Time-lapse Photography for K-12 Education

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Abstract

This paper describes an innovative, new approach to combine visible, infrared, and thermal time-lapse photography from several different cameras to conduct empirical analysis in the K-12 classroom. This project is part of an innovative, new GK-12 STEM Fellowship Program which incorporates contemporary, embedded, real-time sensors and system design into the existing K-12 curriculum. Unlike other GK-12 programs, more focus is placed on Technology (T) and Engineering (E), and less focus is placed on Science (S) and Mathematics (M). The underlying goal of the program is to link cyber physical systems research with science and technology curriculum and create a community of learning, teaching, and mutual support between the higher and pre-college education participants.

Keywords: Education, embedded systems, inquiry, outreach, real-time sensor networks.

1 Introduction

There is a well-recognized national need to inspire much more interest in Science, Technology, Engineering, and Mathematics (STEM) disciplines among K-12 students. Computational thinking is a type of analytical thinking that shares methodology used in other STEM disciplines [1]. Likewise, STEM disciplines have seen an increased emphasis on the use of computational thinking. Thus, it is important for us to increase the number of students from the K-12 level interested in pursuing STEM careers with an emphasis on computational thinking. When young students get excited about science and engineering as a result of experiences in school or informal education settings, they are more likely to pursue classes that properly prepare them for success in undergraduate and graduate programs in STEM fields. A primary goal of our GK-12 STEM Fellowship Program is to incorporate computational thinking into STEM disciplines in the K-12 classroom [2]. As noted by Shreck and Latifi, it is important to provide an infrastructure in which teachers have adequate support and where they are able to change with the new technology [3].

The U.S. National Science Foundation's program to support Graduate Teaching Fellows in K-12 Education (GK-12) strives to improve graduate students' communication, teaching, collaboration, and team building skills through professional training, interactions with faculty, and work in the classroom with K-12 teachers and students. By working with K-12 teachers to integrate their knowledge and research to enhance the classroom, graduate fellows and faculty members also have the opportunity to build partnerships with schools and teachers, and to enrich learning opportunities and increase motivation for K-12 students.

Figure 1. GK-12 STEM fellow helps students with sediment sensor

The graduate fellows also serve as role models for the students that they work with, and they talk with the students about the diverse and exciting careers that can be pursued by those who are interested in STEM disciplines. Although the main focus of the GK-12 program is on the development of graduate students, this paper will focus more on the innovative aspects of the program and some of the modules developed for use in the K-12 classroom. A detailed description of the time-lapse photography module will be given.

2 INSIGHT GK-12 STEM Fellowship Program

Infusing System Design and Sensor Technology in Education (INSIGHT) is the title given to our innovative GK-12 STEM Fellowship Program at Kansas State University. Our program focuses on integrating real-time embedded systems and sensor technology with computational thinking through a standards-based science, technology, engineering, and mathematics curricula.

The underlying goals of the program are to: enhance the usefulness, practicality and relevance of sensor, computing, and information technology education by linking embedded systems research for fellows to science and technology curriculum and to practice for classroom teachers; support technology in rural Kansas through two of the most important aspects impacting rural life in Kansas: agriculture and health; improve the teaching and learning of technology and engineering design in middle school and high school classrooms; and create a community of learning, teaching and mutual support between the both the higher education and pre-college education participants from rural backgrounds.

Project activities team GK-12 fellows with K-12 STEM teachers through summer and academic year training and orientation, and place the fellows in the classrooms of rural Kansas schools. In the summer, project staff provides fellows with training in hands-on sensor-driven systems, STEM concepts and development, Kansas Curriculum Standards, and classroom instruction methodology. Participating teachers also receive two weeks of training and orientation which focuses on sensor technology, computing and information science topics, selected science and technology content areas and the use of appropriate pedagogical and assessment strategies.

