

Upgrading the SplinterBot

By

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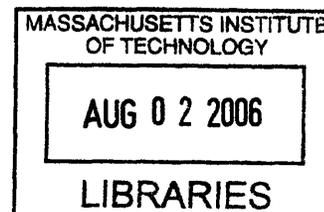
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1. Introduction

Today, we are seeing the beginning of the robotics revolution. In the United States, the company iRobot has developed robots to vacuum the house and scrub the floors.¹ In Japan, Mitsubishi has designed an autonomous robot to live with families, with the ability to take the initiative as well as take commands.² One of the allures of robotics is the fusion of many academic areas, from mechanical engineering to artificial intelligence. However, this combination of academic fields also leads to the difficulty in teaching robotics. Noticing the future demand for robotics, MIT and other top universities have started teaching undergraduate robotics courses to educate new roboticists.

In the fall of 2005, the MIT Computer Science and Artificial Intelligence Lab launched the second part in a two term class, Robotics: Systems and Science II (RSSII). The main goal of this class was to have the students apply all the principles learned over the previous semester on solving a complicated problem. The challenge for the term was to have the robot for the course, SplinterBot, autonomously navigate around the MIT campus and retrieve the plastic bricks scattered around. Once SplinterBot returned to base, it would build a simple structure with the bricks it collected.

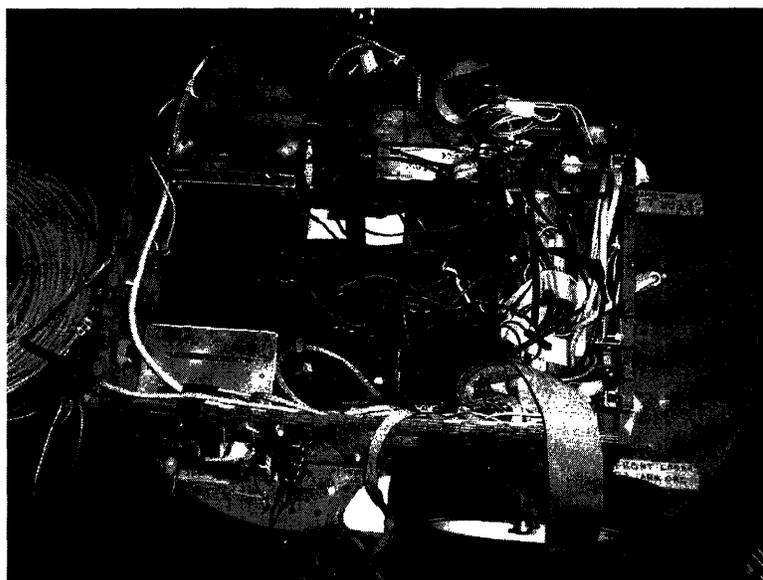


Figure 1: Overview of the insides of the SplinterBot. Tangled wires and densely packed components made it very hard for students to debug the robot's problems.

The SplinterBot had a wide array of sensors, batteries, and computers for use on challenge. This complexity, however, made it tricky to debug the robot when the students needed to troubleshoot. As an example, Figure 1 above shows the tangled wires and components the students had to deal with as they were debugging a problem. Another challenge the students faced was the tendency for the spring pin, for attaching the drive shaft to the wheel, to shear off after making quick movements. Repairing the spring pin

and debugging through the wires absorbed a great deal of the students' time while working on the project.

This project sought to solve the challenges the students encountered over the term. The upgrades for the SplinterBot include the construction of the second layer to separate the computers from the batteries, the construction of a side panel to attach all necessary computer ports to the side of the robot, replacing the wheels with pneumatic tires and a hub, and lastly recommending a new power system.

2. Creating Space with a Second Layer

One of the main challenges in working with SplinterBot in RSSII was the difficulty in debugging hardware problems. An unplugged camera or sensor would be last thing the students would check in debugging the robot's problem. SplinterBot's design had a large storage for the onboard computers and batteries. However, there was little room to change batteries and check the many connections necessary for robot's basic functions. In addition to the lack of space, the disorganized wiring between the batteries, computers, and sensors made determining the source of hardware problems quite laborious. In order to organize SplinterBot's storage area, a second layer was installed to separate the batteries from the onboard computers and the OrcBoard controller board.

