Towards an Augmented Reality Framework for K-12 Robotics Education

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ABSTRACT

In this paper, we investigate how augmented reality (AR) can help students "see the unseen" when learning to operate and program robots. We describe our prototype AR system for robotics education, along with a qualitative pilot study and its preliminary results. The objectives of the pilot study were 1) demonstrate that AR can be successfully deployed in a middle school robotics education setting; and, 2) identify and document how AR might (or might not) catalyze students' ability to understand their robot's behavior and adapt their code accordingly. Overall, the pilot study indicated that AR can help students debug their robot more easily, catalyzing discussions around sensor readings that led to code fixes and a reduction in the "barrier to entry" for some students. At the same time, we also gained some insight into usability issues and current challenges of using AR in the classroom.

KEYWORDS

Robotics Education, Visualization

1 INTRODUCTION

Interdisciplinary robotics activities are becoming increasingly common in K-12 education [2, 3], often used to explore engineering and computer programming (e.g., [26]), participate in international competitions such as FIRST, WRO, Botball, and RoboCup [11, 13, 16], or to support teaching in other STEM disciplines like biology (e.g., [8]), math (e.g., [23]), etc. The goal of this work is to investigate how augmented reality (AR) can help students "see the unseen" when learning to operate and program robots. In particular, we hypothesize that AR can help the student see through the eyes of the robot, from reading sensor values to visualizing the code currently executing - essentially empathizing with the robot. This empathy may be necessary to quickly and accurately debug the robot behavior, a step that often acts as a barrier to entry for students.

Robotics has not been as successful at entering the formal classroom at the pre-college level, for a number of reasons. First, robotics requires an unusual amount of hardware such as computer carts, software installs (sometimes taking up to 6 months in schools), charged batteries, and a lot of pieces of plastic or metal that need assembling. Second, robotics requires teachers that are willing to give students open-ended, authentic problems that will force students to fail and iterate, that are willing to not know answers to student questions, and that are willing to have a little bit of chaos in the classroom [7]. Third, robotics requires school administrations that promote creative learning skills that are currently not on standardized exams. Robotics requires a curriculum where creativity thrives and therefore a teacher that is a real-time mentor for unforeseen and unpredictable problems. In the stereotypical math class, the teacher knows what questions will be asked and where the stumbling blocks will occur. In contrast, within robotics education, the teacher is often just as surprised and confused as the student.

Critical to solving these moments of confusion is the ability of the student (and teacher) to "think like a robot" to diagnose the strange robot behavior in question and fix it. This paper proposes that this issue can be addressed through the use of AR and to that end, we describe a system prototype that enables both teachers and students to visualize robot sensory data using a hand-held device. We conducted a preliminary qualitative study in which we deployed the AR system in a middle school classroom. The pilot study indicated that AR can help students debug their robot more easily, catalyzed discussions around sensor readings that led to code fixes and reduced the "barrier to entry" for some students. At the same time, we also gained some insight into usability issues and current challenges of using AR in the classroom.

2 RELATED WORK

Advances in computing technology and a decrease in the hardware components' cost have spurred an effort to also integrate AR technologies into academic and classroom settings. AR holds strong promise to provide learning experiences that are contextual and embodied [15]. Most research and applications of AR in the classroom have so far occurred at the college level. Despite its potential, AR use and research in K-12 settings is still limited and rare [18]. One of the earliest attempts was the SMART system [12]. The system was used to teach 2^{nd} grade students concepts by superimposing 3D models of relevant objects (e.g., animals) onto the real environment. According to several experiments performed at three different schools, the system increased student motivation and had a positive impact on the students' learning progress (the effect was especially strong on students that were less academically successful) [12].

Research in AR and Education has hypothesized and, to a limited extent, demonstrated that AR technology can benefit students in the following ways:

- Improve learners' understanding of complex dynamic models and causal systems [22].
- Improve learners' motivation and interest [12, 24]
- Develop better investigative skills and knowledge of the topic [24]
- Improve spatial abilities [17, 21]
- Improve transfer of learning through AR-based student-teacher interactions [9]
- Increase in learner engagement [19]

Nevertheless, research in AR and education is still in its early stages and much of the evidence for benefits is shallow when compared to research on integrating the Internet or traditional computer applications in education [27]. A major limitation of existing research is that empirical studies tend to be simple and conducted over short-term periods using small sample sizes, effectively amounting to individual case studies such as the ones conducted by [25] and [10].