During the academic year, fellows support two participating teachers in the classroom an average of two times a week in their area with content-specific embedded sensor technology and computational thinking. Program staff provides semester-long professional development opportunities via guided research and investigations of practical applications of technology integration on agricultural farm fields and within the classroom. Weekly meetings between project staff and fellows provide supervision and feedback.

Sensor systems are poised to revolutionize the way that the physical world is monitored and field experiments are performed with remote, automated real-time data collection and feedback replacing traditional manual methods. The development of cyber-physical infrastructure represents the next step in enabling applications wherein physical entities (humans with body parameters such as heart and respiratory rates, crops with different fertility and growth rates, etc.) and cyber-subsystems collaborate and interact to achieve a common goal.

For example, in health-care systems, the cyber-infrastructure can augment the capabilities of the hospital staff in patient monitoring, issuing alerts, and coordinating usage of resources. Likewise, in rural Kansas, remote monitoring can enable elderly residents to stay in their own homes safely for an improved quality of life and an on-site pharmacist is replaced with a robot that can dispense prescriptions to elderly patients and allow patients to consult with a pharmacist remotely.

As another example, although farm equipment operators can operate with a local visual view of the field, cyber and remote sensing infrastructure in the field can assist them by providing correlated GIS, climatic and vegetation data to support variable rate application of chemicals with precision using GPS. This results in both economic and environmental benefits [4].

Typically, these systems are difficult to develop because their development requires knowledge about many parts of a complex system involving a number of heterogeneous subsystems and components. Their design is often a multidisciplinary exercise involving a variety of domain experts with different views of the system, and there are few formal techniques that can be used to address the integration of individual components. Designers often work on subsystems without fully understanding its impact on other components and the rest of the system. Design of such cyber physical systems has been the focus of researchers from several departments at K-State.

This program represents a unique synergistic opportunity for us to collaborate with our K-12 colleagues in a similar manner, and create and strengthen mutually beneficial partnerships with the many rural school systems in Kansas. These partnerships enhance the education of K-State's technologically-oriented graduate and undergraduate students while simultaneously advancing computing, science, and technology education in rural Kansas middle school and high school classrooms [5].

Sensor technology is the enabling element that pervades the entire science, engineering and technology curriculum, rather than as an entirely new and separate subject or curriculum area, whose introduction would be more problematic. Deductive reasoning, analysis and synthesis, algorithmic problem solving and design, and inquiry techniques are at the heart of each of these disciplines. Regardless of the scientific area, students must learn to formulate questions and hypotheses, plan experiments, conduct systematic observations, interpret and analyze data, draw conclusions and communicate results, using powerful classroom tools. Indeed, these skills are tested in a statewide assessment of students' achievement in science, engineering and technology. Aligning instruction with science, engineering and technology standards requires significant changes to classroom practice, from content, activities, and assessment to classroom management, interaction with students and learning tools. This program has helped to establish hands-on engineering and technology development as a foundational skill for vocational agriculture, science, mathematics, and other areas. Instead of focusing only on Mathematics and Science, the novelty of this project is on its primary focus on Technology and Engineering.

3 Sample Curricular Modules

In this section, we give a brief overview of a few modules that have been developed and/or delivered by fellows in the K-12 classroom. Details can be found on-line at, http://gk12.cis.ksu.edu, through our GK-12 program web-site. In addition, a detailed description of the time-lapse photography module is given below.

Water Filter

In this activity students were asked to create their own sediment water filter using a water bottle and some basic materials. Some of the materials include: flour, sugar, sand, gravel, plastic beads, cotton balls, etc. The students were only allowed to use three materials and it was up to them to create the best filter in the class based on the types of materials selected, and order the materials were placed into the filter. The dirty water, shown in the upper-left corner in Figure 2, is stirred occasionally to keep the sediment suspended, and the sediment shown in the upper-right is used to test filtered samples.

