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LabRat™: Miniature Robot for Students, Researchers, and Hobbyists

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***Abstract*—LabRat™ is an autonomous, self-contained mobile robot kit with batteries, motors, two bumper whisker sensors, and three infrared proximity sensors that double as channels for "Rat-to-Rat" communication. The vehicle determines its position with an optical sensor that detects movement in both lateral directions. The LabRat™ design is completely open source, including software examples and libraries. LabRat™ is designed to fit inside the body of a computer mouse and has applications in the classroom, the lab and the home. The device has been successfully used in an undergraduate robotics class.**

I. Introduction

LabRat™ is a small, open-source robot designed to be used by students, researchers and hobbyists for a variety of applications. What distinguishes LabRat™ from other small robot kits is an optical mouse sensor on the bottom of the robot, providing high-rate, high-accuracy position information, as well as the ability for instructors to incorporate machine vision into their courses, as the optical sensor is effectively a small CMOS camera.

High school and college educators can use LabRat™ to teach programming, electronics, and introductory robotics, while researchers can upgrade LabRat™ with a serial radio and a very small Linux computer to provide an unprecedented level of capability in a small package at very low cost. Hobbyists can change any aspect of the design through the use of freely available open-source tools and documentation for both hardware and software.

II. Background

Robotics is an inherently interdisciplinary engineering field, encompassing electrical, computer and mechanical engineering, as well as computer science, mathematics, physics, systems engineering, and in some instances psychology, cognitive neuroscience, and philosophy. The breadth of the problems presented by robotics development encourages the integration of knowledge and problem solving methods from a wide range of fields. With the advent of autonomous vehicles in the military and consumer robotics products such as the iRobot Roomba, the robotics industry is growing rapidly and is expected to continue to grow as consumer spending on robotics increases. Study of the discipline of robotics can give engineers a valuable perspective on systems integration, as well as experience in a wide range of fields and in real-world problem solving, increasing the flexibility of the engineer in a rapidly changing world.

Recently, engineering educators have started integrating robotics into their classes. The 2005 Computing Curricula recommendations by the Association for Computing Machinery (ACM), Association for Information Systems (AIS), and the IEEE Computing Society (IEEE-CS) specifically mentions robotics in its recommendation to Computer Science educators: "Now CS researchers are working with scientists from other fields to make robots become practical and intelligent aides" [13]. Robotics can apply to lessons across several different disciplines in engineering, science, math and business [17], [19]. Whole institutions are being created to educate students in the robotics field [18].

While some are discussing the inclusion of robotics into existing curriculum, others are writing about the changes required to teach robotics as a major [16]. Dr. McKee describes three basic divisions robotics education should have: designing and building robots, programming robots for practical situations, and making robots act more human. He also believes that education in robotics should start with practice and work its way to theory instead of the other way around, as most engineering is taught.

Robotics competitions have been a big factor in interesting students of all ages in robotics specifically and engineering in general [12]. In 2000, the Society of Manufacturing Engineers offered 14 different robotics competitions from pick-and-place machines to remote control vehicles to maze-solvers. The Association for Unmanned Vehicle Systems International organized six collegiate level competitions in 2008 [2]. These competitions have driven students to learn more about robots through experience. Some schools are developing their own robotics competitions for freshman introductory courses to expose new students to engineering immediately [21].

Several instructors have found it necessary to create their own electronics packages to give their students adequate experiential learning in electrical and computer engineering. One such package used two Atmel AVRs, four H-bridges to control motors, an LCD screen and several general purpose input and output pins to give students a platform for their senior capstone course [14]. Several kits are also commercially available, such as Lego Mindstorms, iRobot Create and

Parallax Scribbler [20]. Table I below summarizes several educational and hobby robotics products. Each of these kits has a niche that it favors in terms of student age, programming proficiency, expandability and expense.

Although the LabRat is the only robot listed in Table I that uses an optical sensor, these sensors have been used for research into position measurement. In [11], the researchers found that the optical sensor they were testing aggregated error at a RMS rate of 0.2 mm over 50 mm. According to their results, placing the sensor on the perpendicular axis to the drive train on a differential drive robot provides the ability to detect lateral motion in both axes as well as arcs in between these axes.