Using AR to enhance robotics education is particularly underexplored with just a few case studies (see [4–6, 14]). These existing studies target primarily college-level students and aim to enable students without access to physical robots to program robots at remote sites, as well as completely virtual robots, using AR. In other cases, AR is used as a tool to teach basic programing concepts that are not unique to robotics (see [20]). In contrast, we want to explore how the barrier to entry for K-12 students can be lowered by utilizing AR in conjunction with robots that are physically present near the students.

3 SYSTEM OVERVIEW

The proposed system was designed to allow users to visualize robot sensory data in a robotics education setting. The assistive AR application was composed of 4 major components:

- **EV3 Robot Environment**: All students programmed robots using the LEGO MINDSTORMS kit, common in the middle school classrooms. The robot was unmodified with the exception of the addition of a ThingMark – a flat Augmented Reality marker which, when places on an object, allows an iPad to detect the position and orientation of the robot when seen from the camera.
- **Mobile AR Application**: The iPad used Thingworx View, a Thingworx Studio front-end that allowed the students to visualize the robots sensor reading superimposed over the camera video image.
- **Data Upload Application**: A separate computer used LabVIEW to continuously pull real-time data from the EV3 sensors and move it to the Thingworx Internet-of-Things (IoT) Cloud Application.
- **IoT Cloud Application**: A server running Thingworx Studio on the cloud, which merges the sensor data (from the Thingworx database) with the camera image, and sends all the information to the Mobile AR application (Thingworx View) on the iPad.

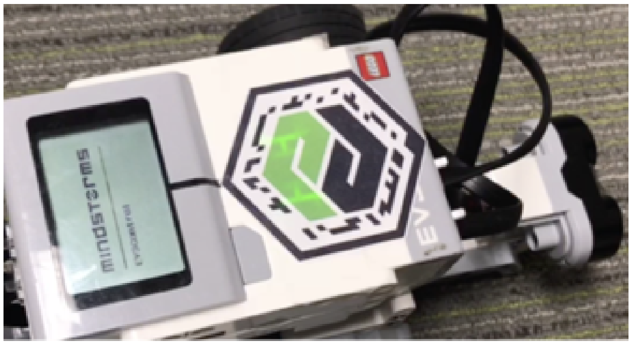

Figure 1: Example EV3 robot with the ThingMark placed on its top side

Figure 2: The tablet used in the AR system

The main tool used to develop the system was ThingWorx Studio, a suite of AR-related software that can be used to design and implement applications (see [1] for a discussion on the platform in relation to other IoT related products). The AR software used ThingMark (see Figure 1) to identify the robot. The Mobile AR Application runs on the Apple iPad 9.7 tablet, shown in Figure 2, superimposed the values of the color and distance sensor on the camera view; in addition, it changed the color of the color sensor to the value it read and showed the cone of the ultrasonic waves from the distance sensor. Figure 3 shows a view from the AR screen, which visualizes the cone emanating from the distance sensor in the front of the robot as well as the color sensor reading.

4 STUDY DESCRIPTION AND PRELIMINARY RESULTS

In the Fall of 2017, we ran a pilot study with fourteen 8th graders in a private school just outside of Boston. The students, working in teams of 2 (with one team of 3), were asked to program an EV3 robot to complete an obstacle course placed on a mat. All students used the "Riley Rover" configuration, which is a popular K12 setup, and they all had previous experience with the EV3 Kit, programming environment, and âĂIJRiley RoverâĂİ configuration. There were two different obstacle courses, shown in Figure 4, that