Figure 2. Sediment water sensor and filters

Wireless Sensor Network to Measure Sediment

At the high school level, students take samples using a hand-held sensor (Figure 1) and take readings using sediment sensors deployed in the field and connected by a three-tiered wireless sensor network [6-8]. A solar panel is used to power the middle tier of the wireless sensor network as shown in Figure 3.

Figure 3. Wireless sensor network

To measure sediment discharge, several turbidity sensors developed here at Kansas State University are organized into a wireless sensor network, and they continuously monitor sediment discharge. The system is organized to automatically adjust sensor reading rates based on the data to limit the power requirements of the wireless sensors. The data is then transmitted to a wireless base station, and on to a centralized database from which the data can be analyzed [6-8]. Sediment concentration is defined as the weight of suspended soil particles per unit volume of water. Turbidity is usually referred to as the optical properties of suspended or dissolved materials in water on transmitting, reflecting, absorbing, and scattering light. Thus, traditional turbidity sensors are not sediment-concentration sensors. A sediment sensor developed in this study uses LEDs that emit lights at three visible and infrared *feature wavelengths*, which were selected through a spectroscopic analysis, with light detectors arranged at different angles from the light sources. Statistical models established based on test data allowed the sensor to be basically insensitive to non-soil, suspended and dissolved objects, such as algae, organic matter, and various microorganisms, and less sensitive to soil texture. A prototype sensor was tested at combinations of four water types and five soil textures in the laboratory. Statistical and neural-network models successfully predicted sediment concentration across samples of all the combinations with R^2 values of no lower than 0.95. An outdoor experiment proved that the influence of ambient light on sediment measurement can be largely eliminated by modulating the lights. More than ten prototype sensors of different designs have been fabricated and calibrated.

Figure 4. Sediment concentration measurement

Several sensors were deployed at low-water crossings at Fort Riley in Kansas and Fort Benning in Georgia for long-term, sediment-runoff monitoring [7]. The sensor case has been modified to improve its waterproof capability. Difficulties encountered during the long-term tests included signal drifting and occultation of the optical lenses by algae and soil particles. Modifications in sensors and software have been implemented to solve these problems [6].

Water sediment concentration

At the elementary level, sediment concentrations in water are measured manually using filter paper and drying equipment after collecting samples at a local lake. They also compared the results they obtained with the measurement taken using an electronic sediment sensor as shown in Figure 4.

Olympic bar acceleration during a bench press

High school students in weight lifting classes at Wamego High School use Velcro to strap on a Wii remote to an Olympic bar to measure each student's acceleration in all directions while doing the bench press lift. A graph of the accelerometer values is projected onto the ceiling of the weight room so that students can watch their acceleration and movements during the lift. This information can be used to determine if the students are using correct lifting techniques.

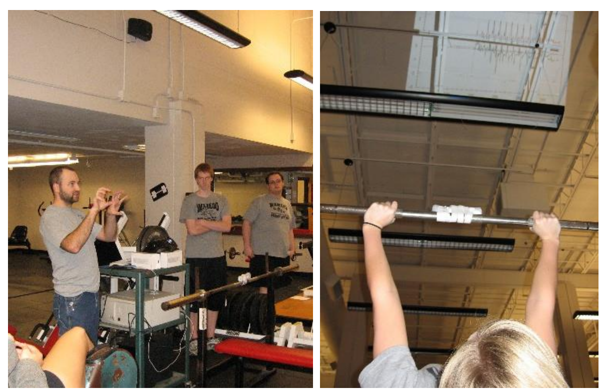

Figure 5. Bench press acceleration

Time-lapse photography

Middle school students analyze the effect of plant spacing on the growth rate of radish seedlings. Weekly measurements are made of average plant height and CO_2 levels in plant starter boxes. In addition to weekly measurements, we also record images of sprouting plants using inexpensive visible/IR cameras controlled by an inexpensive Raspberry Pi computer. Then, the images are automatically translated into a time-lapse video using a standard open-source media encoder called *mencoder* [14].