III. The LabRat™

A. Development

Development of the LabRat™ was greatly accelerated by its open-source design and its use in the Introduction to Robotics Class at the Missouri University of Science and Technology. Primary development was accomplished by Rolla Engineered Solutions, LLC with Cadsoft's Eagle software to design the circuit and lay out the board. This allowed for the development process to go quickly using an inexpensive piece of software. The engineers collaborated through the use of a Subversion Repository, which also allowed for mistakes to be reverted easily. The entire design was then published on Google Pages so that students in the Robotics class could download design details and libraries. The schematic is shown in Figure 1, the top of the LabRat™ board is shown in Figure 2 and the bottom is shown in Figure 3.

The software libraries were created using the freely available AVR Studio in Windows and open-source avr-gcc in Linux. This allows for development in most software environments that students and researchers use. Due to the open source nature of the project, students helped immensely in fixing errors and adding functionality to the libraries as well as suggesting changes in LabRat™hardware.

Initially, two prototype LabRats™ were made. Some errors were found in these and corrected before the first production run of the robots. These robots were delivered to students and other customers in November of 2008 (see Figure 4). This gave the designers more feedback and allowed them to perform further modifications on the case design (see Figure 5).

B. Features

Labrat™ has several features that make it attractive to students, researchers and hobbyists. There are many ways to communicate between LabRat™ and other devices through wire and radio methods. Several sensors combine to allow LabRat™ to accomplish a variety of tasks in the home, the lab and the classroom.

1) Processing Power: The processor on the LabRat™ board is an Atmel AtMega324p AVR. This is a simple yet powerful processor used extensively in industry. The AVR is an 8 bit RISC microprocessor with 32 KB of flash memory running at 8 MHz. The LabRat™ is also expandable with an onboard Gumstix running at 600 MHz with 32 MB of RAM.

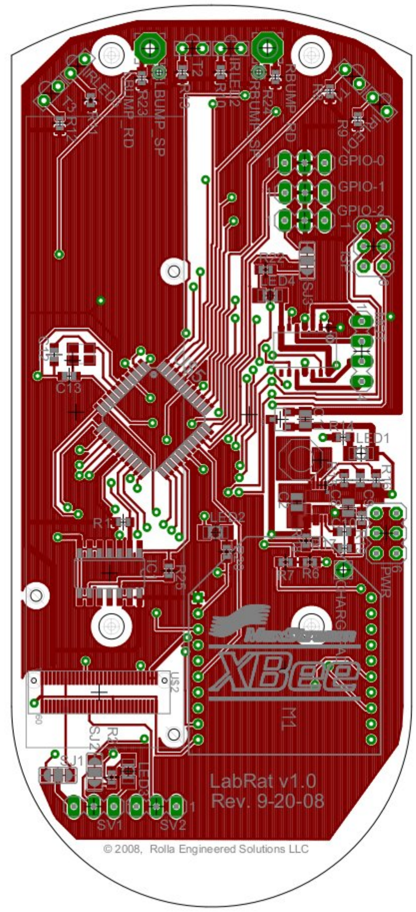

Figure 2. Top of LabRat™ Board

2) Sensors: LabRat™ comes with ranging, proximity and position sensors. Three infrared LED/photosensor pairs are arrayed on the front to allow the detection of objects up to seven inches away. Just in front of these are two whiskers that act as tactile proximity sensors so that LabRat™ can detect when it has run into an obstacle. These whiskers can be bent to the users preference so that LabRat™ can fit into tight spaces or have the range to give objects a wide berth. It is possible to connect an ultrasonic ranging device to the LabRat using the extra general purpose ports, however this sensor would need to be positioned carefully to avoid reflections from the ground. It was determined to be unnecessary as standard equipment on LabRat™ since the vehicle already has IR and touch sensors.

An optical sensor similar to those used in optical computer mice is located on the bottom of LabRat™ to acquire position information. The sensor only provides two dimensional movement information but through on-board software estimates can be made about the rotation of LabRat™.

