

A Learning Support System using Camera Tracking for High School Physics Experiments

SHALIKA PATHIRATHNA^{1,a)} LIEM HOANG^{1,b)} MARC ERICSON C. SANTOS^{1,c)} SIRAWAT PITAKSARIT^{1,d)}
 GOSHIRO YAMAMOTO^{1,e)} TAKAFUMI TAKETOMI^{1,f)} CHRISTIAN SANDOR^{1,g)} HIROKAZU KATO^{1,h)}

Abstract: In the past decades, information communication technology (ICT) have made a great impact on various aspects of human life, including education systems. However, although a lot of education support applications are available in the market, few are adopted to regular use in the classroom environment. There is a mismatch between the application features and the teacher's requirements. To overcome this mismatch, we collaborate with high school teachers to create an application that matches their requirements. In particular, we are developing a motion graphing application for handheld devices like smartphones and tablet computers. Teachers have recommended that this application is useful for high school physics experiments on kinematics. For the future work, we plan to conduct user evaluation in a real classroom environment to explore how we can effectively utilize handheld devices to improve classroom interaction.

1. Introduction

Information and communication technologies or ICT has greatly improved many aspects of human life such as the way we live, work, communicate and acquire knowledge [1]. However, the influences of ICT exceeds beyond the mentioned aspects of live. Modern technology has created new dimensions for education by both supporting the needs of educators and enhancing the learning experience of students. This is often referred to as technology-enhanced learning (TEL). In the past years, TEL research has focused on developing technologies such as e-learning, ubiquitous learning (u-learning), mobile learning (m-learning) and recently, augmented reality (AR) [2].

TEL research is primarily motivated by educational reforms directed towards student-centered learning process. In addition, other motivations include technological development in hardware and software of mobile devices, and the popularity of such devices among the general public, especially with school children and teens. Many studies have attempted to integrate handheld devices such as smartphones and tablets computers in educational settings stating that these devices have a great potential in making significant improvements in the learning experience and outcomes. However, little work has been carried out to explore the mechanisms that can be used to integrate handheld devices into

the classroom environment effectively. The purpose of this study is to explore the use of handheld devices in the classroom environment. In particular, we focus on high school physics experiments. To test our ideas, we developed a prototype application running on handheld devices to observe the motion of objects in kinematics experiments.

Even though there are a lot of mobile applications available in the market, few have been effectively adapted to classroom environment. This might be due to the lack of understanding between the application developers and the educators. The educational researchers and educators do not necessarily have the technological knowledge. Whereas, the application developers do not have the practical classroom knowledge of experienced teachers [3]. To narrow the gap between requirements and the final development module, we consistently discussed with high school teachers to acquire the requirements. Moreover, the incremental development based on the feedback was constantly verified with the teachers. Therefore, as an initial step, we discussed with an experienced high school physics teacher to identify their expectations and requirements. Next, based on the teachers requirements, we designed and implemented the motion graphing system for high school physics kinematics experiments. The final step would be to conduct a user study in an actual classroom environment with the assistance of the physics teachers.

2. Related Work

With development of ICT, there are a large number of commercial and non-commercial applications available to the students. These applications range from web applications to novel AR simulations. Some AR applications have been developed for education, especially for physics experiments. Kaufmann and Meyer presented an AR application for simulating physical experiments

¹ Interactive Media Design Laboratory, Nara Institute of Science and Technology, Ikoma, Nara 630-0192, Japan

^{a)} shalika.pathirannahalage.sk6@is.naist.jp

^{b)} hoang.liem.hc7@is.naist.jp

^{c)} chavez-s@is.naist.jp

^{d)} sirawat.pitaksarit.sh2@is.naist.jp

^{e)} goshiro@is.naist.jp

^{f)} takafumi-t@is.naist.jp

^{g)} sandor@is.naist.jp

^{h)} kato@is.naist.jp

in mechanics education [4]. In this work, students could conduct the experiment in a three-dimensional virtual world. Another study presented a framework for creating interactive physics books with AR [5]. This framework could be used to create AR books that can play three-dimensional animated educational content. AR could be used to explain the concepts that cannot be seen by the naked eye such as concepts of electromagnetism. However, most of the applications tend to be used infrequently because they often require some special hardware.

