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The Design and Evolution of the eROSI Robot

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***Abstract*— The eROSI (Educational, Research-Oriented, Sensing, Inexpensive) robot is a robotic platform designed by the Center for Distributed Robotics at the University of Minnesota. It was designed for two purposes; an educational platform and a distributed robotics platform. These two purposes require very different and oftentimes contradictory abilities. As an educational platform, it must be easy to use and program for. It must also be non-intimidating to students who may not have much experience with robotics. As a research platform, it must be powerful enough to run useful behaviors, and expandable with new sensors.**

These two different purposes have driven the design of the eROSI robot through three generations of development. The first two generations have been tested and evaluated in terms of its two intended purposes. The feedback generated was then used to modify the design of the robot to better accommodate its intended purposes. The eROSI robot is still an ongoing project and aims to create a better platform for both research and education.

I. Introduction

The eROSI robot is a small, relatively inexpensive robot developed by the Distributed Robotics Center at the University of Minnesota. Its name is an acronym that stands for educational, research oriented, sensing, and inexpensive robot. As its name suggests, the eROSI was designed as a demonstration of the technology needed to create a robot that would serve as both an educational tool and as a distributed robotics research platform. For a robot to be useful as a distributed robotics platform, it must be inexpensive enough so that many of them can be built. This was one of the driving factors in the eROSI design.

In order to serve its purpose as both an educational and research platform, the eROSI robot had to meet a variety of design requirements. As an educational platform, a robot must be easy to use and non-threatening. This means that it must be easy to write programs for the robot, and easy to transfer those programs to the robot. There also needs to be an easy way to retrieve information from the robot. The robot would also need to have a useful, default set of sensors, as interfacing new sensors to an existing robotics platform is not an easy task.

As a distributed robotics research platform, a robot must be powerful as well as expandable. It needed to be powerful enough to process its sensor data and act autonomously, as well as be capable of executing simple behaviors. It needed to be expandable so that new sensors could be added to different robots to create a heterogeneous team. The robots also needed some method of communication, both with a central computer and with the other robots. It was decided that equipping the robots with cameras would make them a more useful and interesting research platform.

While there are many commercial robotics platforms available for purchase, the eROSI fills a niche that is left by these other systems. One such platform, the Khepera robot, is small and extensible, but also prohibitively expensive at almost $2000 dollars. Adding a wireless antenna and radio for communication costs an additional $1400 [1]. Two other popular platforms in robotics research are the Pioneer and the Koala [2], [3]. These robots are very large, though, which can cause difficulty in navigating cluttered environments. Their large size also makes them unattractive for use in very large multi-robot groups. A multi-robot platform similar to the eROSI is the CotsBots [4], however the CotsBots do not have the processing power nor the communication infrastructure offered by the latest version of the eROSI.

II. First Generation – The ROSI

The first generation of the eROSI robot was a prototype design intended to serve as a research platform for distributed robotics. As the first generation robot was not intended as an educational aid, it was called the ROSI robot, which stands for research oriented, sensing, inexpensive robot. Because it was a prototype, there were several problems that its creation exposed in the original design, as well as several unexpected practical issues that needed to be addressed. These issues will be discussed in the Feedback section.

Despite the flaws that were discovered, the ROSI proved to be a useful mobile platform that was used for research purposes [5]. Its small size, mobility, communication and sensing capabilities made the ROSI an attractive multi-robot experimental platform. In addition, feedback gained from the use of the ROSI robot provided valuable insight that led to the next iteration of the eROSI robot. The cost of the ROSI robot was approximately $500, with the cost of the camera being an additional $500.

A. Design

The original ROSI robot, which can be seen in Fig. 1 was 15.2cm long and 7.0cm wide. It weighed 200 grams and could operate for about three and a half hours on a full battery under moderate load. It had a maximum speed of