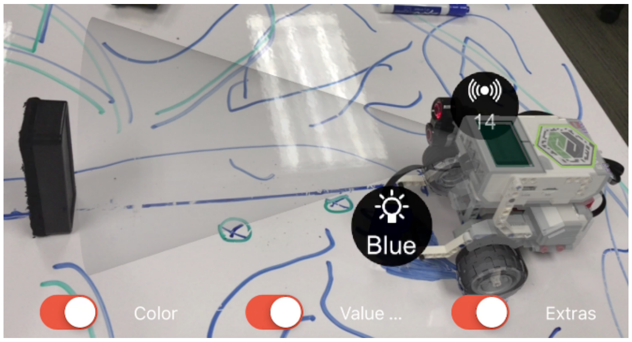

Figure 3: A view from our existing application showing two types of sensory data of the EV3 robot: 1) the sonar reading, shown as a cone and also as a number (14 cm) indicating the distance to the object; and 2) the color reading (in this case, *Blue*)

were purposefully designed to confused the robot. The first mat had purple and orange squares, which the robot's light sensor incorrectly identifies as red. The second mat had irregular foam blocks that confused the robot's sonar sensor used to measure distance to nearby objects. On Day 1, the students were given iPads with the AR software (based on Thingworx Studio) but no instructions and on Day 2, they were given some tips and instruction on how to use the iPads by a Tufts graduate student in computer science.

On the first day (without instruction on how to use the AR tools) most teams did not even pick up their iPads and those that did had issues using it. On the second day (with instruction) they all used it and, when polled, said they liked using it. In some cases, that "like" did not correlate with improved learning that we could detect, but in others, the AR toolkit caused teams to actively discuss various specifics while debugging their code, such as the apparent light sensor color on the iPad for the purple/orange lines.

We also identified several usability issues to be addressed in the next iteration of our prototype. Students had to maintain a proper distance from the robot, far enough to see the path of the robot but close enough for the software to accurately track the robot. Students improved with time and the observers felt that these issues would be small if there had been a third day of testing. Nevertheless, we will address this issue by tracking the robot and the user's tablet simultaneously from a 3rd camera with high resolution and field of view. In addition, the AR marker made it harder to use the buttons on the EV3 as the marker partially covered some of the buttons. This issue will be addressed by slightly modifying the EV3 as to provide better placement of the AR marker.

Figure 4: Two mats used in our pilot study. In the first (left), some colors are difficult to detect by the robot's sensor; In the second mat (right) some surfaces confuse the robot's distance sensor. For both mazes, the robot was tasked to drive around on the mat but never leave it (using the obstacles or color strips to stay on the mat).

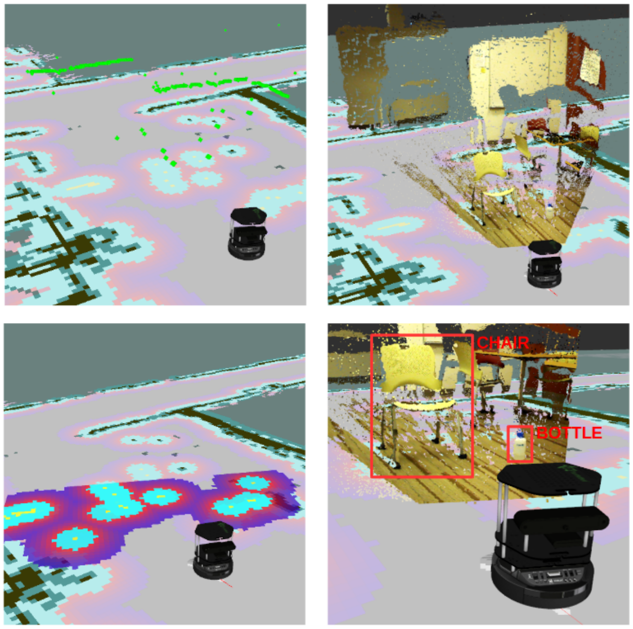

Figure 5: Example types of robot sensory and cognitive data that are currently visualized using a computer screen. All 4 examples also show the robot's map of the environment.

5 CONCLUSION AND FUTURE WORK

This paper described an AR System for robotics education which was tested in a small qualitative study. Overall, observations from the pilot study suggested that AR can help students debug their robot more easily, catalyze discussions around sensor readings that led to code fixes and reduce the "barrier to entry" for some students. Yet, AR may also increase that barrier as a result of usability issues, and by simply requiring another piece of technology to work in the classroom environment. Therefore, while the potential for AR in the classroom is easy to imagine, actual successful implementation is not as straight forward.