Physics education is tightly coupled with experiments. Complex theories are often explained and elaborated using experiments and simple everyday scenarios. Although handheld devices for supporting physics education is still relatively new, there are some existing applications related to physics experiments. Some of them use the handheld device's built-in sensors as a measurement devices even though they lack the precision of dedicated devices. Kuhn and Vogt have used mobile phones as an experimentation tool and explained that mobile phones and smartphones are suitable because they are equipped with a number of sensors [6]. Earlier research [7] documented the use of mobile phones in a physics class. Mobile phones have been used as data acquisition and data processing modules by utilizing the built-in sensors. Their work emphasizes on the use of the mobile phone's accelerometer, magnetometer and GPS sensors in the experiments. However, this research work did not mention how they addressed the requirements of the teachers. Addressing these requirements are important to developing applications for learning support because teachers often consider the curriculum and lesson plans when choosing their teaching materials.

3. System Design

Teachers have extensive knowledge of the classroom environment. As such, we had several discussions with them to retrieve some design requirements. For this research, we discussed with a physics teacher from Miriam College High School in Metro Manila Philippines to identify their specific requirements. Miriam College High School is a private high school for girls which recently adapted a one tablet for one student policy.

Motion graphs are used in physics to illustrate the movement of an object. Using a motion graph, the motion state of an object can be described. For example it can be a constant velocity, accelerating, decelerating, or at rest. The most basic motion graph is the displacement vs. time graph from which it is possible to derive the velocity. After determining the velocity of an object, one can then derive the velocity vs. time and the acceleration vs time graphs of the object.

In the classroom high school physics, motion graphs are used extensively. It also serves as a baseline mechanics skill as agreed upon by both physics educators and physicists. With these graphs, it is possible to elaborate the different conditions of acceleration. Currently, there are stand-alone motion sensors that are used to measure the velocity of an object. The motion sensor is then attached to a computer, and a special software translates the information into the relevant graphs. The motion sensor emit ultrasound signals and detect its echoes from reflecting surfaces. Instead of purchasing relatively expensive motion sensors

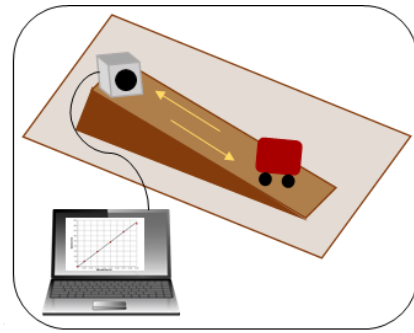


Fig. 1 Ramp motion experiment setup with a motion sensor

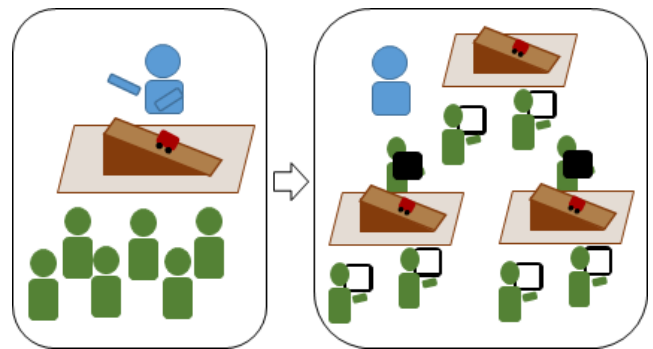


Fig. 2 Two different styles of presenting the kinematics experiment. Left is a demonstration by the teacher. Right is individual experimentation by the students.

and computers to automatically graph motion, handheld devices such as smartphones and tablet computers can be use as an alternative solution.

3.1 Kinematics Experiment

Among several kinematics experiments, we selected a ramp motion experiment which is used to study the acceleration of a trolley on a ramp to demonstrate our prototype system. **Figure 1** show the setup for the ramp motion experiment. The trolley will accelerate down the ramp. The motion sensor detects the speed of the moving trolley and send the recorded data to a designated computer. The students can then view the graphs from computer or download the data for further analysis.

3.2 Teacher's Requirements

Currently, the kinematics experiments were demonstrated by the teacher since they only have one setup. Motion sensors and the setup itself are expensive, and limited to one particular use only. The students were not able to conduct the experiments individually due to lack of resources.

As part of the upgrades and reforms within Miriam College High School, they have adopted a one tablet, one student policy. Since handheld devices are common in the school teacher required a handheld application that can support for physics experiments. In this case, they can use an inexpensive mechanism to conduct the experiment in same amount of effectiveness or even better with the older setup. With this learning support system students can experience the experiment by themselves (**Fig. 2**).