The charge level of the batteries is also monitored through the use of an on-board voltage sensor.

Robot	Vendor	Price	Programming Tools	Prog. Languages	Hardware	Expandable	Compute Power
PPRK [7]	Acroname	$325	proprietary	proprietary	proprietary	very	limited
Create [4]	iRobot	$200-300	proprietary*	C, .Net	proprietary	very	expandable
LabRat™	RollaEng	$120-250	open-source	C	open-source	very	expandable
LegoMindstorms NXT [5]	Lego	$200	proprietary	Java	proprietary	limited	limited
Boe-Bot [3]	Parallax	$160	proprietary	BASIC	proprietary	limited	limited
Scribbler [8]	Parallax	$160	proprietary*	BASIC	proprietary	no	limited
SumoBot [9]	Parallax	$160	proprietary	BASIC	proprietary	limited	limited
PicoBotz [6]	iBOTZ	$140	proprietary	proprietary	proprietary	no	very limited
3pi [1]	Pololu	$120	open-source	C	proprietary	limited	limited
Sumovore [10]	Solarbotics	$100	open-source	C, BASIC	proprietary	limited	expandable

* Open-source tools are also available for the Create and Scribbler, but are not officially supported by their vendors

Table I
EDUCATIONAL ROBOTICS PLATFORMS

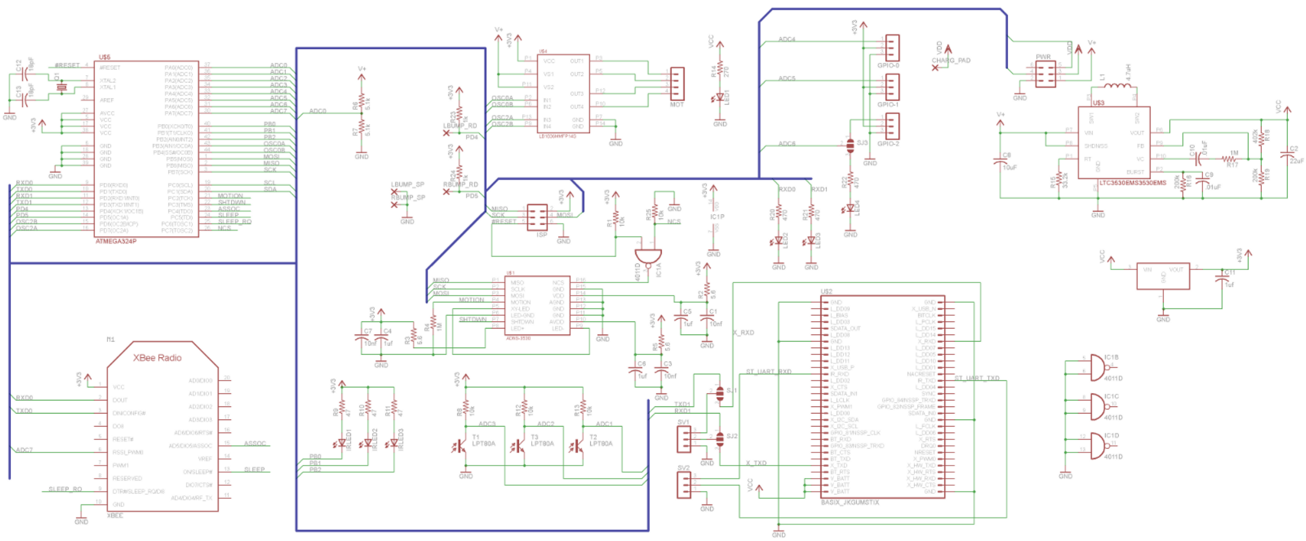

Figure 1. LabRat™ Schematic

3) Communications: The main communication for programming and debugging LabRat™ is a serial port on the back of the board. This allows for quick and easy communication but obviously does not work when the robot is driving around the lab. A second serial port is sent to a port designed for an XBee communications device. This allows for communications at a distance of 100 meters to several kilometers, depending on the XBee device used. The main serial port is shared with the Gumstix device, which allows the Gumstix to receive communication from an external computer and reprogram the AVR in the field. Additionally, the IR transmitter/receiver pairs on the front of the robot can double as "Rat-to-Rat" communication channels through the use of pulsed IR signals.