The purpose of the second layer is to create space in the storage area of the SplinterBot by separating the robot's batteries from the onboard computer and controller board. By creating a second layer, the height of the robot can be effectively used as storage. The second layer also organizes the wiring between the batteries and the computer by using a single set of power wires going to the controller board. In the event that the batteries need to be changed or examined, the second layer easily detaches from the robot by unscrewing several bolts.

The second layer needed to accommodate one onboard computer and two OrcBoard controller boards. However, the area of the second layer was constrained to the area of the of the storage area. The positions of the onboard computer and the controller boards had to be arranged in a way that would allow for organized wiring between the computer and controller board.

The second layer was constructed from 11/32" plywood, to match material the rest of the SplinterBot uses. The detailed drawing of the second layer is in the Appendix. The clearance holes for four 4-40 machine screws are needed to secure the onboard computer. The onboard computer was moved close to one side of board to allow room for the computer port side panel, which will be discussed at a later point. The controller board is secured to the second layer by four 6-32 machine screws. The entire second layer is fastened to the robot by eight 1/4-20 bolts. To allow for easy removal of the second layer to change the batteries, handles are screwed in at the top and bottom of the second layer. The handles require two 8-32 machine screws. The second layer was fabricated on a Universal Laser Systems laser cutter. The laser cutter allows the second layer to be fabricated quickly by a person with minimal machining experience. The speed and power of the laser was set according to the supplied user manual. However, the manual only lists the settings for a limited set of conditions, such as laser power and material thickness. The manual suggests that the speed of the laser be set to 3.1% and power be set to 50% for a 60W laser in order to cut wood with a thickness of 1/8". The laser in the

CSAIL shop is a 120W laser, so either the power must be set to half of the recommended setting or the speed should be doubled. However, the speed of the laser should be decreased or the power of the laser should be increased in order to cut through the additional material. The correct setting was found by attempting to cut a 2" by 2" square on scrap material with the laser settings to be tested. If the square was not successfully cut out at the settings, then either the power was increased or the speed was decreased. If the square was cut out but the sample suffered too much scorching, then power was decreased or the speed was increased. After some tests, it was found that 11/32" plywood was best cut out by setting the laser to run at 65% power and 0.8% speed.



Figure 2: The second layer mounted in SplinterBot's chassis. The second layer provides bolt patterns for two OrcBoards and one onboard computer. The handles allow for easier removal of the second layer. The wires between the OrcBoard and the computer can be made shorter due to the close distance between the two components.

The completed second layer can be seen in Figure 2 above. The close space between the onboard computer and the controller allows for much shorter wires to be used. The wires traveling from the computer to the controller board no longer have to travel the entire length of the robot. It therefore becomes easier to check if all wires are properly connected.

3. Moving the Computer Ports

After ensuring all hardware connections were indeed made, the students needed to check the processes running on the onboard computer to diagnose the robot's problem. Normally, the students would be able to remotely connect to the computer from their remote workstations. However, there were times when the students were not able to remotely connect to the computer. In these cases, the students resorted to working directly off of the onboard computer. The SplinterBot was not designed to necessarily have the onboard computer's ports in an area easily accessible to its users. All of the computer's ports were accessed from sections cut out from the back of the robot. While this allowed students to reach the computer ports, several cables now needed to double

back to return to the controller board inside the robot. To solve this problem, a side panel for the computer connections was fabricated.

The computer port side panel is used to move the computer's port to the surface of the robot. When the students were debugging the robot's problems, they tended to use the computer's VGA, USB, Ethernet, and PS/2 ports. However, all the ports were inside the robot buried under wires and surrounded by batteries. By moving the computer ports to the outside of the robot, the students will have an easier time using the onboard computer because they will no longer have to open the robot to do so.

