MACGYVER ON THE HUDSON – ARDUINOS AND ROBOTICS

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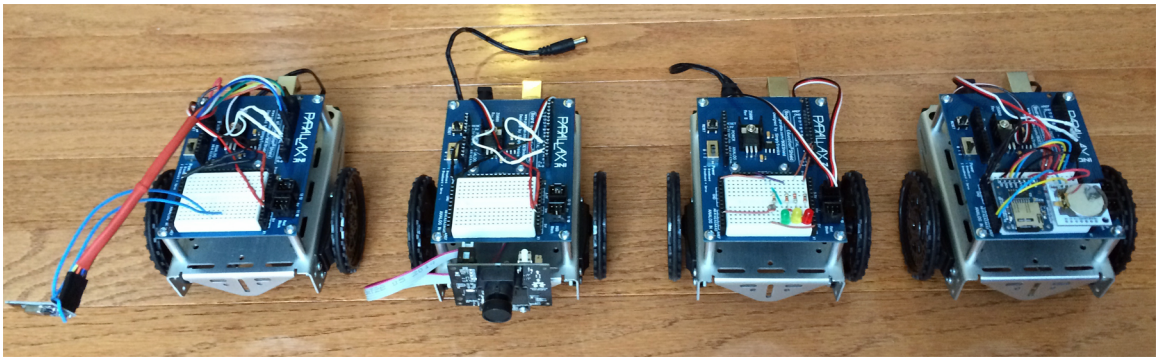

Figure 1: Four Simple Robots

The personal computer "revolution" is less than 40 years old. In June 1977 the Apple II computer went on sale for $1,298, well over $5,000 in inflation adjusted dollars. Now we are at the start of a personal robotics "revolution" whose consequences may rival those of the personal computer revolution. We and our students

[1]The views expressed in this article are those of the authors and do not reflect the official policy or position of the U.S. Military Academy, the Department of the Army, the Department of Defense, or the U.S. Government.

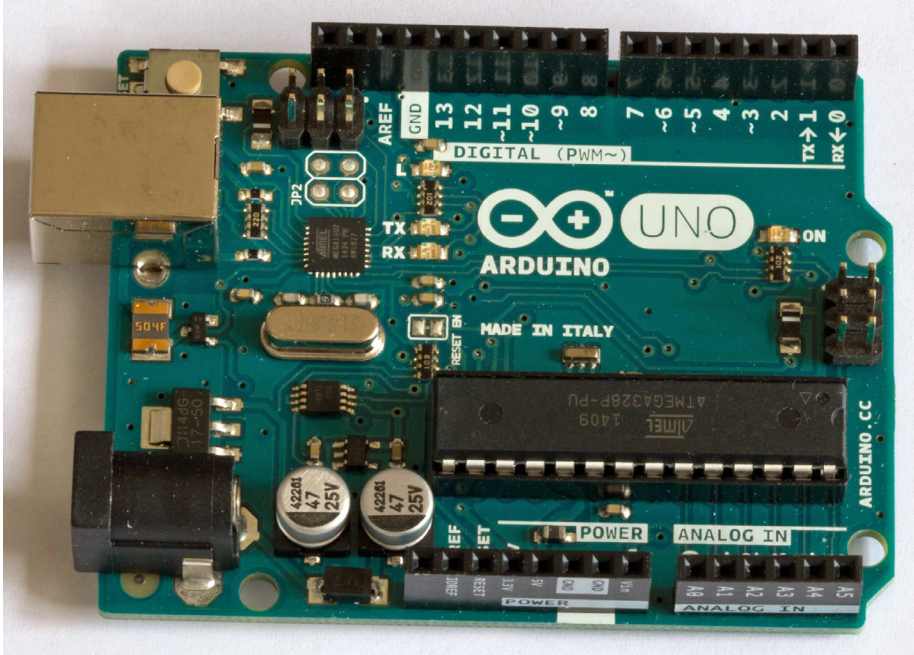

Figure 2: The Arduino Uno

can buy serious robotics kits for under $300.00. Figure 1 shows four simple robots, each made from the same kit, costing less than $150.00. Figure 2 shows the Arduino Uno board that is the heart and brain of these robots as well as many other "smart" devices. The Arduino Uno is available for $25.00 and in a marvelous kit with a great collection of sensors and actuators and an extremely well-written manual for under $100.00.

