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University of Idaho: College of Engineering

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FINAL REPORT:
EDUCATIONAL ROBOTICS PLATFORM
Executive Summary

Team V-BOT, a capstone design team at the University of Idaho, developed a robotics kit for use as an interdisciplinary education tool. The College of Engineering requested the development of the robotics kit to fulfill the need for an inexpensive, versatile robotics platform for University of Idaho students. The V-BOT robotics kit uses a modular, easily customizable platform to ensure a variety of design possibilities and applications. The mechanical platform was designed using basic building-block parts, snap-fit connectors, and standard fasteners. The electrical system utilizes a central processor with standard connections to nodal additions to allow easy incorporation of sensors and actuators. The combination of these features allows for a highly versatile platform capable of multiple educational activities. The advantages of the V-BOT robotics kit is demonstrated by the stationary and mobile prototype designs (pictured on the report cover). By having access to such a platform, the University of Idaho can provide a hands-on learning tool for its engineering students to gain practical experience in the classroom.
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1. Background

It has become apparent to the College of Engineering at the University of Idaho that there is no robotics kit currently on the market that satisfies the needs of novice engineering students. While many robotics kits have been made commercially available, they all have significant drawbacks that make such kits unappealing.

Most of the kits are limited in their applications to education. Many are targeted to a specific level of technical expertise, decreasing the flexibility and growth a student can gain from such a kit. Other kits, though perhaps more flexible, are too expensive to realistically be used in a classroom setting. Further difficulties arise from specialization and brand limitations of such kits. Many kit designs limit the interconnectivity of the included components with other devices not included in the kit. Most robotic kits provide experiences that educate the students on specific areas of interest, rather than capture an interdisciplinary introduction to engineering. These shortcomings have led the College of Engineering to develop a new robotics education kit, unique to the University of Idaho.

Team V-BOT was commissioned to advance and improve the University of Idaho educational robotics kit. The project began in the fall of 2007 when Team O.A.R. (Open Architecture Robot) started researching and compiling information for the project. Team V-BOT improved upon the work achieved by Team O.A.R. to create the V-BOT educational robotics kit. Through designing the V-BOT kit, it is believed that introductory engineering courses can be made more interactive and educational for high school students and college underclassmen. The design could also be developed further and sold to other institutions for profit.

2. Problem Definition

The long-term goal of the College of Engineering is to design and produce an educational robot for use as a teaching aid by the University of Idaho engineering faculty. This robot must be versatile, inexpensive, highly customizable, and unique to the University. The development of the robotics kit is an ongoing project for the Capstone Design course, involving numerous teams advancing the design developed by the preceding teams. As such, Team V-BOT was not expected to fully design and develop the kit, but, rather, to select some aspect(s) of the design to focus on developing.
Team V-BOT’s goal was to design and create two different demonstrative robots using prototype parts designed for use in future kits. These robot platforms included a number of sensors, actuators and end effectors that reinforce robotics education, but also have the capability to use a number of tools not within the kit. The design was built with a building block part system that allows for multiple, structurally stable designs. These building blocks use a combination of snap fit connectors and store bought fasteners. Therefore, supplemental parts for the platform can be fabricated or purchased, depending on which choice is the least expensive. Regardless of acquisition choice, the parts must be easy to obtain when replacements are needed. Additionally, the kit and its components should be durable enough to last through several years of use and should have an efficient means of storage and collection. Table 1 shows a simple setup of functional requirements and tools to fill those requirements.

<table>
<thead>
<tr>
<th>Functional Requirement</th>
<th>Design Part</th>
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<tbody>
<tr>
<td>Electrical Model</td>
<td>Connectivity</td>
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<td>Central Processor</td>
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<td>Programming</td>
<td>Language</td>
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<td>User Interface</td>
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<td>Linear</td>
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<td>Rotational</td>
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<tr>
<td></td>
<td>Propulsion</td>
</tr>
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Table 1. Educational Robot Functional Requirements.

To better prepare the team to anticipate the challenges faced by students using similar robotics kits, the project also included designing and administering the Vandals Robotics Challenge. The competition required regional high school students to design, build, and program a robot to accomplish predetermined tasks. The competition consisted of four parts: a sumo competition (teams were required to push an opponent’s robot out of a ring), a campus map competition (line-following and decision making), a balloon-pop competition (object and color sensing), and a freeze-tag competition (deactivate other vehicles while remaining active). Teams were also required to document their efforts in preparing their robot for the competition.
3. Vandals Robotics Challenge

In addition to developing an educational robotics kit for the University of Idaho, College of Engineering, Team V-BOT was tasked with organizing and running the Vandals Robotics Challenge which took place on May 2nd, 2009. The Vandals Robotics Challenge is an annual competition at the University of Idaho in which regional high school students assemble and program the provided robotics kits to perform in specified competitions. Currently, the students use Parallax Inc. Boe-Bot® kits for the competition; upon sufficient completion of a UI College of Engineering educational robot, however, teams may wish to use the V-BOT kit instead.

For the 2009 competition, teams were invited to compete in 4 competitions, as well as create a poster detailing their work over the course of building their robot to compete. Two of these competitions were repeat competitions from last year’s event, while the other two were new competitions introduced by Team V-BOT. Of the numerous teams invited to compete in the Vandals Robotics Challenge, only 6 teams attended the event on May 2nd. Of those, several chose not to compete in all of the challenges, which lead to scheduling difficulties and a smaller group of participants.

The first competition that the teams competed in was the Balloon Raid. In this competition, teams were given the task of search out and popping balloons of a specified color in a small arena. For the second competition, the Campus Adventure, teams needed to use a combination of line following and decision making to navigate around a course modeled after the University of Idaho campus, and pass various checkpoints to gain points for the round. The third competition was, like the Campus Adventure, a repeat of a competition used for the 2008 Vandals Robotics Challenge. The Sumo Showdown pitted two competing robots against one another with the goal of pushing the other robot out of the small ring. The fourth event, called Vandal Freeze Tag, was marked as a bonus event and did not contribute to the overall score of the participants. Figure 1 shows both the Sumo Showdown and Balloon Raid events from the 2009 competition. Due to a lack of interest and difficulties with preparing those teams interested in competing, the Vandal Freeze Tag competition was canceled. The teams’ scores were based on their performances in the first 3 competitions as well as the poster they were asked to produce detailing their efforts. A copy of the rules for the 2009 Vandals Robotics Challenge, as well as the 4/13/2009 Rules Addendum can be found in appendices 1 and 2, respectively.

The 2009 Vandals Robotics Challenge provided teams of high school students the opportunity to get some hands on experience with engineering in a fun setting. Additionally, the
event afforded Team V-BOT the opportunity to work more closely with the Parallax Inc. Boe-Bot® kit and develop a deeper understanding of the pros and cons of the kit. The team was then able to apply that experience and understanding to the development of the University of Idaho College of Engineering education robotics kit.

4. Concept Development

As mentioned before, the purpose of this project was to design an educational robot kit because currently there is not one available that meets the needs of the university. The university discovered this through use of marketed educational robots in various engineering classes. In an effort to understand the requirements fulfilled and not fulfilled by these kits, we chose two brands of robot kits, as well as the kit designed by last year's team, to analyze and evaluate.