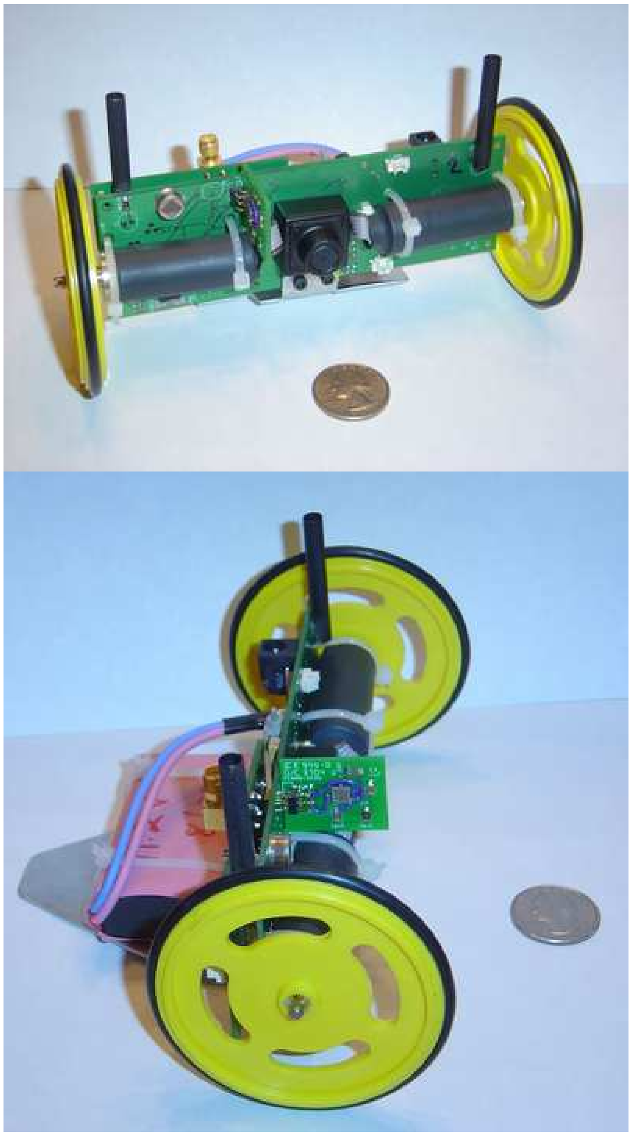

Fig. 1. Front and side view of the ROSI robot.

0.62 meters per second which was more than sufficient for such a small robot.

The original ROSI robot consisted of a circuit board with an ATMega128 micro-controller, several sensors, a battery pack, and two motors, one attached to either end of the board. The robot was kept upright by an aluminum plate, bent at an angle, that was attached to the circuit board. The battery was placed on this aluminum plate and held there with adhesive. The ATMega128 micro-controller was chosen for its low cost, and because many of the designers were familiar with it. The ATMega128 is also supported by the GNU compiler and tool-chain, which is common in university level programming courses. This makes it an attractive option from an educational standpoint.

The ROSI was equipped with a Bluetooth(TM) module that allowed the robot to communicate with a host computer, as well as other robots. Bluetooth(TM) communication is also available on many consumer devices such as cell phones and PDAs. This could potentially allow the robots to interact with a variety of different electronic devices. The Bluetooth module that the ROSIs were equipped with was a low power device, which limited its effective range to approximately 10m. In order to facilitate the use of a different communication method, such as 802.11 the Bluetooth(TM) module was placed on a daughter-card that could be removed from the main-board, and replaced with a different card. Also on the daughter-card was a second ATMega128 micro-controller that served as a dedicated controller for the Bluetooth(TM) module. This freed up processing on the main processor that could be used for more interesting behaviors and programs.

The ROSI was equipped with two different types of sensors, photo-voltaic light sensors and pyro-electric sensors. The robot was equipped with three light sensors, two pointing up and one pointing forward. For the upward facing light sensors, one was positioned on either side of the robot near each wheel. A student could use the upward facing sensors to detect the ambient light levels, while using the forward facing light sensor to detect the light level in the direction the robot was facing. The light sensors were analog which allowed for the level of light in the room to be detected, not just a binary light/dark value. The robot was also equipped with one pyro-electric sensor facing forward. This sensor could be used to detect the presence and possibly track humans or other sources of heat.

It was also possible to add sensors to the ROSI that were not included in the original design. Several of the digital I/O pins on the ATMega128 were available as were the serial ports connected to the micro-controller. This provided an easy way to interface the robot with digital sensors, as well as more complicated sensors that communicated over a serial link. Several of the analog to digital converters on the ATMega128 were also available as solder pads on main circuit board, allowing even greater customization of the ROSI robot.

In addition to these sensors, each motor contained an encoder that could be used to determine how many times its wheel had turned and what direction the motor was turning. These encoders were used to implement a PID controller for the ROSI robot allowing for reasonably accurate speed and distance measurements. The PID controller gives a researcher accurate odometry readings, while allowing a student the opportunity to study closed loop control systems.

