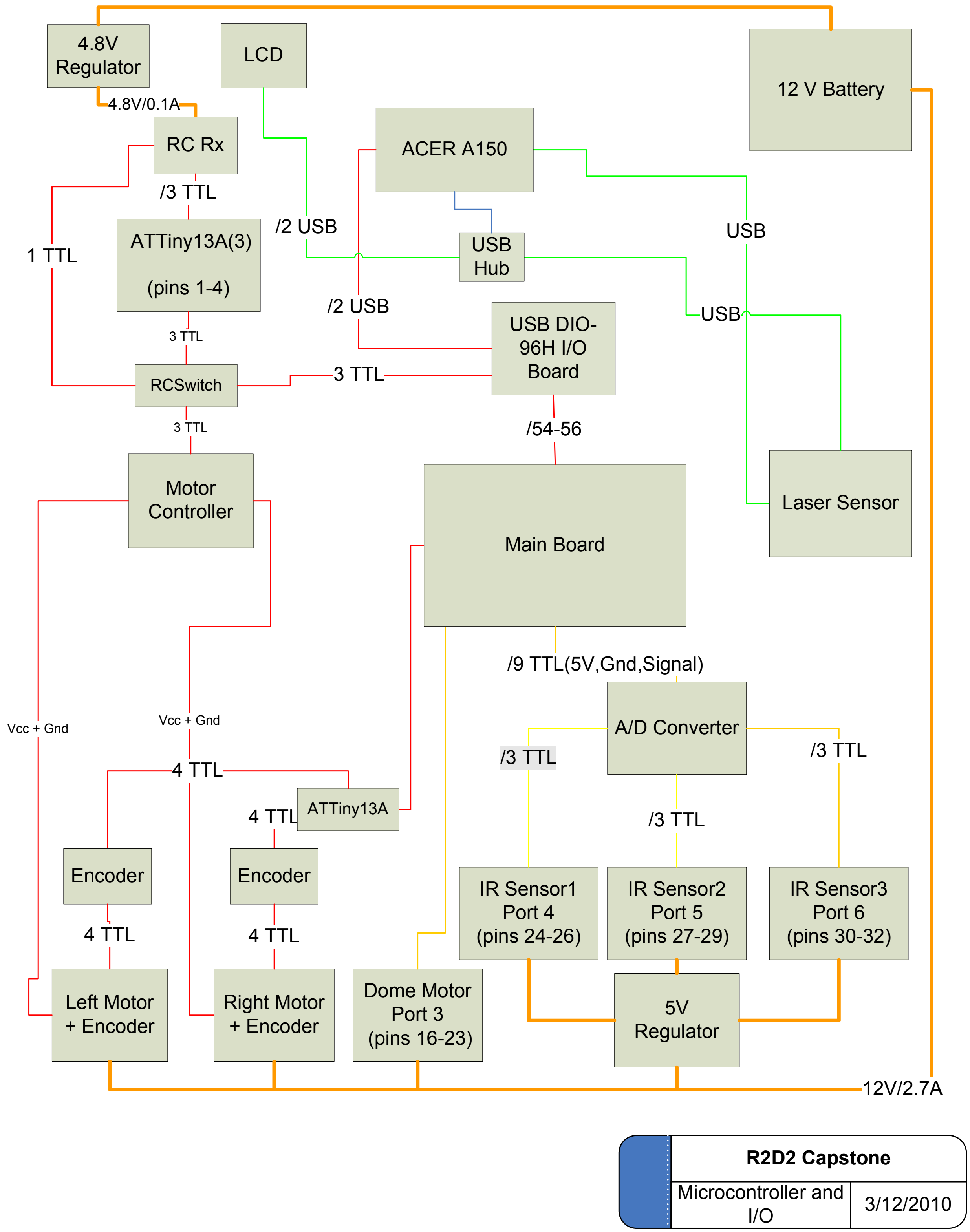

Figure 2. R2D2 System Diagram

Additional Considerations

Whenever dealing with copyrighted and trademarked material, property rights must be respected. Since the robot is a copy of a trademarked character, permission had to be obtained before presenting it in public. This was surprisingly easy as LucasFilms was willing to grant permission as long as the claim was not made that it was the original robot from the movie and that the Air Force Academy or the Air Force did not benefit financially through use of the replica. They wholeheartedly supported the goal of encouraging more students within the US to become engineers.

Project Future

The R2 robot is expected to be a capstone project for the foreseeable future. With the baseline robot built, a goal for the next year is to include a mechanical engineer on the team and design a capability to retract the third leg. This will require the battery to be relocated, most likely being split into two batteries in the saddlebags near the feet. It will also make it impossible to have the open laptop inside the body. Additional lights will be added to mimic those in the movies. An external mp3 player will be included to allow the user to customize audio presentation to a specific audience without manipulating control software. The robot will then be expected to navigate around objects to given locations or waypoints on an established map. In future years, video recording and playback is expected to be added. Developing vision capabilities such as fly-eye sensors and other highly efficient sensors will be experimented with and incorporated. Ultimately, the RC is expected to be replaced or augmented by brain machine interface (recognizing thought patterns for direction control) and voice command recognition will be incorporated. Many years of potential upgrades and capstone projects lie within the R2D2 platform.

Conclusion

Although the authors would love to be able to declare that the R2D2 capstone project motivated below average students to perform at the highest levels, that simply did not happen in this case. Though the mentors anecdotally saw a higher level of personal investment and motivation in this project than an average capstone project, it was not significant or supported numerically. Some lower-performing students performed well above expectations but others did not and one performed lower than expected. The unexpected performance levels cannot definitively be tied to the nature of the project but may be due to unrelated factors such as the student simply maturing. This is supported by the fact that both higher performing students earned a GPA of 0.8 higher than their average while carrying a load of 16 and 19 credit hours, indicating improved performance across the board. The R2D2 capstone project is an interesting endeavor with potential for multiple future projects and obvious Science, Technology, Engineering, and Mathematics marketing potential but, unfortunately, it is not the Holy Grail of student motivation.

Bibliography

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2. http://www.astromech.net/