4) Expansion: Three general-purpose I/O pins are available to experimenters for expansion. Each of these pins can be configured through software for analog input or digital I/O. Two UART ports and one I2C port are available for further expansion. For research applications, LabRat™ has a port to attach a Gumstix board. These open-source, Linux-based embedded systems provide up to an additional 600 MHz of processing power with 32 MB of RAM as well as a USB connection and several other features attractive to research labs.

5) Locomotion : LabRat™ propels itself using two small Solarbotics motors. These motors are controlled by pulse-width modulation, are powered by three AAA batteries and can achieve speeds of up to 42 centimeters per second. At full speed, standard alkaline batteries will provide functionality for over 3 hours.

6) Form Factor: LabRat™ was designed to fit in the shell of most computer mice, providing the entire platform in a small package.

7) Autonomous Charging Capability: The LabRat™ design includes a port for the connection of an external charging circuit. The whiskers of LabRat™ are connected to ground, providing a means for charging and detecting docking. By attaching a charging "tail" that drags on the operating surface, an autonomous charging station and program can be constructed that allows the robot to dock and charge itself.

8) Simulation Environment: The LabRat™ software libraries contain profiles for the open-source Player/Stage Simulation Environment, allowing students and developers to test software designs without wasting batteries. The LabRat™ ap-

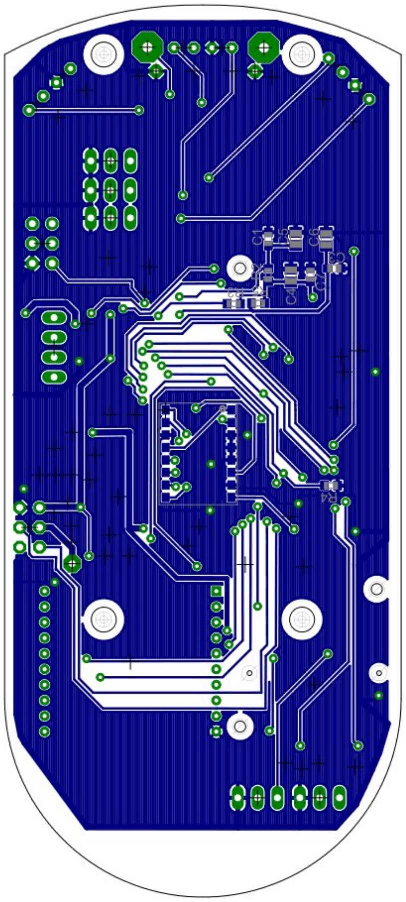

Figure 3. Bottom of LabRat™ Board

Figure 4. LabRats™ Delivered to Students Fall Semester 2008

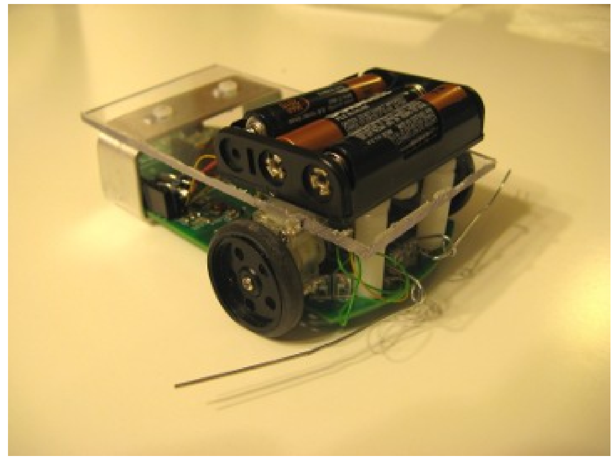

Figure 5. LabRat™ Modification February 2009

plication programming interface is designed to minimize the amount of code changes needed to transfer between the simulated software environment and the real-world hardware platform.