A very popular and commonly used robot kit for competitions and education is the Lego® Mindstorms®. This is a system that uses a combination of electric motors, sensors, Lego® bricks and more Lego® specific pieces to complete a robot of the designer’s choice. Every piece of the Lego® Mindstorms® kit is manufactured by Lego® and made specifically to only work with other parts found in the set. This configuration allows for simple yet effective building, but limits the design to only pieces found within the kit. Additionally, since the parts are made to only fit with each other, the circuitry is self-contained in each part, denying the user the ability to alter the electrical system. Lastly, the programming capability of the robot is very limited. One is forced to use the CPU given with the kit and must program the robot using a
language that is permitted by the system. So, for the V-BOT kit to be effective, it must have a simple and effective building block system that allows the use of components from outside the kit. It also must be accessible to electrical work and advanced programming techniques.

The second kit we evaluated was the Parallax Inc. Boe-Bot®. This is the robotics kit chosen for the 2008 Vandal Robotics Challenge and used again in the 2009 competition. The Boe-Bot® is composed of an aluminum chassis shaped to be used as a two wheeled robot with a tail wheel for balance. The computer board is exposed and rests on top of the chassis attached with fasteners, with other components, such as servos and battery pack, attached to the side and bottom using fasteners in a similar fashion. Given this setup, it is very easy to quickly put together the robot and begin wiring components into the breadboard. Soon after, one can begin programming and attaching a variety of sensors in order to create a fully functional robot. A simple example of Boe-Bot® code for a line-following robot can be found in appendix 3.

Although this kit allows great access to the electrical system and the capability to use a large span of sensors, it is mechanically stale. Regardless of how many components you add to the system, it will still be a three wheeled robot. From the Boe-Bot®, we learned that the V-BOT kit needs to be electrically accessible, allowing the user to choose their own board and sensors, as well as permitting them to do their own wiring. Additionally, the mechanical setup must be more than a shaped chassis while still allowing the addition of components in a simple manner, such as fasteners.

Lastly, we looked to the catapult design created by the 2007-2008 Open Architecture Robot team. This design, shown in Figure 2, uses a plastic chassis and aluminum bars to complete the mechanical structure of the robot. The chassis and bars have threaded holes and require one type of fastener to connect the bars as well as any devices to the robot. Although the combination of these elements allows for a modular robot that is simple to build, the kit would be expensive and requires a plethora of fasteners. Also, a lighter, more appropriate material, such as plastic, should be used for all pieces. Based on this model, the V-BOT kit was designed to have the modularity of the O.A.R. kit, but require less fasteners and simpler parts.
The observations made while analyzing commercially available kits as well as the O.A.R. kit, governed the decisions made regarding the electrical model, the mechanical building blocks and the sensors, actuators and end effectors.

4.1 Electrical Model

The concept of having a main processing unit and subsequent smaller nodes for carrying out main processor commands was brought over from the previous team. Following up from the previous team’s design, a single board computer (SBC) was chosen to be the main processing unit for the robot. Information on several of the SBC options considered by Team V-BOT can be found in appendix 4. All of the boards were very similar in that they share concepts considered in the design of the robot platform. Each has a sufficiently fast processor based on the ARM architecture. This architecture is RISC (reduced instruction set computer) based and allows fast computations and minimal power dissipation in comparison to other high performance architecture.

Several communication links were also considered for attaching nodes to the main processor. The trade-offs for communication links lie between bandwidth and power consumption. Lower speed communications such as I2C and SPI don’t consume as much power
as Ethernet, but do not offer the bandwidth Ethernet does. The ability to choose connection speed provides versatility for the end user robot design.

User interface to the robot was also another important concept. Programming the robot should allow the user freedom in how to they want to implement their robots controls. Having an operating system such as the Linux kernel would allow this concept. Different programming languages and compiler options are available through the operation system. Using scripting languages would also be a possibility in controlling the robot.

Multiple ways for the user to interface with the robot were also considered. Direct USB links would allow just about anyone with a computer to connect to the robot. A wireless network connection would also allow connection to the robot without the inconvenience of wires and the ability to update the robot on the fly. The wireless connection would also give the robot the ability to retrieve internet data.

These concepts led to the creation of the trade study of SBC’s. The study can be seen in Table 2.

<table>
<thead>
<tr>
<th>Attributes of Purchase</th>
<th>TS-7260</th>
<th>iPac 9302</th>
<th>Embest EM104V1</th>
<th>Diopsis</th>
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<td>8</td>
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<td>7</td>
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<tr>
<td>CPU Performance</td>
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<td>8</td>
<td>56</td>
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<td>7</td>
<td>63</td>
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<td>Price</td>
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<td>10</td>
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<td>7</td>
<td>35</td>
<td>8</td>
</tr>
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</table>

| Total                       | 366     | 352       | 354           | 393     |

Table 2. Single board computer trade study.
The electrical model for the robotics platform was created through the generation of the prior concepts. Since most of the SBCs allowed for either high speed or low speed communications, tradeoffs in design were reduced since the end user could decide the communications link requirement for the node being connected. This helps to make the robotics platform more robust. Additionally, this allows the CPU in the model to communicate with both high and low speed devices. The power supply from the main unit will also power the nodes, up to a given limit. Once the limit is exceeded, additional power units may be attached to the model to supply additional energy to the nodes and/or increase the runtime of the main unit. A diagram of the Team V-BOT electrical model can be found in Figure 3.

Figure 3. Team V-BOT Electrical Model diagram.

The V-BOT electrical model was designed to provide an adaptable template to aid in the construction and operation of a wide array of robot configurations.

Several power supply options were also considered. Rechargeable batteries were a must, as the speed at which the Parallax Inc. Boe-Bot® empties non-rechargeable batteries was
Nickel-Metal Hydride (Ni-MH) and Lithium Ion batteries proved to be deemed unacceptable. Both systems allowed for wall-charging stations and both have a life of approximately 700 charges. The Lithium Ion batteries are significantly lighter and recharge more quickly than Ni-MH batteries. With these facts in mind, Lithium Ion batteries were selected as the optimum choice for the electrical model.

4.2 Mechanical Building Blocks

We had several examples of mechanical systems based on building blocks to inspect to assist in establishing design features and criteria for our own system. These examples consisted of the mechanical components included in the Lego® Mindstorms®, the Parallax Inc. Boe-Bot®, and the designs presented by last year’s senior design team, O.A.R. We were able to physically inspect each of these designs, as well as visually inspecting several other similar products available. These inspections, as detailed previously, led us to a few basic design parameters.

First, in order to meet our goal of versatility, we decided that our system needed to consist of a few basic parts that could be combined in numerous ways to create completely custom shapes and structures. In this, we were closely following the design philosophy behind the pieces contained in the Lego® Mindstorms® kit. We felt that the usefulness of the Parallax Inc. Boe-Bot® kit was severely constrained by the fact that the parts it contains can only be used to construct one basic structure, with very little variation.