After the ROSI was deployed, a camera was added to the robot to allow it to serve as a vision platform. The ROSI itself was not capable of processing the video from the camera, so a transmitter was attached that would transmit the video feed over standard television channels. In this way, any computer equipped with TV-decoder could receive the video feed from the robot, process it, and send commands back to the robot based on the processed video.

The ROSI was programmed via an 8-pin molex connector that was attached to the top side of the board near the battery. This connector was also connected to the serial port on the ATMega128 and allowed one to send information to and from the robot using a serial cable. This connector could then be used to send and receive information from a connected computer. The serial connection was instrumental in debugging the program running on the robot.

B. Feedback

One of the largest problems with the first generation ROSI robot was its unreliability. Due to cost concerns, the circuit boards were manufactured elsewhere and then populated in-house. This led to reliability problems because all of the components on the boards were surface mount and thus very difficult to solder. This caused many bad connections as well as connections that would break very easily.

Besides the reliability problems, there were also several issues with the design itself. One such issue was that in very bright lighting the photo-voltaic sensors would over-saturate. When this happened it was no longer possible to read the light level at that location. Even in this case, however, the light sensors would still register light, it was just no longer possible to determine the level of ambient light, as the sensors would always return their maximum value.

Another issue with the first generation robot was that it was difficult to retrieve simple information quickly from the robot while it was deployed. While it was possible to attach a serial cable to the robot and read information that way, it was inconvenient while the robot was moving. Some easily visible simple communication mechanism was needed. Communication was possible over Bluetooth(TM), but at this time the Bluetooth(TM) system was still in the beginning stages and not very robust. Additionally, Bluetooth(TM) communication had significant overhead for a simple status indicator.

In addition to the communications problems, there were also issues associated with the battery on the ROSI robot. The ROSI used a lithium-polymer battery, widely used in robotics for their high power storage and low weight and size. However, lithium-polymer batteries are also somewhat volatile and cannot be charged or discharged too fast, or over-charged. In addition, if a lithium-polymer battery is discharged too far, it will no longer accept charge and will be destroyed. The ROSI had no battery protection circuitry nor did it have a battery charge indicator. Thus, it was impossible to tell when the battery was almost drained, and if the battery was not handled properly, it could cause a fire.

As can be seen in Fig. 1, the motors were attached to the robot using zip-ties. This caused several problems because it was nearly impossible to align the wheels properly using such an imprecise method of attachment. Thus, the robot would wobble as it moved, and would not necessarily move forward in a straight line. This also caused problems with the motor encoders, as rotating the wheels a certain number of times would not necessarily move the robot forward the expected distance.

III. Second Generation – the eROSI

The second generation robot was to be sent to other schools to be used as an educational platform, thus its name was changed to the eROSI which stands for educational, research oriented, sensing inexpensive robot. The eROSI was intended to be an improved version of the ROSI robot that was also viable as an educational platform.

Fig. 2. The eROSI robot.

The second generation, which can be seen in Fig. 2, was the first one that was to be sent to other schools to be used for educational purposes. This necessitated several changes to the appearance of the robot as well as changes for safety reasons. The eROSI was also made easier to use than the original ROSI to make it more effective in an undergraduate robotics program.

The eROSI proved successful in an academic setting, and several robots were sent to Berea College where they were in an educational program [6]. At the University of Minnesota, the eROSI robot has been used for individual projects in classes such as Artificial Intelligence I, Sensing and Estimation in Robotics, and Topics in Computational Vision. The eROSI is also used to demonstrate robotic technologies at a variety of schools in the Minneapolis and St. Paul areas.

A. Design

The eROSI, which can be seen if Fig. 2, was made the same size as the ROSI by placing the circuit board horizontal instead of vertical. It weighed about half again as much at 330 grams, owing mostly to the addition of the case and a tail servo. The addition of the servo also decreased the battery-life of the robot to about 3 hours on a single charge.

A translucent plastic cover was added to the top and bottom of the robot to make it more attractive, as well as to protect the robot internals, such as the circuit board and battery. A colorful translucent plastic was chosen to make the robot less intimidating and allow students to see what the components of the robot looked like. This would allow students to see what the robot was made of and remove some of the "black box mysticism" that can occur with commercial robotic platforms. It was also possible to attach a plate to the top of the robot and add sensors and other hardware there. This gave users an accessible location to place extra hardware.

In addition to the new case, eight LEDs were added to the front of the robot that could be controlled from the software running on the eROSI. This allowed for a fast and simple way to convey information to the programmer of the robot. The LEDs could be used to send status information, or just to ensure the programmer that everything is working properly. It can be very comforting to an uncertain and inexperienced programmer to see lights flashing while a program is executing. It also allows for immediate feedback when there may not be any other debugging information available.