IV. Applications

A. Education

The first use of LabRat™ was as an educational tool for the Introduction to Robotics Class at the Missouri University of Science and Technology. Students started out by programming a simulated LabRat™ in Player/Stage. The simulation realistically portrayed the sensors and capabilities of LabRat™ so that the students would be more familiar with the platform when they received the robots later in the semester.

LabRat™ is a great platform for robotics students because it supplements their education with inexpensive practical experience. LabRat™ can be used to teach simple concepts such as two dimensional Proportional-Integral-Derivative (PID) motion control to keep the robot moving in a straight line at a constant, controlled speed.

Once the students have mastered simple control they can move on to more complicated projects, such as a maze solving robot. A LabRat™ can be placed in a maze and be forced to find its way through using just the infrared sensors and whiskers. This can easily be simulated in an environment such as Player/Stage so that students can prove that their algorithm works before transitioning to the robot. This also gives students the opportunity to gain exposure to the complications of moving between simulated and real environments.

Another Labrat™ project that can easily be simulated is autonomous waypoint navigation. Since LabRat™ has position sensors it can make an accurate estimate of its current location and use that to find waypoints while avoiding obstacles with its infrared sensors and whiskers.

LabRat™ also has the ability to teach the students about swarm robotics methods. In order to keep the expense low for students, the LabRats™ can communicate with their infrared

LEDs and photosensors so that one robot can act as a leader and have the others follow in a formation.

In the first offering of the Introduction to Robotics course at Missouri University of Science and Technology, students utilized the LabRat™ platform in a single semester to complete many interesting and high-quality semester projects. A few of these projects are outlined below.

1) Rotation Sensing : The LabRat™ optical sensor was utilized in a machine-vision project attempting to discern platform rotation from the image returned by the optical sensor.

2) Wireless Control: This project utilized a modified PlayStation game controller and two-way XBee communication to remotely control the physical operation of the LabRat™. On-board software was developed that temporarily interrupts normal LabRat™ program execution and passes control to a remote operator. When remote operation is complete, the on-board LabRat™ program execution resumes where it was interrupted.

3) Autonomous Charging Dock : Students developed both hardware and software to enable autonomous charging on the LabRat™ . The developed hardware consisted of a charging station and an IR blaster circuit that was used to signal the location and direction of the charging station to the LabRat™ . LabRat™ software included voltage sensing and autonomous seeking of the charging beacon.

B. Research

Using the XBee (IEEE 802.15.4) radio and Gumstix with LabRat™ makes it a versitile research platform. The extra processing power and communications range give LabRats™ the ability to perform complex exploration and searching tasks with several inexpensive robots. Using the Gumstix, it is feasible to mount a small camera to a LabRat™ and gather visual information in addition to proximity data about the environment.

The XBee radios allow LabRat™ to communicate over great distances so that one LabRat™ can travel without communication relays. Without the Gumstix, this can be a great benefit as LabRat™ is perfectly capable of accomplishing searches such as particle swarm optimization using the onboard AVR. Another interesting research project is to autonomously communicate in an area with many radio obstacles such that LabRats™ have to navigate to optimal coverage areas and send messages from one location to another. Using methods such as in [15], an individual LabRat's position can be determined based on known positions of other transmitters.

Without adding a XBee or Gumstix, LabRat™ can function as an interesting platform for researching distributed behavior in autonomous vehicles with limited communication ability. The robots can relay information using their infrared LEDs across an unknown environment. This has much shorter range, but could be applicable for research that does not allow for radio transmissions to be sent, such as within swarms of autonomous underwater vehicles.

C. Hobby

The low price point allows hobbyists to purchase a LabRat™ and use it for any interesting project they can imagine. The open source nature of the project allows hobbyists to understand the inner workings of the robot and extend the platform to meet their needs. Open source projects tend to be attractive to hobbyists as they like a project that they can fully understand and help create.

Using the LabRat's™ optical sensor, hobbyists can implement simple line-following algorithms without requiring additional hardware or sensors. Additional LEDs, speakers, and other devices can be attached to the board and interfaced to the microcontroller, for example to provide visual or auditory feedback.