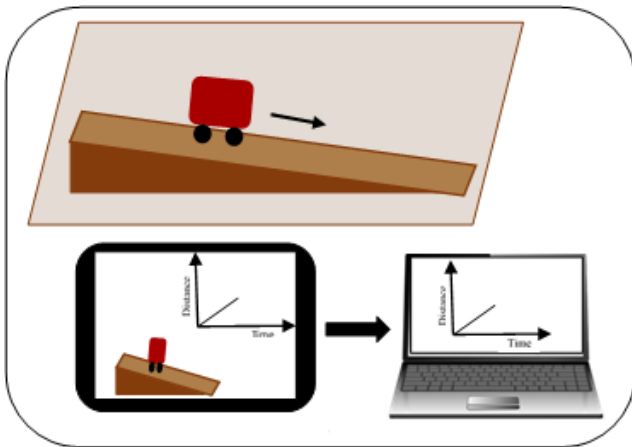


Fig. 3 Our design based on the teacher’s requirements

3.3 Our Design

Based on the teachers requirements, we designed a motion graphing application for handheld devices with real-time graphical display. In the designing phase, we made sure not to use additional equipment other than than the handheld device. **Figure 3** shows the new experiment setup analogous to the regular experiment setup. We have replaced the ultrasonic motion sensor with a handheld device. Handheld device’s camera is use to track the motion of the moving object.

4. Implementation

Our motion graphing application caters to both Android and iOS handheld devices with a supporting web service and web application. There are 3 main components: the mobile component, the server component and the web component.

4.1 Mobile Component

In order to develop a handheld application for both Android and iOS platform, we utilized the cross platform integrated development environment called Unity. The mobile component contains several sub-components for tracking, database, calculator, networking and graphing.

The concept of the tracking component is to utilize computer vision and computer graphics to calculate the distance between two specific positions in the real world. To solve this problem, we used a marker-based tracking technology called Vuforia with multiple markers. Vuforia already supports a plug-in for Unity which is suitable for our purpose of cross-platform handheld application development. **Figure 4** shows the setup for ramp motion experiment with the motion graphing application. We attach 2 markers: one into the car, and one at the lower end of the ramp. We estimate the velocity as the change in distance between the 2 markers divided by the interval time.

The most primitive data that can be captured is the displacement of the object. We implement this using Vuforia. This library can measure distance between two fiducial markers. If we fix one marker as a reference and one marker as a moving target, we can measure how much the car travelled by calculating the difference of distances between them. Using Unity, we can easily design an interface button to start recording this distance. Moreover, this

Table 1 Web service methods

method name	input parameters	return value
authenticateUser	user name, password	user id if authenticated else null
addExperiment	user id, experiment name, distance, velocity, time	true if success else false

user interface will scale nicely across different devices and screen size.

After capturing the distance over time using the record function, we process the data to eliminate noise. This filtering includes removing data spikes which could result from the losing track of the markers momentarily.

After processing the captured data, it can be displayed on the graph to help experimenter visualize the result that they have just captured. This graph has been implemented using Unity plug-in from the Unity Asset Store. In the internal data, we can also calculate velocity and acceleration. From this point users can move to a new experiment, browse old experiments or delete experiments.

The user can then use the upload functionality to submit the captured experiment data to the server. When the user presses upload, the program will send POST request with predefined format to the IP address specified. Results of submission will also be displayed in the program’s message box located at the top of the screen.

4.2 Sever Component

According to requirements, the graphs should be available from both mobile component and web component. The data collected via the mobile component should also be transfer to the web component. Thus, there should be a central location for the collected data. We used a server to host the database. The database stores user information and experiment data. We have used MySQL for database management.

A web service was used as the communication channel between the server database and the mobile component. Java and Apache Axis2 are used to create the web service. Implementation classes were written using the Java programming language. Then, we created a *.aar archive (Axis Archive) for the web service using Apache axis 2 code generator plug-in for Eclipse. Apache axis 2 code generator plug-in is used to generate a WSDL from a Java source file. Finally, we deployed the *.aar archive in Jboss application server.

This web service exposes methods for user login and saves collected data (**Table 1**). The web service method “authenticateUser”, authenticates the user with a user name and password. The “addExperiment” method inserts experiment details into the database. When “addExperiment” method is called, it calculates the acceleration using velocity and time, and inserts it into the database with other experiment details.