The Bluetooth(TM) module and accompanying micro-controller were removed from the daughter-card and placed on the main circuit board. This meant that there was only one board that needed to be produced and populated. This made the circuit board more complex, and resulted in the need to move to a four-layer board. A connector for the programming and serial ports for both micro-controllers was added to the front of the robot. This made the ports more accessible and improved the look of the robot. In addition, it was possible to plug the Atmel in-circuit serial programmer directly into the programming port on the robot. This made programming the robot much easier as no extra hardware or special cable were required.

B. Improvements

Based on the feedback received from the first generation ROSI robot, there were several improvements that were incorporated into the design of the second generation eROSI. One change that made the eROSI more reliable was to have the boards manufactured and populated professionally. Also, the Bluetooth(TM) daughter-board was moved onto the main board to decrease cost. This had the added benefit of decreasing the complexity of the robot itself, as there was only one circuit board instead of two. These changes resulted in the robot being much less prone to breaking.

When redesigning the main board, the 8-pin molex connector used to program the robot was replaced with a connector that fit the Atmel In-Circuit Serial Programmer. This allowed the user to plug the programmer directly into the robot without needing another cable, making the robot more user-friendly to program.

In addition to the changes made to the electronics, there were several changes made to the chassis as well. Once such change was the creation of an enclosure on the interior of the robot to house the battery as a safety measure. The battery was accessed via a metal plate that was held on using a thumb screw, allowing access to the battery while discouraging casual handling that could damage it. In addition to this housing, a protection circuit was added that would prevent the battery from being drained so far that it was destroyed. When the battery was drained to a certain voltage, the robot would automatically shut off ensuring the battery was not damaged. In addition, a two-color LED was added that indicated when the battery was running low.

In order to allow the camera to view things above the robot, an actuating tail was added to the eROSI, enabling it to tilt forward and back. The tail consisted of a length of foam attached to a hobby servo. To prevent the robot from being too front-heavy and tipping over, washers were attached to the other end of the tail to act as a counterweight.

The issue with the light sensors over-saturating was fixed by adding a capacitor to each of the light sensors. By charging the capacitors, waiting, and reading the analog voltage across the capacitors using the analog-to-digital converter, the value of the light sensor could be calculated. This removed the possibility that the sensors would over-saturate at the cost of drastically increasing the latency of reading from the light sensors.

C. Feedback

One minor issue with the eROSI robot was that the tail would drag when the robot was turning on rough terrain, due to the washers attached to the tail. This would make the robot jerk while moving, and could possibly affect the odometry readings. One solution to this problem that was employed was to replace the washers with a plastic sphere, allowing the tail to move more freely. Motor mounts were also added to the main board to ensure that the motor shafts were straight. This helped to reduce the wobble when it was moving.

Another improvement that caused additional problems was the changes that were made to the light sensors. The charge, wait, read cycle of the light sensors required much more time to read than the digital sensors. Most of the extra required time was attributed to the reading of the analog-to-digital converter and to the large number of floating point operations required in the calculations. Compounding this was the fact that this sequence could only operate on one light sensor at a time. These issues increased the latency of reading information from the light sensors.

The addition of the battery low-voltage detection circuit caused no problems of its own, however it did not solve all of the issues associated with the lithium-polymer battery. While the protection circuit did prevent one from discharging the battery too far and destroying it, there was still the issue of over-charging the battery and causing a fire. For the eROSI, the solution was to use an external charging device that contained all of the protection circuitry necessary to ensure safety. However this solution was not ideal because in an educational environment, it is not guaranteed that everyone will follow the proper charging procedures.

While this generation of the eROSI robot was successful as an educational platform, it quickly became apparent that it was of limited use as a research platform due to it lack of processing power. The ATMega128 is an 8-bit micro-controller running at 16MHz, which was more than suitable as a controller for the motors and sensors but inadequate for implementing anything more than simple behaviors. The ATMega128 also had no floating point unit, causing floating point calculations, such as the calculations required for the light sensors, to operate very slowly because they were emulated using 8-bit integer units.

The ATMega128 also had a limited amount of memory; only 4K of data memory and 128K of program memory. The lack of data memory on the ATMega128 meant that it was not possible to process video on board the robot, since it was not capable of storing a single frame. This meant that for any application requiring video processing, another computer was required to receive the video feed, process it, and send commands back to the robot. While this encourages multiple robot solutions, it also removes some of the possibilities of autonomy from the eROSI robot.