Secondly, in order to meet our goal of versatility, we wanted our system to be capable of handling a large range of forces and stresses in a variety of uses. This was demonstrated most clearly by the parts fabricated from the design of last year’s senior design team. The parts that they designed were extremely rigid and were fastened together using traditional fasteners such as bolts that can withstand many different stresses of many different magnitudes. The parts contained in the Lego® Mindstorms® kit were also somewhat rigid, but only on a small scale, and the connection types between them could only withstand specific stresses, such as compression but not torsion or tensile, and the stress of the connection tended to rest on the snap connector itself, which was usually the weakest location on the part, making the entire assembly as weak as the connecting mechanism.

Thirdly, in order to maintain ease of use and to minimize the number of parts needed in the kit, we decided to make the fastening mechanism included on each part without the need for an additional fastener, such as with a snap connection or fitting. The pieces contained in the Lego® Mindstorms® kit demonstrated this idea. Both the designs of last year’s senior design team and the Parallax Inc. Boe-Bot® kit had to include a large number of fasteners (in this case,
bolts) for assembly, and the number of included fasteners quickly became a limiting factor in the
design of custom assemblies. These fasteners were also the item to be missing the most from
the Parallax Inc. Boe-Bot® kits that we inventoried.

Fourthly, in order to meet our goal of an open architecture, and to aid in our goal of
versatility, we wanted our parts to be capable of interfacing with other common parts and
materials via the most widely available fasteners. This way, commonly available store-bought
parts could be added to our parts to make a more broad and unique platform for specific
applications. The Parallax Inc. Boe-Bot® kit and the designs of last year’s senior design team
successfully used the same design philosophy to ensure that non-proprietary parts could be
interfaced with their parts via bolted connections. We felt that this concept limited the
usefulness of the parts contained in the Lego® Mindstorms® kit since they do not have any
designed way to interface with any other components on any of their parts. If such an interface
is created, it is not by design, and is usually very difficult to assemble.

Combining all of these design considerations, we needed a design that was made up of a
few basic parts, with an included interface connection that makes a solid connection between
parts without limiting the strength of the assembly to the small forces required to make the
connection, and with ways to connect other common parts with common fasteners in addition to
the included interface. These other common fasteners could also be used to compliment the
included interface to increase the strength of the assembly. The design we initially selected as a
proof of concept for these considerations is loosely based on the snap connection used to secure
the protective cover on many common calculators. The design uses two extruded cylinders to
bear the stress of the joint, with a slight interference fit against the frame. The cylinders are
tapered slightly to allow the interference fit to be done and undone with hand strength. This
design is shown in Figure 4 below, with an example of the connection shown in Figure 5.
Figure 4. The figure above shows a close-up image of each mating end of our first prototype of the snap fit connector. The tapered angles on the extruded cylinders allow the interference fit on the frames to come together.

Figure 5. The figure above shows a close-up image of two of our first prototype of the snap fit connectors snapped together.
We produced a prototype of the parts above using the Rapid Prototyping Machine (3D Printer). The connection fit together as planned, but was much looser than anticipated in the design.

Several problems with this prototype became immediately apparent. Most importantly, the connection could only bear bending moments in one direction; bending moments in the other direction acted to “unsnap” the connection, and could therefore not be transmitted through it. It was also unable to transmit torsion for the same reason. Secondly, the connector was physically large, which made small pieces impossible, and made the unusable space taken up by corners and other specialized connectors too large. The smallest piece called for in our design would have been smaller than the connector itself. Lastly, the tighter tolerances required to make this connection as tight as desired would not have been possible at this size with the 3D printer, and would have been more expensive with injection molding. All of these considerations led to a new design.

The second and final prototype was based on the same principles as the first. It used an interference snap-fit that relied on pliant plastic, with a separate protrusion to bear the load independent of the snap motion. Unlike the first prototype, the connection motion was in the axial direction, so that it could transmit bending moments in all directions. It also had a second protrusion perpendicular to the first that transmitted torsion. The absence of tapered edges made the tolerances fit within what the 3D printer is capable of, and made it cheaper to produce with injection molding. The size of the connection was also half that of the first prototype. The new design is shown in Figure 6 below, with an example of the connection shown in Figure 7.
Figure 6. The figure above shows a close-up image of each mating end of our final prototype of the snap fit connector. The second protrusion or “key” transmits torsion while also providing a surface for the interference fit.

Figure 7. The figure above shows a close-up image of two of our final prototype of the snap fit connectors snapped together.

This final prototype, shown above, met all of our original design considerations and specifications. It provided a fit that was even slightly tighter than anticipated. Parts built from this design will be very sturdy and easy to produce in bulk through the injection molding process.
4.3 Sensors, Actuators, and End Effectors

The team’s focus, in the development of sensors, actuators, and end effectors for the educational robot was to design a kit that is not limited to using only those components included with the product. The V-BOT kit allows for additional sensors to be added by the user, accommodating the needs of the teachers and students who will be using it. Likewise, flexibility in the addition of new actuators and end effectors allows for a large range of options for manipulation and movement. By building parts that use standard sizes and fasteners, adding additional components will not require special processing to interact with the kit. In the same manner, using standard electrical connections (both in hardware and software) eases the task of integrating the information gained from additional sensors and the commands sent to new actuators and end effectors.

While the design of the kit was focused on allowing the incorporation of additional sensors by the user, a small selection of sensors is included with the kit. Team V-BOT considered both ultrasonic and infrared sensors to act as object sensors for the robot. Both sensors were selected for their simplicity and inexpensiveness, though the specific models of sensors were not determined. Where other sensors may accomplish the same task as an ultrasonic or infrared sensor in detecting objects of various sizes, these same alternatives suffer from the drawbacks of being either too expensive or overly complicated (or both). One such alternative is to use a visual ‘color’ sensor to detect objects. Unfortunately, the cost of such a sensor, with the capability to detect objects at long ranges, is too expensive to be included in the robotics kit. While not feasible for object detection, similar sensors, which can detect the intensity of incoming light, can be used at a shorter range and are significantly less expensive. Such sensors can be adapted to sensing colors at short range by using LEDs to reflect different colored lights on the object. By measuring the intensity of the reflected light, and comparing the measurements for different colors, an estimation of the color of the object can be made. This is one type of sensor that was designed by the team for use in the Vandals Robotics Challenge to determine colors of balloons for the Balloon Raid event. Another sensor being developed for the high school design competition is a mechanical pressure-switch. By adhering a small, inexpensive SPDT (single-pull double-throw) switch onto a bumper-on-rails mechanism, and wiring the switch to the processor, a pressure-switch was created and used in the freeze-tag competition event. This same switch can be adapted for use in the robotics kit prototype design.

The same methodology for sensors is applied to the design and development of the actuators and end effectors. While the type and capabilities of the components included with
the kit is limited, the design of the robotics platform allows for easy integration of additional, original actuators and end effectors. To keep the kit inexpensive, the included actuators will be only simple pieces. A means of propulsion was included in the prototype design, using inexpensive wheels and rotational actuators. This platform allows users to design and attach their own, additional attachments with relative ease; a user could build a claw with a single linear actuator, accepting commands from the central processor and moving several small bars to open or close.

5. Final Design

The stationary design, and the mobile design, shown in Figure 8, demonstrates two possible designs using parts found in the V-BOT kit. These were created using Solidworks models of the kit pieces.