Figure 6. Time-lapse photography

At the beginning of the experiment, classes set up two groups of radishes. Groups consist of seven pots in an air-tight pan with a plastic lid. Holes are made 1.5" from the bottom of pans for use with a CO_2 probe (and subsequently taped over) and cameras are taped to the inside of lids. Treatment groups are either planted at a rate of one seed/pot or five seeds/pot. Students are shown connecting Raspberry Pi cameras to the inside of their pans in Figure 7.

Figure 7. Students connecting Pi cameras to plant boxes

All radishes are grown under a UV grow light for three weeks. Sprouting behavior is monitored by time-lapse photography during the first week of growth. Average plant height and CO_2 levels are measured at the end of each week for each box.

To make it easy for classroom teachers to set-up the cameras and specify experimental parameters, we have the Raspberry Pi's configured to look for a text file containing the specifications on a thumb drive and, if found, convert the text file to a script that is automatically executed to take pictures and store the images on the thumb drive. Then, the script is used to automatically generate a time-lapse video from the images stored. The steps to configure the Raspberry Pi systems are outlined below:

1. On Raspberry Pi, install the Raspbian GNU Linux 7 distribution and enable cameras [15].
2. Then, modify file /etc/rc.local, which is executed when the system is booted up, so that the system mounts the USB thumb drive under /mnt/usb and executes the commands in a script file called raspistill.txt or raspistill.py to capture the (.jpg) images and generate a video file (timelapse.avi) from the images generated, and then simply shut the Raspberry Pi system down. The original rc.local shell script file contains:

```
/etc/rc.local:
#!/bin/sh -e
#
# rc.local
#
# Print the IP address
_IP=$(hostname -I) || true
if [ "$_IP" ]; then
  printf "My IP address is %s\n" "$_IP"
fi
# ADDED CODE HERE
exit 0
```

We modify the file just above exit 0, as shown below, to add some code to tell the system to execute the commands listed in the script file on the thumb drive, for brevity we only show how to execute a shell script, but a comparison can be added to determine if a python script is available on the thumb drive as well:

```
# Added for time-lapse photography
mount -o uid=pi,gid=pi /dev/sda1 /mnt/usb
#
# Copy raspistill.txt to raspistill.cmd,
# convert to Unix format, and execute
cp /mnt/usb/raspistill.txt /mnt/usb/raspistill.cmd
dos2unix /mnt/usb/raspistill.cmd
sh /mnt/usb/raspistill.cmd
```

Some of the applications used are not installed by default, they can be installed them from the Internet using apt-get:

```
pi@raspberrypi $ sudo apt-get install dos2unix
pi@raspberrypi $ sudo apt-get install mencoder
```

Then, create a directory to be used to mount the USB drive, and set "pi" to be the owner of the directory:

```
pi@raspberrypi $ sudo mkdir /mnt/usb
pi@raspberrypi $ sudo chown pi /mnt/usb
pi@raspberrypi $ sudo chgrp pi /mnt/usb
pi@raspberrypi $ ls -l /mnt
drwxr-xr-x 2 pi pi 4096 Jan 14 19:30 usb
```

Then, we use any Windows editor to create an ASCII text file called raspistill.txt in the top-level directory on our USB thumb drive:

```
sleep 10
mkdir -p /mnt/usb/pictures
cd /mnt/usb/pictures
rm a*.jpg
rm timelapse.avi
raspistill -tl 5000 -o a%04d.jpg -t 30000
ls *.jpg > stills.txt
mencoder -nosound -ovc lavc –lavcopts
    vcodec=mpeg4:aspect=16/9:vbitrate=8000000 -vf
    scale=1920:1080 -o timelapse.avi –mf
    type=jpeg:fps=4 mf://@stills.txt
sync
sudo shutdown now
```

This example results in a picture once every 5000 ms (5 seconds) for 30 seconds. It's generally good to test a short running sample before you let it run for hours and hours. After 30 seconds, it will still take about 30 more seconds to create the video. Then, you can just turn off the Raspberry Pi, remove the thumb drive, and enjoy your video. If your time-lapse video includes hundreds of frames, it will take a bit longer to create the video, or you can create the video from the still images on a more powerful platform.