The computer ports were moved to the side of the robot by various extension cables. The extension cables included two six inch USB extension cables, one six foot VGA extension cable, one RJ45 coupler, and one six foot PS/2 extender. The extender cables should ideally be about one foot long to minimize the clutter inside the robot, but the common length of the extension cables is six feet. Due to the short length of the USB extension cables, the onboard computer must be position close to the side panel. Longer cables could have been cut and soldered back together, but its effects on the shielding is unknown.

The side panel is cut out from 7/32" plywood. Two 0.275" by 0.585" rectangles were cut out for the two USB ports. The USB extension cables were attached to the side panel by the hooks at the end of the USB port. One 0.353" by 0.750" rectangle was cut out to accommodate the VGA extension cable. The VGA extension cable is bolted to the side panel by two 4-40 machine screws. Two pockets are cut for the 4-40 nuts to accommodate the depth of the VGA cable to connect to the port. A 0.452" circle is cut for the PS/2 extender. In addition to the close fit, epoxy is used to fasten the extender to the side panel. A 0.885" by 0.653" rectangle with two 0.250" by 0.125" notches is cut out to secure the RJ45 coupler. Two 0.250" by 0.250" square holes are cut out from the center of the couple for the two notches to fit in. The RJ45 coupler is easily opened, which allows the wires to be removed and each side of the coupler to be attached to the side panel. The side panel also has two power switches to power the controller board and the onboard computer. Finally, four 6-32 mounting holes for the OrcBoard's LCD display, the OrcPad, are cut into the side panel. Having the OrcPad on the outside of the robot allows the students to see vital information on the OrcPad's LCD display and allows for easy access to the robot's emergency stop button.

The side panel was fabricated using a Universal Laser Systems laser cutter. As with the second layer, using the laser cutter allows a person with minimal machining experience to quickly fabricate the panel. Similar testing was conducted to determine the correct laser cutter settings. After several tests, the laser cutter was found to best cut 7/32" plywood with the laser cutter set to 100% power and 2% speed.

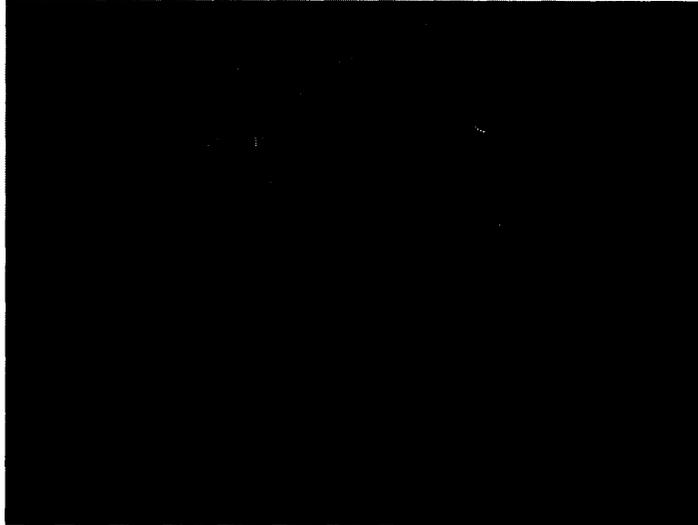


Figure 3: Computer port side panel mounted on the SplinterBot. The panel supports two USB ports, one VGA port, one Ethernet port, and a PS/2 port. The panel also includes the power switches the OrcBoard and computer, in addition to space for the OrcBoard's LCD display, the OrcPad.

The completed computer port side panel is shown in Figure 3. The computer port side panel only extends the necessary ports to the surface of the robot chassis. All connections between the computer and the controller board are kept within the chassis, which allows the students to easily follow all the connections. Also side panel allows the students can quickly connect to the robot and troubleshoot why the robot is acting up because all the computer ports the students use are on the outside.

3. Mounting Pneumatic Wheels

The original SplinterBot design used two plastic wheels with press fitted hubs secured with a 1/16" spring pin. While this design was suitable for a lighter robot, the weight from the extra batteries and SICK laser scanner caused the spring pin to shear. The students found that the quick movements exerted a force on the spring pin large enough to shear it. When the spring pin would shear, the lab assistants would have a difficult time removing the spring pin because of the spring pin's proximity to wheel. The lab assistants wanted to use a larger spring pin, but enlarging the hole in the shaft was difficult due to the lack of clearance from the wheels.