![Figure 8. Mobile platform prototype (left) and stationary platform prototype (right).](image)

Figure 9, on the following page, is a photo of the two robot designs. Items such as the fasteners, standoffs and wiring were not included in the model for convenience.
These two designs were chosen to validate the versatility of the V-BOT kit. The mobile robot, a simple two dimensional platform, was built specifically to perform the same functions as the Parallax Inc. Boe-Bot®. It utilizes the same board, standoffs, battery pack, servos and wheels found on the Boe-Bot® in addition to a Parallax Ultrasonic Ping))® sensor. Having a design that imitates an existing educational robot allows for a quick evaluation and comparison of the kit to that of a researched product. The stationary robot was chosen for its contrast to the mobile robot. It is programmed to locate nearby objects and calculate its distance, which is portrayed as a color using a multi-colored LED. This robot uses two Arduino boards, a Parallax Inc. servo and ultrasonic sensor, and a Ni-MH rechargeable battery. Though Lithium Ion was selected as the premier choice as a power supply, Ni-MH batteries were more accessible locally, so these were selected for this prototype. Each robot design uses the building blocks found in the V-BOT kit.

For demonstration purposes, the electrical model was implemented in the stationary robot. Due to shipping and manufacturing delays no SBC was used, but two Arduinos purchased by last year’s team were used as a proof-of-concept. One board was used as the central unit and
the other as a node unit. I2C was used as the low speed communication link between the two units. One 9.6V 1600mAh Ni-MH rechargeable battery was purchased and re-wired to correctly power the Arduino boards. Both boards were run off the same battery for convenience. The node moved the servo around as well as collecting sensor readings. The main unit requested readings from the node unit and then reported the readings.

Code development for the proof-of-concept was done through the Arduino programming interface. The code was written in the C language and used Arduino library extensions. The Wire library handled the I2C protocol commands. Each board had separate programs compiled and uploaded to it. The algorithm for object distance detection is shown in Figure 10, below.

![Figure 10](image)

**Figure 10. Distance detection software program design.**

A set of 10 different snap-fit building blocks were considered necessary to create the mechanical structure of an educational robot. These pieces can be seen in Figure 11.
The bars are ½ in. by ½ in. and come in lengths of 2 in, 4 in, and 8 in. These lengths were chosen so that two of a smaller bar could replace that of a larger bar. Each bar has 1/8\textsuperscript{th} in holes spaced ¼ in apart both vertically and horizontally throughout the piece. This configuration allows for the use of fasteners regardless of how the bar is oriented. The two dimensional and three dimensional corners allow bars to be connected perpendicularly to each other. The mid-connector piece is designed to connect the end of a bar to the middle of another bar using the fastener holes instead of a snap fit. The female couple and male couple pieces are designed to allow the connection of two corner pieces or two bar pieces when desired. Lastly, the servo brackets allow a standard servo to be fastened to the mechanical structure. These parts were created using the rapid prototype printer, a device that layers ABS+ material continuously until the model is created.

Figure 11. The 10 individual snap-fit pieces included in the V-BOT kit.
6. Design Evaluation

The V-BOT kit, currently containing the ten mechanical building block pieces and a small array of sensors and actuators, allows for the design and building of a vast variety of robots. The mechanical structure is simple to build and reduces the number of fasteners needed, yet allows for the addition of components from outside the kit. These components include but are not limited to standard and continuous servos, infrared and ultrasonic sensors, as well as a university made line sensor. The devices mentioned are just a few of the important tools used in robotics, but the addition of more sensors, actuators or end effectors can easily be done in the future. All components on the mobile robot are controlled using the adopted Parallax board, which allows for simple programming and connection between nodes. This board was useful for demonstration purposes, but a more robust board is preferred. Additionally, the stationary robot, which used two Arduino boards in a master-slave configuration, worked well but could be improved by a more powerful central unit.

The mobile robot, which was chosen for its similarities to the Parallax Boe-Bot®, can indeed perform the same actions that the Boe-Bot® can perform. Every competition of the Vandals Robotics Challenge in which a Boe-Bot® is used, the mobile robot can also participate. Both robots can be equipped with the same sensors, servo, board, wheels and more. The size and weight of the robots are roughly the same, which means both robots can face off in competitions such as the Sumo and Freeze-tag event. Overall, the mobile design shows that the V-BOT kit can carry the strengths of the Parallax Boe-Bot® while not confining it to a mechanically stale product. The stationary robot, designed from the ground up, achieves its purpose and proves that the kit can be used to create a variety of robots depending on the need of the user.

To further analyze the effectiveness of the V-BOT kit, a Design Failure Mode Effects Analysis (DFMEA) was implemented. Important aspects of the robot kit are found within this analysis and improvements for future teams are suggested. A simplified DFMEA spreadsheet can be found in appendix 5. Through this analysis, we’ve discovered the most likely mode of failure is through fatigue of the building block pieces. This can be remedied with a different fabrication technique.

The most convenient way to test out the mechanical snap-fit connections and build the robots using the prototype parts was to utilize a rapid prototype printer. This allowed for simple construction of intricate parts without the need of molds or other high initial cost manufacturing techniques. Although this process was efficient for prototype purposes, it is not a viable solution for long term manufacturing plans. The durability of the parts is greatly compromised by the
building procedure of the printer. The layering of the ABS+ material increases the chances of fracture parallel to the layers and reduces the effectiveness of the snap-fit.

The cost of using the rapid prototype printer was relatively inexpensive considering the possible costs of the alternative processes. The combined cost of materials and machine time to create the parts required to build the stationary and mobile robots was about $210, while experimental printing of early snap-fit parts sums up to no more than $45. Also, the time required to create the parts using the printer was miniscule to that of other processes. The creation of all the parts needed to build one robot took about 27 hours, and was printed locally. Some additional time was spent cleaning the parts and refining them for building. The cost and time required to make the prototype parts was acceptable, but not for finalized parts on a large production scale. Another manufacturing process will be needed for mass production of the V-BOT kit.

7. Recommendations

Although the work done by team V-BOT was extensive, the V-BOT kit is not yet complete. The educational robot project was continued by team V-BOT and will be passed on to another team next year. Many important concepts for the educational robot were discovered by team V-BOT, and the following is a collection of that information provided for future work.

As mentioned previously, the prototype parts were created using a rapid prototyping printer. Although this was an excellent means of creating proof of concept parts, it is in no means a final form of production. In order to manufacture a large quantity of the same part and increase the strength of that part, a process such as injection molding is required. With building block parts confirmed, a mold can be made of each part and used to create as large a quantity as desired in an inexpensive manner. This will also increase the strength and durability of the part, as it will not have the layers found on the prototypes that easily split. Additionally, different colors could be used in each part to give the kit a bit of flare.