The Raspberry Pi can also be used to control the FLIR Lepton™ Thermal Imaging Camera. Simple scripts can be used to control the image capture and processing. Other scripting languages can be used to develop the scripts. Once the K-12 students gain an understanding of the simple scripting languages, they easily update the scripts to conduct their own experiments, and even write their own scripts. Since Python 2.7 is installed by default, to use python, just replace raspistill.cmd with raspistill.py, and invoke the shell by replacing the /bin/sh command with the python command: $ **python /mnt/usb/raspistill.py**. We also updated raspberry_pi_capture.c from Pure Engineering [11] to allow command line arguments to specify the output file name to enable the capture of numbered images for time-lapse photography. The new version is compiled as **rpcapture**, and incorporated into the inner-most portion of the python script as shown below.

```
# Jump to folder with visible/infrared images
os.chdir("/mnt/usb/normal")
# Take a visible/infrared pic of size 560x420
subprocess.call("raspistill -w
  "+str(imageWidth)+" -h "+str(imageHeight)+"
   -q 75 -o image"+str(i)+".jpg -t 50",
   shell=True)
# Jump to folder with thermal images
os.chdir("/mnt/usb/thermal")
subprocess.call("./rpcapture "+str(i),
   shell=True)
# Convert .pgm file created to .jpg and resize
subprocess.call("convert -resize
   '"+str(imageWidth)+"x"+str(imageHeight)+"!'
   thermal"+str(i)+".pgm thermal"+str(i)+".jpg",
   shell=True) …

def CombinePictures(leftPic, rightPic, number):
 newPic=Image.new("RGB", (cWidth, cHeight))
 left=Image.open("/mnt/usb/normal/"+leftPic)
 right=Image.open("/mnt/usb/thermal/"+rightPic)
 newPic.paste(left, (0, 0))
 newPic.paste(right, (secondPicX, secondPicY))
 newPic.save('combined'+str(number)+".jpg")
```

ImageMagick and Pillow can be used to perform image processing – converting .pgm to .jpg, and combining visible and thermal images into a single image to be included in the time-lapse video as shown in Figure 8 [12, 13]. This makes it a simple task to simultaneously capture both visible or infrared images using the Raspberry Pi camera port and thermal images using the Lepton FLIR Thermal Imaging camera connected to the GPIO pins.

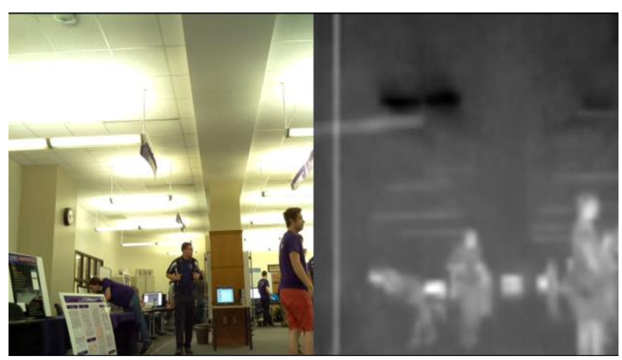

Figure 8. Simultaneous visible and thermal image capture

To make it simple for K-12 students and teachers to focus on their experiments, and simplify the data capture and image processing, we just configured a master Raspbian OS image to have the additional software already pre-installed, and to have the modification already made to the rc.local file to automatically invoke a script if found on the thumb drive. The updated master image only needs to be copied onto an SD card for a new Raspberry Pi to be set up and ready to use.

4 Conclusions

This paper describes several new curricular modules for K-12 education. One module combines either visible or infrared images, with optional thermal images, for time-lapse photography. This module uses an inexpensive Raspberry Pi. It was developed as part of an innovative GK-12 STEM Fellowship Program that incorporates contemporary, embedded, real-time sensors, computational thinking, and system design into the existing K-12 curriculum.