Figure 4: The previous SplinterBot wheel. The wheel is press fitted into a hub, which is secured to the drive axle by a spring pin. The spring pin sheared off on several occasions due to the robot's quick acceleration and large inertia.

Toward the end of the semester, the lab assistants purchased a set of 10 inch pneumatic tires to replace the problematic plastic wheels. However, the new tires brought new problems. The first problem was that the tires were not designed to fit the axles of the SplinterBot's motors. The tires were designed to be used with a $3/4$ " diameter axle, and the SplinterBot's axles have a diameter of $25/64$ ". The second problem was that the new tires had bearings in their hubs. The power from the robot's electric motor would have to be transferred with another mechanical element, like a spring pin.

The pneumatic tires can be modified with a custom hub for use on the SplinterBot. The custom hub was fabricated from 4" aluminum round stock. The hub was turned on a lathe to have a diameter of 3.347" and a thickness of 0.375". A hole was bored out of the center of the hub to a diameter of 0.386" for the electric motor axle. To match the bolt pattern on the pneumatic tire's hub, four additional 0.323" holes were drilled out every 90° from a radius of 1.378" from the center. A $3/32$ " key and keyway were used to transmit the torque to the wheels used instead of using a spring pin because of the higher loads a shaft key can handle.

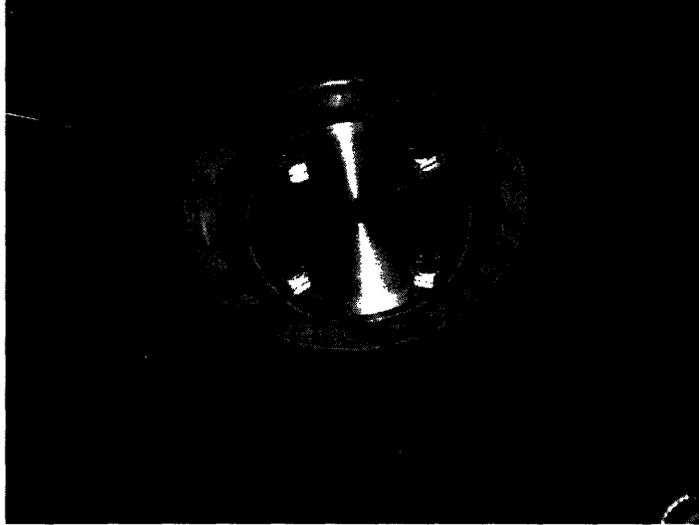


Figure 5: The custom made hub attached to the pneumatic tire. The hub allows the pneumatic tire to be attached on the SplinterBot's drive axle by using a shaft key.

In order to attach the custom hub to the tire's hub, the tire's bearings need to be removed from the hub. The pneumatic tires use a 2 piece hub, which are bolted together and secured with lock washers. Fortunately, the bearings are only on one of the hub pieces. If there are multiple tires, then the hub piece with the bearings can be replaced with another hub piece without the bearings from another tire. A completed custom hub attached to the pneumatic tire is shown below in Figure 6.



Figure 6: The pneumatic tire attached to SplinterBot.

The pneumatic tires help the SplinterBot in two ways. First, the lab assistants no longer need to constantly change sheared spring pins. Secondly, the pneumatic tires also provide a simple damping system. The SplinterBot's original plastic wheels transmitted any bounces and disturbances from the ground to the chassis, which would shake the onboard camera. The new pneumatic tires allow for some deformation in the tire, which would absorb smaller bumps and bounces.

