Robotics Games for STEM Education

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Abstract:

This paper presents use of robotic floor games to enhance students' abilities and interests in STEM fields. Undergraduate students will build low cost robotic platforms that will be used by high school students to build their own intellectual and/or fun games. These robotic platforms (or kits) will be engineered to be inexpensive so high schools can afford them. We utilize open source software and hardware to achieve this.

Introduction:

There is an unmet need among high school students to combine gaming and robotics in their own imaginative way. This requires students to apply knowledge of science and mathematics to practical problems in engineering. Often, when solving problems in school science and mathematics, students have difficulty applying the knowledge they have learned. In the examples shown in this study, the students are highly motivated because they have selected the problem to be solved.

We propose to use autonomous robots and mobile phones to teach math and physics to high school students. This paper is based on a new undergraduate engineering course that is being offered for the second time this semester. During the first offering, the enrolled students developed hardware and software components that will be used this semester to build a set of autonomous robots that can be managed from smart phones. The eventual goal is to develop two games (Tic-Tac-Toe and Chess) that can be played with these robots in an indoor arena. Thirty high school students are expected to take an introductory engineering course next summer when they will use these robots and learn to play and modify these games. Such a game integrates well the concepts of peer-to-peer cooperation, coordination, and communication, despite varied

behaviors of robots, to achieve an overarching goal. We eventually hope to make these robotic kits low cost, modular, and incrementally acquirable, to enhance their affordability by high schools. We will utilize open source software and hardware to achieve this[1]. Note that Lego sells a robotic chess system for $30,000, typically out of reach for high schools.

The robots will use low power near-neighbor communication links, with optical/ sonar /IR/RF transceivers. These will allow the robots to self-organize in response to a chess move conveyed from a phone. Simple cameras will be used for robotic localization and navigation on & off the board. The high school students will be able to program the robots with different behaviors and plan/play different types of games/activities. This will increase their interest in the STEM curriculum and enhance their soft skills (team building, project management, communication, systems thinking, abstract thinking, and problem solving); this will also bring to the fore innovation and entrepreneurship, two hallmark qualities of the US economy, since these applications can be marketed, with these students sharing in the revenue (as per their institution's intellectual property policy).

Method:

Figure 1 depicts mockup of a robotic chess game set up to communicate our vision (Please note: The students shown are enrolled at our developmental research school and their parents have signed Photo / Video Release forms.), Imagine that the chess pieces are powered by autonomous robots (notice the opposite color coasters under the chess pieces). Further imagine that the two players play the chess game, not by directly manipulating the chess pieces, but by making the move on the virtual chess boards displayed on the touch screen of their smart phones. The autonomous robot invoked to implement the move would negotiate its motion via occupied and unoccupied squares, to its ultimate destination. Communication and sensor technologies will be invoked to avoid collisions and to create a path, while actuator technologies will be utilized in executing the motion. STEM principles in the use of optics, sound, IR, and RF, motion, and distance estimation are evident. Global positioning, localization, and centering of the pieces will require the use of communication beacons (notice the 'red' cone near the bottom right) located at four corners of the board and use of physics and math principles for vectors and triangulation. Optimization of battery power, game speed, and acquisition cost will help develop problem solving skills also, in a fun and informal environment. The background utilization of engineering and technology principles, we hope, will enhance interest in (and reduce anxiety about) science and engineering. Advanced students will have access to C and Java-based tools for experimentation. Team-based new game development will allow the students to develop all the soft skills that are identified in [2]. Entrepreneurship and innovation, key US advantages in global competition, will be emphasized since the student teams will use their imagination in developing new games (and relevant marketing material, such as videos), and with the intent to market these games and to share in the royalties received.

Figure 1: Mockup of Chess Game

Advancement of Knowledge:

Many of the algorithms can be implemented in a variety of ways, along the dimensions of STEM. Over the years, increasingly sophisticated and robust protocols and technologies (such as Bluetooth) have evolved (and are falling in price) that may persuade some to believe that this multi-dimensional exploration, while useful from a STEM learning perceptive, is not economically productive, and thus may not advance knowledge. However, as chronicled by Christensen[3], low cost solutions, developed after the arrival of ultra-sophistication in many a domain, have not only found a niche, but also have launched a host of new products and applications that compete with the mainstream technologies (an example is the rapid encroachment of USB flash drives into the domain of magnetic hard drives with terabyte capacity [4]). As an example, we may explore the use of Morse code with LEDs (and later on, via the Android monitor), for example, for peer to peer communication and recognition. Our first instinct was to develop this for educational purposes as a visible communication protocol (as compared to a non-visible protocol, such as Bluetooth), but cost and battery life considerations may pave the way for its use in our kits. Simply making these 'old' technologies available for experimentation by students may unleash their imagination in many new directions. Recent discussion on co-existence of Wi-Fi and Bluetooth[5] devices highlights the susceptibility of such links for both unintentional and intentional interference. A robust backup technology, perhaps for improvisation, may be low-tech.