A novel aspect of the time-lapse photography module is that K-12 teachers and students only need to edit a simple ASCII text file on a thumb drive to specify exactly the parameters to be used to capture the images and process the data retrieved. This empowers students to conduct their own empirical analysis in the K-12 classroom.

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References

[1] J.M. Wing, "Computational thinking and thinking about computing", in Philosophical Transactions of the Royal Society A, Vol. 366, pp. 3717-3725, July 31, 2008.

[2] M. L. Neilsen, N. Bean, G. Singh, J. Spears, V. Wallentine, and N. Zhang, "INSIGHT: Infusing system design and sensor technology in K-12 education", in Proceedings of the 2012 International Conference on Frontiers in Education: Computer Science and Computer Engineering (FECS'12), 2012.

[3] S. Shreck and S. Latifi, "K-12 computer education deficiencies in Nevada", in Proceedings of the 2011 International Conference on Frontiers in Education: Computer Science and Computer Engineering (FECS'11), pp. 114-118, 2011.

[4] M. N. Rao, D. Waits, M. L. Neilsen, "A GIS-based modeling approach for implementation of sustainable farm management practices", Environmental Modeling and Software, Vol. 15, pp. 745-753, 2006.

[5] M.L. Neilsen, N. Bean, and J. Spears, "Infusing cyber-physical systems into a standards-based K-12 curriculum", in Proceedings of the First Workshop on Cyber-Physical Systems Education (CPS-Ed), Philadelphia, PA, Apr. 8-11, 2013.

[6] N. Wang, N. Zhang, and M. Wang, "Wireless sensors in agriculture and food industry--Recent development and future perspective", Computers and Electronics in Agriculture, Vol. 50, No. 1, pp. 1-14, 2006.

[7] Y. Zhang, N. Zhang, G. Grimm, C. Johnson, D. Oarrd and J. Steichen, "Long-term field test of an optical sediment-concentration sensor at low-water stream crossings (LWSC)", *ASABE Paper No.* 072137, St. Joseph, Michigan, 2007.

[8] J. Wei, N. Zhang, D. Lenhert, M.L. Neilsen, M. Mizuno, and J. Schmidt, "Using smart transducer technology to facilitate precision agriculture systems", In Proceedings of the ASAE Annual International Meeting (ASAE Paper 03-3145), Las Vegas, NV, July 27-30, 2003.

[9] John Maloney, Mitchel Resnick, Natalie Rusk, Brian Silverman, and Evelyn Eastmond, "The Scratch Programming Language and Environment", *Transactions on Computer Education.* 10, 4, Article 16 (November 2010), pp. 16:1-16:15.

[10] M.L. Neilsen, D.H. Lenhert, M. Mizuno, G. Singh, J. Staver, N. Zhang, K. Kramer, W.J. Rust, Q. Stoll, M.S. Uddin, "Encouraging interest in engineering through embedded system design", In American Society of Engineering Educators (ASEE) Computers in Education Journal, Vol. XV, No. 3, pp. 68-77, July 2005.

[11] Lepton Engineering, LLC, "FLIR Lepton Module: raspberry_pi_capture.c", retrieved on 10/20/2014: https://github.com/PureEngineering/LeptonModule/blob/master/raspberrypi_capture/, 2014.

[12] ImageMagick Studio LLC, "ImageMagick Command Line Tools", http://www.imagemagick.org, retrieved on 10/20/2014 (use ***convert*** in python script).

[13] Fredrik Lundh, Alex Clark, and Contributors, "Pillow: Python Imaging Library (Fork) 2.8.1 for PI", https://pypi.python.org/pypi/Pillow/2.8.1, retrieved on 10/20/2014.

[14] Mencoder and mplayer official website and news: https://www.mplayerhq.hu/design7/news.html, retrieved on 10/20/1014.