In addition to the ten building blocks in the kit, more pieces could be created to allow for other angles besides 90 degrees. A corner piece with 30, 45 or 60 degrees could be created to further increase possible robot designs. Also, more pieces could be created to host a larger variety of sensor and actuator brands. Although our design should encompass standard devices, the capability to house uniquely shaped parts will greatly increase the versatility of the kit.
Subsequent teams should look for a Lithium Ion battery that is both affordable and strong enough to meet sensor and processor needs. This battery exists somewhere in the 10 to 12 volt range. It is important to remember that it must be able to connect to the processor board to supply power to the system. Many can be purchased that allow the user to connect their own ports, but it would be best if the batteries are functional off-the-shelf. This is the most practical for mass production.

It is suggested that a computer science major is added to the team for future work on the user interface and behavioral programming. This addition would greatly simplify the control of the robot as well as aid the team in understanding programming techniques. Also, the implementation of a cross platform graphical user interface will allow a wide range of students to use the kit. The Qt development kit would be an excellent tool for this purpose. Such a platform would run more efficiently using a more powerful SBC, specifically concerning USB host and device support.

A significant portion of the time spent by Team V-BOT on the project was dedicated to the organization and management of the Vandals Robotics Challenge. Like the educational robot, this part of the project will be continued in future years by the subsequent teams, and it is important that these teams improve upon the final product. To do so, there are a few important areas for improvement. The primary area for improvement lies with the distribution of information and materials to the high school students before the competition. The majority of the students who participated in the Vandals Robotics Challenge had little to no prior experience with designing and programming robotic machinery. As such, it is important to distribute information and kits as early as possible to provide the students with sufficient time to prepare for the competition. The second area for improvement is in the event organization. Subsequent senior design teams will be able to significantly reduce their workload by recycling the work of Team V-BOT and Team O.A.R. By repeating the successful events from previous years (such as Sumo Showdown and Campus Adventure), and making changes only where necessary, teams may avoid some unexpected difficulties that may arise from significant changes to the competition structure.
8. Appendices

A.1: 2009 Vandals Robotics Challenge Rules

COMPETITION RULES

Created by University of Idaho V-BOT Senior Design Team

These rules are subject to revision as the need arises. It is important that teams use the most recent revision whenever possible*. Be sure to check the Google Groups page for the latest revisions.

COMPETITION ITINERARY

MORNING SESSION: Balloon Raid and Campus Adventure

AFTERNOON SESSION: Sumo Showdown and Vandal Freeze-tag

GENERAL COMPETITION RULES

All rules are enforced by the tournament officials, at their discretion. If a team disagrees with the decision of an official, grievances can be filed with the tournament scorekeeper.

- No objects functioning as remote controls are allowed at the competition.
- Only one member of each team is allowed next to the table during a match. All other members must remain further than 5 feet from the event table.
- During a match, team members may switch in and out of the table area as long as only one team member is next to the table at any time.
- No coaches, teachers, or parents may be within 10 feet of the competition table.
- The main tournament floor is divided into sections: Mission Control, Competition Sector, “On Deck”, and the Score Zone.
- Each team will be provided a “Mission Control” Center to keep its equipment and personal items and to make repairs to its robot.
- The “On Deck” area is for those teams immediately next to compete and is used as a means to make sure the competition stays on schedule.
- The Score Zone is off-limits to team members and coaches/teachers.
- All timing will be done with a stopwatch and controlled by a tournament official at each table.

ROBOT REGULATIONS

- The robot must be able to fit inside a box 5 in. by 8 in. by 5 in. high.
- The robot’s weight (including accessories) must not exceed 20 ounces.
- Teams are only permitted to spend $25 on extra parts or sensors, but the robot must stay within the size/weight limits. All additional parts must be accounted for, whether purchased by the team or donated by an outside party.
- Tournament officials will evaluate the robot upon check-in to see if the robot has been modified beyond the supplied kit and supplemental parts supplied by the College of Engineering. If it has, teams are required to bring receipts and document expenses in the Engineering Notebook.

* This Edition Revised: May 12, 2009
• receipts, the team will be asked to remove all parts or sensors not provided in the kit or by the College of Engineering before competing.
• Teams may not use any motors, other than the ones provided in the kit.
• The robot may not include any parts that might damage or deface the competition arena.
• The robot may not include any device designed to damage the opposing robot. Such devices may include, but are not limited to:
  • A device that insufflates (pour, spill, drop, ooze, eject, fire, shoot, squirt, etc) any liquid, powder, or gas.
  • An inflaming device.
  • A throwing device.
• The robot may not include a device that obstructs the control of the opponent’s operation, such as a jamming device or strobe light.

COMPETITION 1: CAMPUS ADVENTURE

EVENT DESCRIPTION – CAMPUS MAP “SCAVENGER HUNT”

This is an individual event. One at a time, teams will place their robots at the start of the campus map. The robots will then proceed around the map, following the designated paths and making decisions at intersections. Teams will be awarded points based on their robot’s performance, according to the rules below.

CAMPUS ADVENTURE COMPETITION RULES

• A sample track will be available for ”test drives” the night before the competition, to perform testing and calibration.
• Before the contest starts, all contestants are invited to examine the course. Any issues the contestants have with the course (smudges, uneven surfaces, etc.) must be brought to the attention of the judges at this time.
• All robots must be ready to run at the start of the contest. The order of running will be determined prior to the start of the tournament, based V-ROC Identification Number.
• All teams must be in the “On Deck”, ready to compete immediately after the team preceding them is finished. All information regarding where each team will be competing and the order will be clearly posted in the competition area. Every team is responsible for being ready on time.
• Once a match has started, no contestant or official may touch the track or interfere with the robots in any way except to reset a robot as stated below. Resets are done only by one pre-selected team member.
• The pre-selected team member may pick up the robot and place it behind the previous checkpoint on the track at any time.
• The team’s run will continue to be timed as a vehicle is reset by a team member. Placement is to be no further than the previous checkpoint along the track.
• Each match is at most TWO minutes long.
• A robot’s run ends when it has completed the course, or it is deemed by the official to be unable to track the line, or at the end of the TWO minute time limit.
• The robot will start in a designated starting zone.
A robot earns points for each designated building that it passes on the map, each with a different amount of points attributed (for example, the Administration Building could be worth 25 points, while the Engineering Physics building could be worth 15).

Points for each building are awarded only when the robot has crossed the dashed scoring lines near each building. Next to the scoring lines are the values for each building or landmark.

The general layout of the campus competition map will be posted online during the Challenge season. Each team can opt to go for any number of goal buildings within the time limit. Robots must stay on the road or face a 10 point penalty for each infraction in which no part of the robot lies over the black line.

If the robot stops following the road that it is currently on or traverses over any dead zones to get to another road, the team incurs a 10 point penalty.

Each team will get only one run at this competition. Winner is determined as the team with the most points.

COMPETITION 2: BALLOON RAID

EVENT DESCRIPTION – BALLOON POP COMPETITION

This is a head-to-head event. Two at a time, teams will place their robots at the designated start point inside the Balloon Raid arena. The goal of the event is for a team’s robot to pop all of the balloons of that team’s color, before its opponent’s robot does so. Object and color sensors will be used to find the balloons and to determine if the robot should pop them. A team will be declared victorious based on robot’s performance, according to the rules below.