Implementation of products and services in schools on a large scale:

Our goal is to develop low cost robotic kits that are incrementally acquirable. Open sourcing will allow the cost to fall further. Thus, a school can initially acquire a few robots (or build them at still lower costs) at a cost of $100 each, and incrementally add a few more robots every six to twelve months. Even a few robots will be able to give an adequate educational environment for the students. Availability of low-cost downloadable applications may persuade the pooling of robotic resources among schools to host games and design their own new games, which can then be marketed to generate revenue. Our experience with marketing Android smart phone applications developed at our university is the inspiration for this proposal. In this era of reduced budgeting, creative solutions are warranted; and further, in this era of heightened global competition, we need to emphasize innovation and entrepreneurship [2], the earlier the better. We

thus expect a trend towards low cost and open source solutions that will benefit all, not just a few major business entities. This is a welcome change and provides a way out in the changing world with pressing economic challenges. We also perceive the evolution of a healthy and social environment since such a game is not solitary (or a virtual on-line game), as many video games are, and can be held in open space as a community activity. Further, it will not be just limited to robotic enthusiasts.

We hypothesize that hands-on robotic games will enhance high school students' understanding and/or interest in the STEM disciplines. We were impressed with the phenomenal way high school students worked during summer '10 and summer '11 to develop applications on Google's Android Phone. We believe there is an unmet need among high school students to combine gaming and robotics in their own imaginative way. Robotics has excelled with super-sophisticated games, such as indoor soccer [7], which may be the ultimate experience; this may, unfortunately, have raised the bar too high and made it a costly activity. Our goal is to bring robotics to a level that is within the reach of most schools and integrate it with the students' need for social networking.

Our design is based on our experience in rapid prototyping and incorporation of future skills identified in [2]. An overview follows:

Game development as a 'rapid prototyping' activity: The high school students will use a top-down system design approach in building their game software, during a six week summer session. The students will use good software development tools to program pre-built robotic platforms [8]. The game development process in the course will proceed in three stages: (1) STEM material coverage illustrated with PC simulations and field tests with robots (weeks 1 to 4), (2) Discussion of the Tic-Tac-Toe [9] and Chess games as a total experience (game playing to understanding the algorithms, technologies, and the code involved in implementing the game), during weeks 3 and 4, and (3) Use of these games as game platforms to implement their own games (weeks 5 and 6). Storyboarding, and discussions with faculty and engineering students, will help them implement their own game. The faculty will ensure that the high school students' abstract model is implementable, while engineering students will help them implement this model. The high school students will do the actual implementation and troubleshooting, and will ultimately deliver a working game. Code development will be facilitated by a good GUI and APIs (Application Programming Interfaces).

Integration of hard and soft skills:

We agree with the need to integrate both hard and soft skills in the curriculum, as discussed in [2] and actively incorporate it in all the courses that we teach. Team projects with STEM focus, and development of their own games, will lead to a quasi-competitive environment that keeps the experience educational and interesting at the same time. We add another element that [2] alludes to: the US advantage in innovation and entrepreneurship. The student games will be marketed and the resulting revenue will be shared with them, as per university IP (intellectual property) policy. This early exposure will help the students to fine tune their entrepreneurial skills and develop more innovative ideas along the way. As an anecdotal example, the first author's early

success with biomedical research and licensing, has persistently kept him fascinated with these aspects and led him to other successes.

Results: Impetus for this came from a local school that had a robotic club, but no robots. The boys and girls at this high school met every other week, but could make no progress, since they could not afford to purchase expensive robotic systems. Further, they lacked the ability to take advantage of existing low cost kits and integrate them. To address this, we offered a course in fall '10 in which engineering students explored ways to build low cost robotic systems that can act as game platforms. The focus was on the design of hardware and software components to reach that goal[8]. We now have a good feel on the appropriate combination of new and old technologies that can lead to this [8]. We are currently offering a course on embedded robotics to undergraduate and graduate engineering students. They are working in groups of 3, typically with one each from computer science, computer engineering, and electrical engineering. The students have built low cost mobile robotic platforms (with a Uno platform from Arduino, ultrasound and infrared range sensors, and stepper motors with optical encoders) that will be used to create robotic art on large sheets of paper (6' x 6'), by semester end. These robotic platforms are also being optimized for power dissipation. A course is also scheduled for next semester: A class of 15 high achieving high school students will be involved in building five stationary robots ('beacons') with Bluetooth, camera, and XBee technology. We have already completed App development to establish communication between Android phones and these beacons. Thus, all the building blocks will be ready for use by another group of high school students by summer 2011 or soon after. They will use these to develop robotic games as discussed earlier.

Conclusion:

We have presented an outline for the use of robotic floor games to enhance students' abilities and interests in STEM fields. Here are some of the impacts: (1) Advances knowledge and understanding: STEM principles in the use of optics, sound, IR, RF, motion, and distance estimation are evident. Game development will emphasize the soft and entrepreneurship skills as well; (2) It is transformative, creative, original: This effort goes beyond typical STEM education, and gives the students an opportunity to improve their soft and innovation skills; (3) It enables advanced discovery and understanding: An open source and low-cost tool kit will open up the robotics field to all, enhancing potential for new ideas and products; (4) It helps enhance participation of underrepresented groups: Our experience with teaching courses on Android App development to high school students makes us believe that this process of fun, informality, creativity, and graphics will achieve this goal. (5) Enhances infrastructure for research and education: Sale of the robotic kits will help raise funds to sustain programs like ours. (6) Benefits to society: it is expected that some of these students will start their own businesses later on, impacting the local economy and community positively.

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