Another consequence of the choice of the ATMega128 micro-controller is that, by virtue of having no operating system, it does not support the programming conveniences that students are used to. There is no file system, threads are not available, and there is no hardware interface. Everything, from networking libraries to hardware drivers, must be implemented from scratch. Since there is no concept of a process on the ATMega, a single program must be responsible for every task that the robot will perform. This includes communicating, moving, processing, as well as all of the background tasks such as charging the capacitors when checking the light sensors.

One consequence of this problem was the lack of functionality of the Bluetooth(TM) subsystem on the eROSI robot. The Bluetooth(TM) interface on the eROSI implemented discoverability and the serial port profile, but that was it. The eROSI was also only able to connect to one other Bluetooth(TM) device at a time. The reason for this was the difficulty in creating a viable Bluetooth(TM) stack in the absence of any supporting libraries. As a result only serial port communication over Bluetooth(TM) was available, not some of the more useful profiles, such as the network access point profile, which provides TCP/IP over Bluetooth(TM).

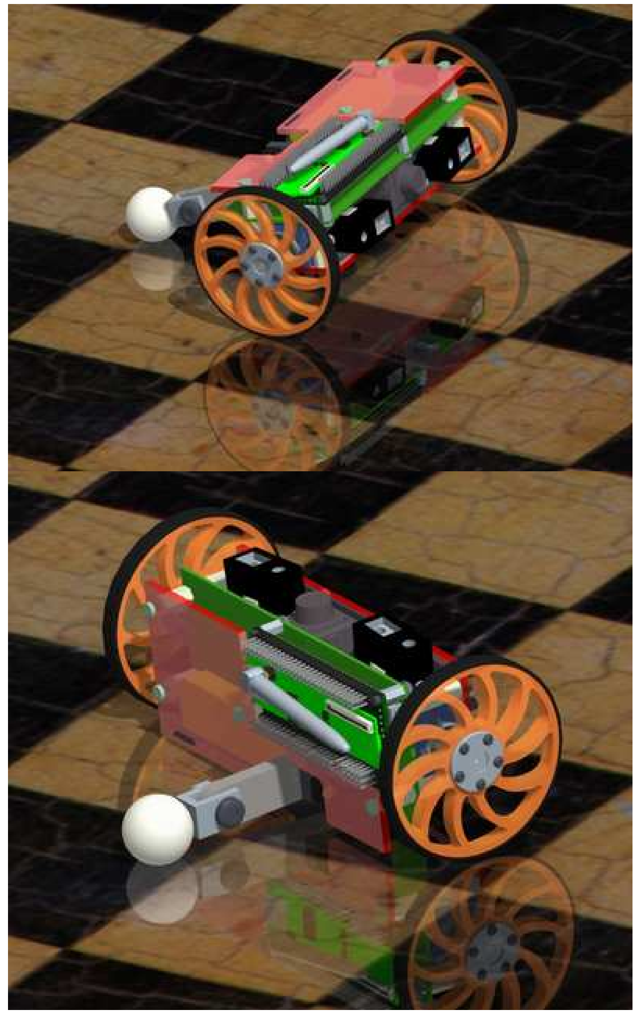

Fig. 3. Mockup of the Explorer.

IV. Third Generation

From the design of the eROSI, we learned that the robotic platform itself was sound as well as useful, but it needed to have a more powerful processor. One problem with this is that more power processors are also more difficult to integrate into a design. They require more components to work properly, such as RAM and a hard drive, both of which were built into the ATMega128. As a result we looked at commercial solutions that would give us a reasonably powerful processor that was still cheap, small, and easy to integrate into our design.

We found that all of our requirements were met in the Gumstix from Gumstix Inc. [7]. The Gumstix is a very small (20mm x 80mm x 8mm) computer featuring an Intel PXA255 processor running at either 200 or 400 MHz, 16MB flash memory, 64MB RAM, and a Bluetooth(TM) module. It also has two hirose connectors that can be used to add peripherals to the Gumstix to increase its capabilities. Gumstix Inc. also sells a Gumstix add-on board called the Robostix that incorporates an ATMega128 micro-controller that can be used to control a robot platform and is 80 x 36mm. Together the Gumstix and the Robostix cost $220, making them an inexpensive robot control system. The entire robot is expected to cost slightly more than $500.

Already, an incomplete version of the robot has been used in for a personal project in the Artificial Intelligence I class at the University of Minnesota. It is also being used for projects in a seminar class on Computation Vision and Robotics. There have also been discussion on using a completed version of the robot is a Real-Time Systems class.