BALLOON RAID COMPETITION RULES

- The Balloon Raid contest involves two robots seeking to outscore their opponent according to the game rules presented here.
- There will be three rounds, each will be TWO minutes long at most.
- Teams will start in one of the two designated starting areas, and will be allowed to start their robot after the round is officially begun by the judge.
- The goal of the competition is to pop as of the balloons of the color designated to the team as possible.
- The total number of balloons popped will be counted from all three rounds.
- Points will be awarded based on total balloons popped, not just the ones popped by one team’s robot.

COMPETITION 3: SUMO SHOWDOWN

EVENT DESCRIPTION - MINI-SUMO COMPETITION

This is a head-to-head event. Two at a time, teams will place their robots at the designated start points inside the Sumo ring. The robots will attempt to push their opponent’s robot out of the ring, while remaining inside of it itself. The victorious robot will be declared according to the rules below.
SUMO SHOWDOWN COMPETITION RULES

- The Sumo Showdown involves two separate teams who compete by having their robots attempt to push the opponent out of the sumo ring according to the game rules presented here.
- Each round is TWO minutes long at most.
- When neither contestant has a clear win, the winner will be decided by the tournament official. The official will select the winner based on which robot was the most successful competitor. This decision is to be made at the official's discretion, and if no decision can be reached, an extra two-minute match can be played.
- The robot may not include any part that fixes the robot to the sumo ring surface and prevents it from moving (such as suckers, glue, and so on). The robot must always be able to move.
- The robot may not include any device that increases the apparent weight of the robot. Examples include: using vacuum, fans, or magnetic systems to pull/push the robot down onto the sumo ring surface.

UNDER THE FOLLOWING CONDITIONS A TEAM WILL WIN THE ROUND:

- When a robot ejects its opponent from the sumo ring with a fair action. The robot is considered ejected the moment any part of the robot contacts any part of the exterior of the sumo ring. A robot hanging over the edge of the sumo ring or touching any part of the cylindrical side of the sumo ring is not considered ejected, and the robot is still in play.
- When the opponent's robot steps out of sumo ring on its own (for any reason).
- When the opponent's robot or team is disqualified or has had more than one violation or warning.

ANY OF THE FOLLOWING ACTIONS WILL RESULT IN THE TEAM LOSING THE ROUND:

- A part (or parts) of the robot that exceeds a weight of 10 grams is separated or dropped from the robot. Any separated parts will be weighed following the conclusion of the round, to avoid disruption of play.
- The robot stops moving on the sumo ring for more than 10 seconds.
- The robot emits smoke.

A CONTESTANT WHO TAKES ANY OF THE FOLLOWING ACTIONS WILL RECEIVE A WARNING:

- Any team member reaches into the table and sumo ring before the referee’s call ends the match.
- Preparation for the restart of a match takes more than 30 seconds.
- Any other actions deemed by a judge to be unfair or unsporting.
- Continued complaints or inappropriate remarks made by a contestant (verbally or non-verbally) about a referee’s decision, condition of the sumo ring, or environment, after the officials have made an attempt to correct the problem.
- When a contestant/team receives two warnings, the contestant’s opponent will be deemed the winner.

A MATCH WILL BE STOPPED AND A REMATCH WILL BE STARTED UNDER THE FOLLOWING CONDITIONS:

- The robots are locked together in such a way that no more action appears to be possible or they rotate in circles several times.

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1 Sumo competition rules adapted from SeattleRobotics.org Robothon website.
Both the robots are moving, but they don't appear they will ever contact each other.

Both robots touch the exterior of the sumo ring at the same time.

When a robot gets stuck on the border line and cannot move off the border line on its own and the other robot does not interact with it for over 10 seconds.

Any other conditions under which the referee judges that no winner can be decided.

In the case of a rematch, maintenance of competing robots is prohibited until a winner is observed, and the robots must be immediately put back to the starting location.

If neither of the competing robots win nor lose after a rematch, the referee may reposition both robots to a specified location and restart. If even that does not yield a winner, the match may continue at any location decided by the referee, until the time limit is reached.

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**COMPETITION 4: VANDAL FREEZE TAG**

**EVENT DESCRIPTION - FREEZE-TAG COMPETITION (BONUS ROUND)**

This is a group event. All teams wishing to participate in the Vandal Freeze-Tag Bonus Round will place their robots inside the designated arena. The goal of the competition is to disable other robots while remaining active. All teams will be provided with a “kill-switch” to place, unaltered, on their robot for this competition (as well as accompanying code). Robots will be disabled according to the rules below, with the final remaining robots receiving awards for their performance.

**VANDAL FREEZE-TAG COMPETITION RULES**

- The freeze-tag contest involves many separate robots seeking to disable all other robots by engaging the opponents’ “kill-switch”.
- All robots must use the supplied kill-switch and accompanying code to shut-off their vehicle if contacted by another robot.
- Teams may not modify their vehicle’s “kill-switch”, or the code used to “freeze” the vehicle. Teams may not obstruct access to their vehicle’s “kill-switch.”
- Any disabled vehicle will be removed from the arena by a judge.
- A vehicle is considered disabled if:
  - Its kill-switch is engaged
  - It remains stationary for more than 10 seconds
  - It crosses the boundary of the arena
- The last 3 vehicles remaining active will be declared the competition winners. A time limit will be determined based on the number of participants in the competition.
ENGINEERING DESIGN POSTER

The Engineering Design Poster is your chance to show off the design process your team used to create your final robot. Posters will be set up around Mission Control for judges and spectators to view during the competition on May 2. Posters should represent your team spirit as well as demonstrate the engineering principals you learned during the Challenge Season.

Key stages of the Design Process: Ask, Imagine, Plan, Create, and Improve!

TIPS AND HINTS:

- Posters should be approximately 36”x48” and able to support themselves on an easel.
- Keep words to a minimum and use descriptive pictures.
- Highlight your results.
- Describe your goals and how you met them.

ENGINEERING NOTEBOOK – BONUS POINTS

One of the goals of the Vandal Robotics Challenge is to recognize the engineering design process and the journey that a team makes during the phases of the problem definition, concept design, system-level design, detailed design, test and verification, and production.

Throughout the building of your robot, you will come across obstacles, lessons learned, and the need to draw things out on paper. This is where you and your team will use an engineering notebook, which will follow your team through the entire design process. Your Engineering Notebook may be a physical, written booklet, or could be in the form of a team website.

Your engineering notebook will be used to create your Design poster which the judges will review at the competition.

GUIDELINES AND FORMAT

The Vandal Robotics Challenge Engineering Notebook is the complete documentation of your team’s robot design. It should include sketches, discussions from team meetings, design evolution, processes, “Ah-Ha” moments, obstacles and resolutions, and each team member’s thoughts throughout the journey. Here are some suggestions:

- Document everything!
- Organize your Engineering Notebook so an outsider will understand your team and journey.
- Make entries in permanent ink, not pencil.
- Draw a single line through the errors/incorrect data. Do NOT erase or use correction fluid. Initial and date all corrections.
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<td><em>What the team is doing and discovering.</em></td>
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**TIPS AND HINTS**

- Every notebook should be a work in progress, forever changing and developing.
- When looking at your poster, judges will want evidence that you had a unique design or playing strategy, so make sure you record the substance to support its reasoning.
- Use pictures or sketches of your robot designs as part of a thorough documentation.
- When creating your design poster it may be good to highlight your team’s top 10 best moments as a team. Use your notebook to keep track of these milestones!
- Remember you can post discussions question or comments you have on the Google Groups site. Your input really helps us improve the competition for future years, and other teams may be interested in things you’re discovering as well!
- Don’t be afraid to customize your Engineering Notebook to reflect your team’s personality! At the end of the season, this notebook will be a great piece of memorabilia for your team.