We can outfit an entire lab with workstations for 32 students working in pairs for less than the inflation-adjusted cost of a single Apple II computer. In this lab students can build and program their own robotic systems and "smart" devices and in the process develop and learn a great deal of mathematics.

The electronic games we play today may be replaced in a few years by games with robots. The early electronic game Pong, for example, may be reborn as a physical game against a robotic opponent. Tomorrow's billionaires may still labor in their parents' garages but they are more likely to be building robotic systems than computers ... and they are building on the foundation laid by personal computers.

Over the next twenty years many of the most important personal and public policy decisions we make and many of the advances we make will involve robotics, embedded programming, and artificial intelligence in the broadest sense. This gives us as mathematicians and as mathematics educators an enormous opportunity and an enormous responsibility.

Our mathematics courses can become excitement- and demand-driven rather than requirements-driven and we can help our students and our country make better decisions about, for example, how human-drivers and robot-drivers share the roads and about how intelligent robots can assist human first responders. Our students will no longer look at gray pages in the back-of-the-book to see how they did on their homework. They will judge their work by, for example, how well a robotic car navigates an obstacle course . . . or how well it makes ethical decisions when a squirrel darts in front of a vehicle with a baby in the front seat.

One of the most insightful metaphors[2] used by the best teachers is setting up a playground for recess. We want to scatter various things around the playground – things that enable and challenge kids' creativity. Robotics is an ideal playground for enabling and challenging students' mathematical and scientific creativity. Just as baseballs and basketballs can be used for a variety of games, the parts in Arduino and robotics kits can be used to create awesome inventions and adventures.

We are often frustrated that our students don't remember ideas from earlier classes. But, this is not surprising. Although we, ourselves, use these ideas over and over again in the normal course of our lives, our students often learn new ideas only to put them aside after the final exam. As students build their own robots, they will find themselves using mathematics and science routinely. They won't forget the ideas they learn because they will need and use them over and over again as they build ever more wondrous things.

We call our project "MacGyver on the Hudson" because students will develop the resourcefulness and the ability to tinker, epitomized by the television show "MacGyver," that they will need as they invent their future. We combine MacGyver's duct tape and Swiss Army knife with their modern day equivalents, microprocessors and programming.

In this series of papers we begin with the ways that these ideas fit into the courses we are teaching now with our current syllabi but ultimately our courses will become richer and more difficult as they rise to meet the demands of our students. The figure

[2]The authors first heard this metaphor from Kathi Snook.

$300.00 for the cost of a well-equipped personal robotics laboratory is important because the low cost of the equipment we use means we can use these ideas now in our classes. We recommend the following equipment (Incidentally, this equipment makes great birthday and holiday presents):

- The Arduino Starter Kit. This is available from Amazon.com[3] and elsewhere for under $100.00. With this kit alone one can do many interesting things. In particular, it comes with an excellent manual. The manual contains all the instructions and parts needed to build 15 projects, projects that are carefully chosen to build the basic understanding of electric circuits, programming, and mathematics that students need to build their own creative projects.
- The Parallax Robot for Arduino Kit and an extra Arduino Uno board. These are available for a total of just under $150.00 from Adafruit.com.[4] This kit really gets one into the robotics world. It comes with excellent online documentation. It is also reasonable to start with just this item.
- Miscellaneous tools, sensors, and actuators. We budget $50.00 for this category giving us a total of $300.00. If you don't have needle nose pliers they are really useful. We will discuss many sensors and actuators in this series of papers. This budget item will support several of these. Which ones you buy will depend on your own interests.

This paper introduces a suite of related papers with four additional papers from the same group of authors:

- **Programming Arduinos, Robots, and Quadcopters** by Frank Wattenberg and Matthew Mogensen: This first paper focuses on the $100.00 Arduino starter kit and a few additional sensors. Yet even with this basic start, you will learn how you and your students can build many, many different gadgets. Moreover, the programming you and your students learn and the MacGyver abilities you develop are exactly what you need as you branch into robotics.