A. Design

Due to the success of the design of the previous ROSI and eROSI robots, we decided to stay with the same basic design. A mock-up of the design for the new robot can be seen in Fig. 3 and is tentatively named the Explorer. It is slightly larger at 17cm by 14.4cm due to additions such as battery monitoring circuitry. It is also slightly heavier at 360 grams. It has the same 3 hour battery-life the eROSI had and moves slightly faster at 0.66 meters per second.

We included the actuating tail and replaced the washers with a plastic sphere to alleviate the dragging issues that the eROSI tail had. The same shape and translucent plastic cover are used as those aspects of the eROSI design worked very well. The location of the other important components, such as the motor mounts, battery, and camera will also remain the same. The primary design change is the addition of a place to seat the Gumstix/Robostix combination.

With the new robot design comes some improvements to the old design as well. One such improvement is the addition of better battery management circuitry. The battery manager on the new Explorer will still ensure that the battery is not discharged too far, but it will also provide charging protection as well as battery cell balancing. The charging circuitry will allow the robot to be charged from a standard wall-wart style power adapter, making the robot much easier to maintain. The battery cell balancing functionality will ensure longer operation time on a single charge, and increase the amount of time the battery will last. The battery circuit will also make the battery system much safer to inexperienced users.

The new design will also incorporate infrared range finders into the front of the device, while the light sensors will be removed. The light sensors were not used often, while range finders, either infrared or sonar, were frequently added to the eROSI to make them more useful. The transmitter will be removed from the camera, and the camera will be attached directly to the Gumstix instead. The Gumstix is powerful enough to perform simple video processing, and if more complex processing is needed, the Gumstix will be able to send the image to another computer over Bluetooth(TM).

Space has also been set aside on the top of the robot for a breadboard to take advantage of the large number of expansion options available on the Gumstix and the Robostix. The Gumstix has over ten digital I/O pins available for custom hardware, while the Robostix has over 20 digital I/O pins, eight analog-to-digital converter pins, and six PWM pins available. In addition, there are more expansion boards available from Gumstix Inc. that provide even more expansion capability, such as the Audiostix that has two-channel inputs and outputs available. All of these expansion pins combined with a breadboard allows users to implement custom sensors as well as providing a platform for a more hardware-centric learning experience.

B. Advantages

The primary advantage of the Gumstix is that it is capable of running the Linux operating system. Linux provides the Gumstix with many drivers, applications and libraries that make the task of programming the robot much easier. Linux already provides both a driver and a Bluetooth(TM) stack for the Bluetooth(TM) device on the Gumstix. This alleviates one of the two biggest problems with the eROSI, namely the lack of a powerful, robust wireless communication system. The Linux Bluetooth(TM) stack implements all of the useful profiles and is routinely updated.

Running Linux also gives the Gumstix access to a large number of supporting libraries that make the programmers job easier. Some of the libraries available for the Gumstix include networking libraries, xml libraries, image manipulation libraries, and audio libraries for use with the Audiostix. There are also many applications available for the Gumstix such as audio players, an ssh server, and a small web-server. Of particular note is that the Gumstix can easily run player, which is part of the player/stage project [8]. Player Stage is a simulation environment for distributed robotics and is very useful in the testing and implementation of multi-robot algorithms.

Gumstix Inc. also provide many more expansion boards that expand the capabilities of the Gumstix. Some of these expansion boards include GPS devices, compact flash and MMC card support, and 802.11 wireless support. Documentation is also available for the expansion board connectors on the Gumstix allowing one to create expansion boards particularly suited to a certain task.

V. Conclusions

The progression of the ROSI robot through three consecutive generations provided a great deal of information about how to design small robots useful in both a research and an educational setting. The first two generations of the robot provided valuable insight on the useful aspects of the design, such as the actuating tail. It also provided information on what sensors were most useful. The most valuable lesson learned was the need for processing power to take advantage of the multitude of sensors available on the robot, as well as to ease the programming task by running standard programs such as Linux and player/stage.

Future work with the Explorer will include multi-robot behaviors with using sensors that were previously unavailable to the platform. These sensors include laser range-finders as well as cameras with on-board video processing. Using Bluetooth(TM), the robots will be able to communicate with other robots as well as other Bluetooth(TM) enabled devices. This will enable them to form ad-hoc communication networks that can incorporate other devices, such as wireless sensors and desktop or laptop computers.

VI. ACKNOWLEDGMENTS

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