The Engineering Notebook can be turned in for bonus points on Friday, May 1 at the V-Bot booth at the Engineering Design EXPO.
AWARDS AND COMPETITION SCORING

Guidelines for winning Awards at the Vandal Robotics Challenge:

- Team must demonstrate respect good sportsmanship both for team members and fellow teams
- Engineering Notebook must be submitted, and must impress the judges
- Team displays good communication and team work skills within the team
- Team communicates clearly about their robot design to the judges
- Robot effectively competes in the game challenge and impresses the judges
- Team and Robot consistently performs well during matches
- Team is a strong contender for all other judged awards

ENGINEERING DESIGN POSTER

<table>
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<th>Activity</th>
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<tbody>
<tr>
<td>CAMPUS ADVENTURE:</td>
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<td>150</td>
</tr>
<tr>
<td>BALLOON RAID:</td>
<td>100</td>
</tr>
<tr>
<td>BONUS – ENGINEERING NOTEBOOK:</td>
<td>50</td>
</tr>
</tbody>
</table>

Up to 50 bonus points may be awarded to each team based on content and creativity of the team design notebook. Points will be awarded to each team by decision of the competition judges.

BONUS ROUND - VANDAL FREEZE TAG

The Bonus Round is conducted separately from the rest of the competition. A team’s performance in the bonus round will not affect the standing in the competition, but awards will be presented for the winners of the Bonus Round.

THE EXPO INNOVATOR AWARD

“Engineering at Idaho” means working as a team to create a truly amazing product. At the University of Idaho, our engineers know the value of competition! We know that your team has devoted a lot of time to develop the best robot – and we want to reward you for your hard work. Because of your demonstration of engineering excellence, we’d like to welcome you to our College of Engineering team!

This award recognizes the three teams who have excelled in every area of the competition. These teams have taken their design “out of the box” and shown judges that they have what it takes to excel at engineering.

Students on the top three teams who will be attending the College of Engineering at the University of Idaho will be receiving scholarships for the first semester enrolled.

- Engineering Design Poster – 10% of score
- Campus Adventure points: – 30% of score
- Sumo Showdown points: – 30% of score
- Balloon Raid Points: – 30% of score
ROBO-VANDAL AWARD

The Robo-Vandal Award is for the team whose robot excels at the Campus Adventure challenge. Line recognition is a critical programming tool that provides a foundation for many robotics applications used in the real world. Mastery of this skill shows that the team recognizes the importance of establishing the groundwork in robot programming and design in order to prepare for future success!

SUMO SHOWDOWN – SPECIAL AWARDS

The top four performers in the Sumo Showdown will be recognized in the spirit of traditional Japanese Sumo Championships:

- **The Emperor's Cup - 天皇賜杯** – Tournament Champion
- **Gino sho - 技能賞** - Technique Award
- **Shukun sho - 殊勲賞** - Outstanding Performance Award
- **Kanto sho - 敢闘賞** - Fighting Spirit Award

THE RAIDER AWARD

The Raider Award is for the team whose robot excels at the Balloon Raid challenge. Color and light sensing brings robotics to the next level of sophistication. A strong performance in this competition demonstrates a whole new range of capabilities for the robot. Who can know what your robot could see in the future!

ENGINEERING DESIGN AWARD

Design is a process. The team who can keep track of all key players, note important milestones, and stay focused on its objective will always be better off than a team who cannot – even without multiple wins in the competition. For taking the time to learn the process, this team is a winner, on and off the playing field.

- Engineering Notebook – 70% of score
- Campus Adventure points: – 10% of score
- Sumo Showdown points: – 10% of score
- Balloon Raid Points: – 10% of score

For any questions or clarifications on the competition rules, please contact:

Team V-BOT

v-bot@uidaho.edu
The competition rules are subject to revision as the need arises. It is important that teams use the most recent revision whenever possible. Be sure to check the Google Groups page for the latest revisions.

## COMPETITION ITINERARY

<table>
<thead>
<tr>
<th>MORNING SESSION:</th>
<th>9:00 AM – 9:45 AM</th>
<th>BALLOON RAID</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9:45 AM – 10:15 AM</td>
<td>‘PIT’ TIME</td>
</tr>
<tr>
<td></td>
<td>10:15 AM – 11:30 AM</td>
<td>CAMPUS ADVENTURE</td>
</tr>
<tr>
<td>LUNCH:</td>
<td>11:30 AM – 12:30 PM</td>
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<tr>
<td></td>
<td>2:15 PM – 2:45 PM</td>
<td>VANDAL FREEZE TAG</td>
</tr>
<tr>
<td></td>
<td>2:45 PM – END</td>
<td>AWARDS AND CHECK-OUT</td>
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## ENGINEERING NOTEBOOK – POSTER PREPARATION

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1 This Edition Revised: May 11, 2009
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- When creating your design poster it may be good to highlight your team’s top 10 best moments as a team. Use your notebook to keep track of these milestones!
- Remember you can post discussions question or comments you have on the Google Groups site. Your input really helps us improve the competition for future years, and other teams may be interested in things you’re discovering as well!
- Don’t be afraid to customize your Engineering Notebook to reflect your team’s personality! At the end of the season, this notebook will be a great piece of memorabilia for your team.

The Engineering Notebook is designed to aid your team through the engineering process and to make the process of designing a poster easier for your team. While individually worth no points, a well-kept and frequently updated notebook will make it easier you’re your team to construct an informative poster for the competition.
AWARDS AND COMPETITION SCORING

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- Team must demonstrate respect good sportsmanship both for team members and fellow teams
- Engineering Notebook is encouraged to illustrate the team’s progress
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</table>

COMPETITION TOTAL:

<table>
<thead>
<tr>
<th></th>
<th>Possible Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500</td>
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</tbody>
</table>

BONUS ROUND - VANDAL FREEZE TAG

The Bonus Round is conducted separately from the rest of the competition. A team’s performance in the bonus round will not affect the standing in the competition, but awards will be presented for the winners of the Bonus Round.

ENGINEERING DESIGN AWARD

Design is a process. The team who can keep track of all key players, note important milestones, and stay focused on its objective will always be better off than a team who cannot – even without multiple wins in the competition. For taking the time to learn the process, this team is a winner, on and off the playing field.