[3] http://www.amazon.com/Arduino-Starter-Official-170-page-Projects/dp/B009UKZV0A/ref=sr_1_1?ie=UTF8&qid=1432293774&sr=8-1&keywords=arduino+starter+kit. Accessed 22 May 2015.

[4] http://www.adafruit.com/product/749 and http://www.adafruit.com/product/50 Accessed 22 May 2015.

- **Sensors and Actuators** by Drew Wilkerson and Frank Wattenberg: The heart of the Arduino kits is a microprocessor on a development board. For less than $100.00, anyone can work on a project that uses a computer at its heart, that can perceive its environment through sensors, and that change the world around it with output devices, called actuators, like servos and motors. In this talk, we explore some basic sensors coupled with the Arduino Uno. Then using some high school and college mathematics, we show how easy it is to create whole new devices that will excite and inspire young students. This talk goes more deeply into the world of sensors and actuators. We conclude with a review of the ever expanding Arduino ecosystem of devices.

- **Robots** by Matthew Mogensen and Benjamin Minden: Robot technologies have been on the rise for a number of years now. Even at the elementary school level and above, today's youth are exposed to Lego and Vex robotic systems. It is quite possible that in our near future our cars, homes, and other devices will be partially controlled by robotic systems. The technologies that are enabling these innovations include vision based systems and Lidar. In this talk we examine how vision based systems can be combined with the Arduino processor to control robotic systems. At the center of this marriage is mathematics and we will give several examples that combine robotics, computer processing, and mathematics to create a learning environment for students.

- **Quadcopters** by Benjamin Minden and Drew Wilkerson: Aerial drones have captured the imagination of the public in the past year. CNBC estimates that nearly 200,000 aerial drones were sold each month in 2014. That number is expected to double in 2015. These drones are controlled by devices like the Arduino. This talk examines the current capabilities of small affordable drones, how their use might be expanded through the use of simple sensors and actuators devices and the math that is required to make this a reality. We examine some of the high school and college mathematics that is involved in flying these drones.

We have focused so far on the low-hanging fruit – using Arduinos and robotic systems to help our students learn the mathematics already in our courses – but the best fruit requires ladders (or perhaps, robotic apple-pickers). Over the next 25 years we will create a symbiotic relationship between humans and robotic systems powered by artificial intelligence. As mathematicians and scientists we have the ability to create and shape this future. This is an essentially interdisciplinary effort and as educators we must approach it as a team drawn from across all the disciplines:

- This new world is made possible by the hard sciences – mathematics, physics, engineering, computer science, chemistry, and the life sciences.
- The best and most creative thinking is found in science fiction. The arts and humanities, English and other natural languages and their literature are absolutely essential not only for imagining the future but also for understanding its human consequences.
- As this new world explodes on the scene (we would use the word "evolves" but that word implies a more luxurious time scale than we have), law, ethics, and political science will play fundamental roles.
- Economics is absolutely necessary as robots replace much of the work done by humans and completely upend our current economic system. Think, for example, of what will happen when self-driving cars invade a taxicab industry already reeling from Uber.
- The social sciences and understanding diverse cultures. How we use these new tools and how we react to their introduction will depend very much on our cultures and our conceptions of ourselves.

References

[1] *Arduino Projects Book* – Projects and Text by Scott Fitzgerald and Michael Shiloh. This is the book included in the Arduino Starter kit that we recommend. September 2012.

[2] *Robotics with the Board of Education Shield for Arduino.* This is the online manual that accompanies the robot kit we recommend. http://learn.parallax.com/sites/default/files/content/shield/robo-block/Shield-Bot-2013-12-01.zip. Accessed 27 January 2015.

[3] *Programming Arduino: Getting Started with Sketches* – by Simon Monk. McGraw-Hill 2012.

[4] *Exploring Arduino: Tools and Techniques for Engineering Wizardry* – by Jeremy Blum. Wiley 2013.