For future work, we plan to extend the AR framework such that it scales to multiple types of robots (e.g., Turtlebot2 using ROS), as well as additional types of robot data (e.g., sensory data such as

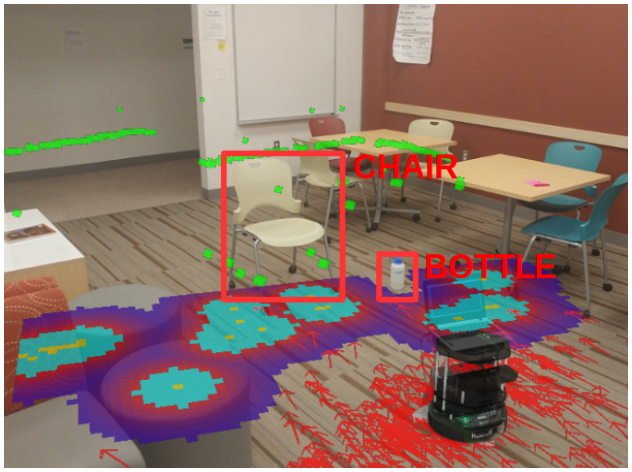

Figure 6: Example AR view of a subset of the robot's sensory data: laser scan reading (in green), localization hypothesis (shown as red arrows), object detections, and 2D cost map. Note that this is a composite sketch rather than the output of any existing system.

3D point-clouds to cognitive data such as the robot's motion and symbolic plans). Figure 5 shows several different types of robot data that is typically visualized on a computer screen when operating and programming the Turtlebot2 robot. Currently, we are in the process of extending the existing prototype to visualize these types of information, with the goal of producing visualization on AR devices similar to the composite sketch shown in Figure 6.

A major limitation of our pilot study is that it was qualitative in nature. In future work, we plan to conduct quantitative studies to evaluate the effect AR has on robotics education in K-12 classrooms. In particular, we have identified the following research questions:

- How do the design features of the AR-enhanced learning environment contribute to student learning and self-efficacy?
- What student conversations (e.g., higher-level theoretical robotics concepts vs. low-level debugging logistics) are enabled through use of the AR-based tool?
- What kinds of materials and assistance do teachers need to enact effective AR-based robotics activities, in support of productive student learning?
- What are the set of design principles, and accompanying learning impacts, associated with developing new augmented reality educational technologies?

Conducting larger-scale, controlled studies will enable us (and others) to answer some of these questions. Finally, we plan to use the data from such studies to iteratively address some of the usability issues that we observed over the course of the pilot project.

REFERENCES

[1] Amin Atrash and Joelle Pineau. 2010. A Bayesian Method for Learning POMDP Observation Parameters for Robot Interaction Management Systems. In *The POMDP Practitioners Workshop*.

[2] Fabiane Barreto Vavassori Benitti. 2012. Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education* 58, 3 (2012), 978–988.

[3] D Bernstein, K Mutch-Jones, M Cassidy, E Hamner, and J Cross. 2016. Robots and Romeo and Juliet: studying teacher integration of robotics into middle school curricula. In *International Conference of the American Educational Research Association, Washington, DC*.

[4] A Mejías Borrero and JM Andújar Márquez. 2012. A pilot study of the effectiveness of augmented reality to enhance the use of remote labs in electrical engineering education. *Journal of science education and technology* 21, 5 (2012), 540–557.

[5] Francisco A Candelas-Herías, Jara Bravo, Carlos Alberto, and Fernando Torres. 2006. Flexible virtual and remote laboratory for teaching Robotics. (2006).

[6] Chih-Wei Chang, Jih-Hsien Lee, Chin-Yeh Wang, and Gwo-Dong Chen. 2010. Improving the authentic learning experience by integrating robots into the mixed-reality environment. *Computers & Education* 55, 4 (2010), 1572–1578.

[7] Jonathan D Cohen, W Monty Jones, and Shaunna Smith. 2018. Preservice and Early Career Teachers' Preconceptions and Misconceptions About Making in Education. *Journal of Digital Learning in Teacher Education* 34, 1 (2018), 31–42.