4. Power System Recommendation

As with any mobile robot, the design of SplinterBot's power system needed to overcome many challenges. Since the robot needed to scour the MIT campus for bricks, SplinterBot needed a great amount of batteries to be able to venture on its own. The electrical components necessary for the challenge, like the laser scanner and onboard computer, further burdened the robot's power system. It was determined that the SplinterBot needed a total of 576Whr of energy operating at 12V in order to run long enough to search a significant portion of the campus. SplinterBot used eight sealed lead acid batteries wired in parallel to provide the power. The weight of the batteries totaled 16.3 kg. The weight of the robot made it very difficult for the students to lift the robot when necessary. The number of batteries also required a long amount of time to recharge the robot. The required charging time was made even longer due to using 300mA chargers, which completely charges the batteries in 160 hours. In order to solve the challenges due to the weight and required charging time, alternative batteries were investigated to replace the lead acid batteries.

The main considerations for the SplinterBot's power system are the battery's energy density, internal resistance, charging complexity, and the cost. The energy density, given in watt-hour per kilogram, allows the weight of the batteries to be approximated for the energy required. The internal resistance of the batteries determines the maximum current the batteries are able to source. The electric motors, the onboard computer, and the laser scanner all need large amounts of current and can operate incorrectly when not enough current is available. During the semester, insufficient current was found to cause the OrcBoard to rest after quickly accelerating the robot when only connected to the 300mA DC charger. The charging complexity determines the simplicity in implementing a charging circuit for the robot. As one example of the complexity in charging batteries, some rechargeable batteries need to have temperature sensors in order to prevent damage to the battery. An onboard battery charger would need to incorporate a thermocouple or some other temperature sensor, which makes designing the charging circuit more complex. Above all, the cost of the batteries needs to meet the budget available for the power system.

The SplinterBot currently uses a system of sealed lead acid batteries. Lead acid batteries are typically very inexpensive compared to other battery chemistries, with a 12V 7Ahr battery costing \$12.³ However, their low cost is offset by their large weight. Lead Acid batteries have an energy density of about 40 Whr/kg.⁴ They have an internal resistance of about 0.006 ohms.⁴ Lastly, recharging lead acid batteries is fairly simple, requiring only a way to monitor the charging current in order to switch to slower charging.

An alternative to the system of lead acid batteries uses nickel metal hydride batteries. They tend to have higher energy densities than lead acid batteries, with an average energy density of 57 Whr/kg.⁴ However, the internal resistance of NiMH batteries is higher, with a resistance of 0.015 ohms.⁴ They are also fairly expensive, with a 12V 7Ahr battery costing around \$90.⁵ In addition, NiMH batteries require a complicated charging circuit that monitors the battery's temperature to prevent the battery's internal pressure from building up and venting electrolyte.

Nickel Cadmium batteries are very similar to nickel metal hydrides. While they have a higher energy density at 42 Whr/kg than lead acid batteries, NiMH batteries have a higher energy density.⁴ However, NiCds have a lower internal resistance than NiMHs at 0.009 ohms.⁴ Both NiMH and NiCd batteries cost about the same, with a 12V 7Ahr battery costing around \$90.⁵ Also, both NiMH and NiCd batteries require a temperature checking charger.

After consider all choices, nickel metal hydride batteries would be the best alternative to a lead acid battery system. The low weight of the NiMH batteries would reduce the SplinterBot's overall weight, which might solve the problems with the drive wheel's spring pin. Reducing the robot's weight would also enable the robot to use less energy, since the robot is no longer carrying the extra mass. With any battery system, a charger with an adequate charging time is required

5. Conclusions

The upgrades done to the SplinterBot help the students work better with the robot. The second layer helps to minimize the clutter of wires by separating the batteries and the computer. This also allows the students to check that all sensors and components are connected. The computer port side panel helps the students by moving all the necessary computer ports to location that is easily accessible. In the event that the students need to use the onboard computer to troubleshoot, they will no longer need to open the SplinterBot and untangle all the wires. The pneumatic tires are able to withstand more torque than the spring pin was able to. The reduction in the amount of time the robot is being repaired gives the students more time to work on the assignment. Lastly, a new battery system comprised of nickel metal hydride batteries would lighten the robot's weight and would have a quicker recharging time with a new charger.

References:

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³ www. Battery Mart's 12V 7Ahr Sealed Lead Acid Battery.
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⁵ www. Battery Space. <<http://www.batteryspace.com>>

B. Detailed Drawing of Side Panel