- Engineering Poster/Notebook – 70% of score
- Campus Adventure points: – 10% of score
- Sumo Showdown points: – 10% of score
- Balloon Raid Points: – 10% of score

For any questions or clarifications on the competition rules, please contact:

Team V-BOT

v-bot@uidaho.edu

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A.3: Sample Line-Following Boe-Bot® Code

' (STAMP BS2)
' (SPBASIC 2.5)

'Constants definitions
BLACK CON 0 'sets 0 as BLACK
WHITE CON 1 'sets 1 as WHITE
RWHEEL CON 12
'650 is forward, 750 stop, 850 back
LWHEEL CON 13
'850 is forward, 750 stop, 650 back

'Variable definitions
sl VAR BIT 'left side sensor
sr VAR BIT 'right side sensor
fr VAR BIT 'right front sensor
fl VAR BIT 'left front sensor

DO
  fr = IN4 'yellow - port 4
  sl = IN5 'blue - port 5
  sr = IN6 'white - port 6
  fl = IN7 'green - port 7

  DEBUG CLS
  DEBUG "fr = ",DEC fr, CR
  DEBUG "fl = ",DEC fl, CR
  DEBUG "sr = ",DEC sr, CR
  DEBUG "sl = ",DEC sl, CR 'each sensor.

  'normal navigation
  IF (fr = BLACK) AND (fl = BLACK) THEN 'move forward if seeing a black line
    DEBUG "Moving forward"
    PULSOUT RWHEEL, 690
    PULSOUT LWHEEL, 810
    PAUSE 1
  ELSEIF (fr = WHITE) AND (fl = BLACK) THEN 'right white turn left
    PULSOUT RWHEEL, 690
    PULSOUT LWHEEL, 740
    'PAUSE 1
  ELSEIF (fr = BLACK) AND (fl = WHITE) THEN 'left white turn right
    PULSOUT RWHEEL, 740
    PULSOUT LWHEEL, 810
    'PAUSE 1
  ELSE 'backward
    PULSOUT RWHEEL, 800
    PULSOUT LWHEEL, 700
    'PAUSE 1
  ENDIF

  'Turn on LED if we're moving forward, tell debugger window.
  IF (sr = BLACK) OR (sl = BLACK) THEN
    DEBUG "Moving Forward"
    HIGH 9
  ELSE
    DEBUG "NOT MOVING"
    LOW 9
  ENDIF

  PAUSE 20

LOOP
<table>
<thead>
<tr>
<th>A.4: SBC Product Information</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TS-7260</th>
<th>iPac 9302</th>
<th>Embest EM104V1</th>
<th>Atmel Diopsis Dev Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
<td>Cirrus EP9302</td>
<td>Cirrus Logic EP9302</td>
<td>Samsung S3C2410A</td>
<td>Atmel Diopsis</td>
</tr>
<tr>
<td>Core</td>
<td>ARM9 (200Mhz)</td>
<td>ARM9 (200Mhz)</td>
<td>ARM9 (200Mhz)</td>
<td>ARM926EJ. Magic DSPTM DSP</td>
</tr>
<tr>
<td>Power Supply</td>
<td>4.5V</td>
<td>5V</td>
<td>5V</td>
<td>5V</td>
</tr>
<tr>
<td>Communications</td>
<td>RS232: 2(shared) USB: 2 I2C: 2(shared) SPI: 2 CAN: 0 Ethernet: 1</td>
<td>RS232: 2 USB: 2 I2C: (Within 9 sync. serial lines) SPI: (Within 9 sync. serial lines) CAN: 0 Ethernet: 1</td>
<td>RS232: 3 USB: 2 I2C: Bus SPI: 2 Channel CAN: 2 Channel Ethernet: 2</td>
<td>RS232: 1 USB: 2 host, 1 device I2C: 2 SPI: 2 CAN: 2 Ethernet: 1 Audio I/O: 8</td>
</tr>
<tr>
<td>Kernel (with Memory Management Unit - MMU)</td>
<td>Debian Linux</td>
<td>Linux, Windows embedded</td>
<td>Linux</td>
<td>Linux</td>
</tr>
<tr>
<td>A/D</td>
<td>12-bit, 2 channel</td>
<td>12-bit, 5 channel</td>
<td>10-bit, 4 channel</td>
<td>8 Channel?</td>
</tr>
<tr>
<td>PWM</td>
<td>-</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>I/O</td>
<td>30</td>
<td>48</td>
<td>40</td>
<td>96</td>
</tr>
<tr>
<td>Price</td>
<td>$280</td>
<td>$230</td>
<td>$299</td>
<td>$1250 ($500 for universities)</td>
</tr>
<tr>
<td>Misc.</td>
<td>Includes dev kit, can run on ½ watt in low power mode</td>
<td>FPU processor, complete IDE included (with example code for Ethernet, USB, etc..)</td>
<td>4*8 Keyboard interface</td>
<td>Tutorials, examples and support included, SD card with Linux, c programmable DSP</td>
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</tbody>
</table>
### A.5: DFMEFA Failure Analysis

<table>
<thead>
<tr>
<th>PART FUNCTION</th>
<th>POTENTIAL FAILURE MODE(S)</th>
<th>POTENTIAL EFFECT(S) OF FAILURE</th>
<th>OCCUR</th>
<th>RECOMMENDED ACTIONS</th>
<th>CURRENT DESIGN CONTROLS</th>
<th>RPN</th>
<th>ACTION TAKEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snap-fit Pieces</td>
<td>Loose snap break</td>
<td>No part connect</td>
<td>4</td>
<td>Over use</td>
<td>3 Testing limits</td>
<td>3</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Bad hole size</td>
<td>Fastener interfer.</td>
<td>1</td>
<td>Poor creation</td>
<td>2 Inspection test</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Sensors + Servos</td>
<td>Arives broken</td>
<td>N/F but can fix</td>
<td>5</td>
<td>Bad part</td>
<td>1 Inspection</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Inner damage</td>
<td>N/F but can fix</td>
<td>4</td>
<td>Misuse</td>
<td>2 Using part</td>
<td>4</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Port damage</td>
<td>N/F but can fix</td>
<td>4</td>
<td>Misuse</td>
<td>2 Using part</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>Comp Board</td>
<td>Arives broken</td>
<td>N/F but can fix</td>
<td>5</td>
<td>Bad part</td>
<td>1 Inspection</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Overheating</td>
<td>Shut down</td>
<td>4</td>
<td>Too cluttered</td>
<td>2 Using part</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Poor wiring</td>
<td>Poor function</td>
<td>3</td>
<td>Bad wire / board</td>
<td>3 Using part</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>User interface</td>
<td>Glitches</td>
<td>N/F but can fix</td>
<td>3</td>
<td>Poor coding</td>
<td>3 Testing</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Port errors</td>
<td>Poor function</td>
<td>4</td>
<td>Poor coding</td>
<td>2 Using part</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>Circuitry</td>
<td>Wires disconnect</td>
<td>Not functional</td>
<td>3</td>
<td>Bad board</td>
<td>3 Using part</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>frayed wires</td>
<td>Poor function</td>
<td>2</td>
<td>Bad part</td>
<td>4 Inspection</td>
<td>2</td>
<td>16</td>
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<tr>
<td>Fasteners</td>
<td>Faulty part</td>
<td>N/F but can fix</td>
<td>3</td>
<td>Bad part</td>
<td>1 Inspection</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Wear and tear</td>
<td>Poor function</td>
<td>3</td>
<td>Over use</td>
<td>1 Inspection</td>
<td>2</td>
<td>6</td>
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</table>