By attaching a XBee radio and a temperature sensor, a hobbyist could use a LabRat™ as a mobile temperature sensor. This could help the user by finding hot spots in an area with sensitive equipment (such as a server room) or by checking the temperature control in one floor of a building.

V. Conclusion

LabRat™ is a small, open-source robot designed to be ideal for students, researchers, and hobbyists. It has a low price point so that it is affordable to all of these groups while still being highly competitive in terms of features. A highly capable robot, it can accomplish most tasks required in educational and experimental use of autonomous ground robots.

More information about the LabRat™ can be found at www.labratrobot.com.

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References

[1] 3pi. *http://www.pololu.com/catalog/product/747*, Accessed February 28, 2009.

[2] Auvsi student competitions. *http://www.auvsi.org/competitions/*. Accessed Jan 29, 2009.

[3] Boe-bot. *http://www.parallax.com/Store/Robots/RollingRobots/-tabid/128/CategoryID/3/List/0/SortField/0/Level/a/ProductID/296/-Default.aspx*, Accessed February 28, 2009.

[4] irobot create. *http://store.irobot.com/product/index.jsp-?productId=2591900*, Accessed February 28, 2009.

[5] Legomindstorms nxt. *http://www.robotstore.com/store/product.asp-?pid=1928&catid=1637*, Accessed February 28, 2009.

[6] Picobotz. *http://www.robotstore.com/store/product.asp?pid=766-&catid=1554*, Accessed February 28, 2009.

[7] Pprk. *http://www.acroname.com/robotics/parts/R277PPRKBS2-BLACK.html*, Accessed February 28, 2009.

[8] Scribbler. *http://www.parallax.com/Store/Robots/RollingRobots/-tabid/128/CategoryID/3/List/0/SortField/0/catpageindex/2/Level/a/-ProductID/323/Default.aspx*, Accessed February 28, 2009.

[9] Sumobot. *http://www.parallax.com/Store/Robots/RollingRobots/-tabid/128/CategoryID/3/List/0/SortField/0/catpageindex/2/Level/a/-ProductID/316/* Default.aspx, Accessed February 28, 2009.

[10] Sumovore. *http://www.solarbotics.com/products/k_sv/*, Accessed February 28, 2009.

[11] The optical mouse for indoor mobile robot odometry measurement. *Sensors and Actuators A: Physical*, 126(1):141 – 147, 2006.
[12] Carol Anderson. Student robotic challenges. *Tech Directions*, 60(3), October 2000.
[13] The Joint Task Force for Computing Curricula 2005. Computing curricula 2005. *http://www.acm.org/education/education/curric_vols/CC2005-March06Final.pdf*, Accessed January 28, 2009.
[14] David Livingston. A controller for robotics and microcontroller applications instruction. In *2007 ASEE Annual Conference and Exposition*, 2007.
[15] D. Marinakis and G. Dudek. Probabilistic self localization for sensor networks. In *2006 AAAI National Conference on Artificial Intelligence*, 2006.
[16] G. T. McKee. The robotics body of knowledge (education). *Robotics and Automation Magazine, IEEE*, 14(1):18–19, March 2007.
[17] Afsaneh Minaie and Reza Sanati. An international study of robotics courses in the computer science/engineering curriculum. In *2006 ASEE Annual Conference and Exposition*, 2006.
[18] K Nagai. Learning while doing: practical robotics education. *Robotics and Automation Magazine, IEEE*, 8(2):39–43, June 2001.
[19] Terri Varnado. Robotics across the curriculum. *Tech Directions*, 60(4), November 2000.
[20] Richard Weiss and Isaac Overcast. Finding your bot-mate: Criteria for evaluating robot kits for use in undergraduate computer science education. *Journal of Computing Sciences in Colleges*, 24(2):43–49, Dec 2008.
[21] Jason Yao, Gene Dixon, William Howard, Rick Williams, Keith Williamson, Geoffrey Dieck, and Steve McLawhorn. "who is the biggest pirate?" design, implementation, and result of a robotics competition for general engineering freshman. In *2006 ASEE Annual Exposition and Conference*, 2006.