4.3 Web Component

The motion graphing web application is developed using struts and hosted in Jboss application server. Struts is a framework for develop java-based web applications and it is based on model, view, controller (MVC) architecture. Users are able to view



Fig. 4 Detected markers indicate with an arrows



Fig. 5 Movement of the car on the ramp

distance-time, velocity-time, acceleration-time graphs as well as the raw data via the web application. Moreover, we have provided print and download options. This allows the students to have access to their data and conduct further analysis for making reports later on. To implement the chart function, we used Highcharts charting library which is written in JavaScript.

4.4 Testing and Result

In our system, virtual arrows (Fig. 4) appear to indicate that the markers are being tracked. After the markers are detected by the system, users can start the experiment by moving the car. **Figure 5** depicts the movement of the car as seen from the handheld device. At the end of the experiment, the velocity-time graph is displayed on the handheld device. Then, results are sent to the server for future use. Distance-time, velocity-time, acceleration-time graphs and raw data can be viewed via web application.

We encountered several problems during the development process. Because the application is based on marker tracking, the lighting condition affects our application. Too much lighting can often make the marker difficult to recognize thereby losing the track. As a result, the distance is not calculated accurately, and the output becomes noisy. The frame rate of the application is based on a real camera, so the update rate is higher than the actual data necessary for graphing. We capture too much noise with a 30fps frame rate so the distance is not stable. As a simple solution, we decreased the frame rate of the application resulting to smoother and more consistent graphs. For future improvements, our idea is to use some filter to obtain more accurate distance calculations.

5. Conclusion and Future Work

In this work, we developed a motion graphing application based on the requirements of a physics teacher. Running on a handheld device, our motion graphing application could be used to measure displacement, velocity and acceleration in kinematics experiments. The application can both calculate the above mentioned measurement and display them in a real-time graph. In addition, the application can save data offline and upload the raw data to the server. Furthermore, students can access their experiment data and observe the graph on the web. This data is similar to the graph they see on the handheld device. Furthermore, they can store the data and use for further study.

We plan to evaluate this system using several approaches. First, we will compare the system with real hardware (i.e. ultrasonic motion sensor for measuring speed) to verify the accuracy and reliability. Next, we plan to conduct a user study with the physics teachers of Miriam College High School to conduct a heuristic evaluation for their practice. This evaluation is important since it can provide information related to the modifying of the system to better accommodate to the classroom context. Finally, we would like to compare the the two types of experiment, the previous method which is a demonstration by the teacher, and the individual experiments using handheld devices.

Acknowledgments This work is funded by the Creative and International Competitiveness Project 2014 Extended Track for students of International Priority Graduate Programs (IPGP) which is supported by Nara Institutes of Science and Technology (NAIST). Also this is supported by the Grant-in-Aid for JSPS Fellows, Grant Number 15J10186. We would like to show our gratitude to Mr. Resty Collado a Teacher in Miriam College High School, Metro Manila Philippines for supporting us.

References

- [1] Ala-Mutka, K., Punie, Y. and C.Redeker: ICT for Learning, Innovation and Creativity, Technical report, Institute for Prospective Technological Studies (2008).
- [2] Bacca, J., Baldiris, S., Fabregat, R., Graf, S. and Kinshuk: Augmented Reality Trends in Education: A Systematic Review of Research and Applications, *Journal of Educational Technology & Society*, Vol. 17, No. 4, pp. 133–149 (2014).
- [3] Vanderlinde, R. and Braak, J. V.: The gap between educational research and practice: views of teachers, school leaders, intermediaries and researchers, *British Educational Research Journal*, Vol. 36, No. 2, pp. 299–316 (2010).
- [4] Haufmann, H. and Meyer, B.: Simulating Educational Physical Experiments in Augmented Reality, *Proceedings of ACM SIGGRAPH ASIA 2008 Educators Program*, New York, NY, USA, ACM Press (2008).
- [5] Dünser, A., Walker, L., Horner, H. and Bentall, D.: Creating Interactive Physics Education Books with Augmented Reality, *Proceedings of the 24th Australian Computer-Human Interaction Conference*, New York, NY, USA, ACM Press, pp. 107–114 (2012).
- [6] Kuhn, J. and Vogt, P.: Applications and Examples of Experiments with Mobile Phones and Smartphones in Physics Lessons, *Frontiers in Sensors*, Vol. 1, pp. 68–73 (2013).
- [7] Opera, M. and Miron, C.: Modern Phones in the Modern Teaching of Physics, *Romanian Report in Physics*, Vol. 66, pp. 1236–1252 (2014).