[8] Dan Cuperman and Igor M Verner. 2013. Learning through creating robotic models of biological systems. *International journal of technology and design education* 23, 4 (2013), 849–866.

[9] Chris Dede. 2009. Immersive interfaces for engagement and learning. *science* 323, 5910 (2009), 66–69.

[10] Matt Dunleavy, Chris Dede, and Rebecca Mitchell. 2009. Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology* 18, 1 (2009), 7–22.

[11] Amy Eguchi. 2016. RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition. *Robotics and Autonomous Systems* 75 (2016), 692–699.

[12] Rubina Freitas and Pedro Campos. 2008. SMART: a SysteM of Augmented Reality for Teaching 2 nd grade students. In *Proceedings of the 22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction-Volume 2*. BCS Learning & Development Ltd., 27–30.

[13] Erica Rosenfeld Halverson and Kimberly Sheridan. 2014. The maker movement in education. *Harvard Educational Review* 84, 4 (2014), 495–504.

[14] Carlos A Jara, Francisco A Candelas, Santiago T Puente, and Fernando Torres. 2011. Hands-on experiences of undergraduate students in Automatics and Robotics using a virtual and remote laboratory. *Computers & Education* 57, 4 (2011), 2451–2461.

[15] Larry Johnson, Alan Levine, Rachel Smith, and Sonja Stone. 2010. *Simple augmented reality: The 2010 Horizon Report.* ERIC.

[16] Mohammad Ehsanul Karim, Séverin Lemaignan, and Francesco Mondada. 2015. A review: Can robots reshape K-12 STEM education?. In *Advanced Robotics and its Social Impacts (ARSO), 2015 IEEE International Workshop on*. IEEE, 1–8.

[17] Hannes Kaufmann, Karin Steinbügl, Andreas Dünser, and Judith Glück. 2005. General training of spatial abilities by geometry education in augmented reality. *Annual Review of CyberTherapy and Telemedicine: A Decade of VR* 3 (2005), 65–76.

[18] Lisabeth J Leighton and Helen Crompton. 2017. Augmented Reality in K-12 Education. In *Mobile Technologies and Augmented Reality in Open Education*. IGI Global, 281–290.

[19] Robb Lindgren, Michael Tscholl, Shuai Wang, and Emily Johnson. 2016. Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers & Education* 95 (2016), 174–187.

[20] Stéphane Magnenat, Morderchai Ben-Ari, Severin Klinger, and Robert W Sumner. 2015. Enhancing robot programming with visual feedback and augmented reality. In *Proceedings of the 2015 ACM Conference on Innovation and Technology in Computer Science Education*. ACM, 153–158.

[21] Jorge Martín-Gutiérrez, José Luís Saorín, Manuel Contero, Mariano Alcañiz, David C Pérez-López, and Mario Ortega. 2010. Design and validation of an augmented book for spatial abilities development in engineering students. *Computers & Graphics* 34, 1 (2010), 77–91.

[22] Eric Rosenbaum, Eric Klopfer, and Judy Perry. 2007. On location learning: Authentic applied science with networked augmented realities. *Journal of Science Education and Technology* 16, 1 (2007), 31–45.

[23] Eli M Silk, Ross Higashi, Robin Shoop, and Christian D Schunn. 2010. Designing technology activities that teach mathematics. *The Technology Teacher* 69, 4 (2010), 21–27.

[24] Sofoklis Sotiriou and Franz X Bogner. 2008. Visualizing the invisible: augmented reality as an innovative science education scheme. *Advanced Science Letters* 1, 1 (2008), 114–122.

[25] Kurt Squire and Eric Klopfer. 2007. Augmented reality simulations on handheld computers. *The journal of the learning sciences* 16, 3 (2007), 371–413.

[26] Igor M Verner, Shlomo Waks, and Eli Kolberg. 1999. Educational robotics: An insight into systems engineering. *European Journal of Engineering Education* 24, 2 (1999), 201–212.

[27] Hsin-Kai Wu, Silvia Wen-Yu Lee, Hsin-Yi Chang, and Jyh-Chong Liang. 2013. Current status, opportunities and challenges of augmented reality in education. *Computers & Education* 62 (2013), 41–49.