Monitoring 3D Printer Performance using Internet of Things (IoT) Application

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Abstract

Most of the current desktop 3D printers are built based on open-source designs from online communities. The largest group of open-source 3D printers is the Self-Replicating Rapid Prototype (RepRap) 3D printers. A RepRap 3D printer needs to connect to a computer or a microprocessor to feed G Code and provide interface for users to control the 3D printer. However, local computer is a relatively expensive solution comparing to the cost of a RepRap 3D printer; while the microprocessor has much less computing capability comparing to a normal computer, and cannot handle computing-intensive jobs like slicing 3D objects or generating G Code.

An alternate solution is to use the internet of things (IoT) application to control and monitor 3D printers. IoT is the network of physical devices, vehicles, buildings and other items, allowing objects to be sensed and controlled remotely across existing network. IoT and 3D printing are two important new technologies, which progressively impact a lot of areas of the industries and also our everyday life. Students need to be introduced to these technologies, and get ready for future career opportunities.

A multidisciplinary student project is developed to provide students access to both 3D printer and IoT platform, and also learn to collaborate with engineers from other disciplines to solve complex engineering problems. The objective of the project is to design and develop an IoT application to remote monitor the performance of a RepRap 3D printer including the printing progress and the temperatures of the heated bed and hot end. Major tasks involved in the project are: to inspect and upgrade the current 3D printer to avoid any possible compliance issues between the 3D printer and the hardware components or software tools for the IoT application; to connect the 3D printer to the Raspberry Pi microprocessor; and to design and develop the IoT application.

The methods and algorithms of connecting a 3D printer to an IoT application is reported, and the IoT application interface and workflow will be presented in the results section. As a pilot study, this project provides first-hand data on the requirements of time and resources to introduce IoT to undergraduate students.

Introduction

The internet of things (IoT) and 3D printing are two new technologies, which progressively impact a lot of areas of the industries and also our everyday life.

IoT is the network of physical devices, vehicles, buildings and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data [1]. The IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and

economic benefit. Experts estimate that the IoT will consist of almost 50 billion objects by 2020 [2]. It is no doubt one of the "big things" in current technology world.

Another important new technology that draws a lot of attention from both industry and academia is 3D printing. Most of the current desktop 3D printers are built based on open-source designs from online communities. The largest group of open-source 3D printers is the Self-Replicating Rapid Prototype (RepRap) 3D printers [3]. A RepRap 3D printer needs to connect to a computer or a microprocessor (for example, raspberry Pi) to feed G Code and provide interface for user to control the 3D printer. However, the local computer is a relatively expensive solution comparing to the cost of the 3D printer; while the microprocessor has much less computing capability which cannot handle compute-intensive jobs like slicing 3D objects or generating G Code.

An alternate solution is to use the internet of things (IoT) application to control and monitor 3D printers. A multidisciplinary student project is developed based on the idea to provide students access to both 3D printer and IoT platform, and also learn to collaborate with engineers from other disciplines to solve complex engineering problems.

The overall objective of this project is to design and develop an IoT application to remote monitor the performance of a 3D printer including the printing progress and the temperatures of the heated bed and hot end.

Study Design

The 3D printer used in this project was design and fabricated by another team including 3 groups of students (2 Mechanical Engineering Technology groups and 1 Electrical Engineering Technology group, total number of 8 students) in 2015. This 3D printer was designed based on the RepRap Wallace printer.

The IoT platform used in this project is the PTC ThingWorx Technology Platform. It contains a complete set of integrated IoT-specific tools and capabilities that can support the development of the IoT application.

The layout for the 3D printer and the IoT remote monitoring application was shown in Figure 1.
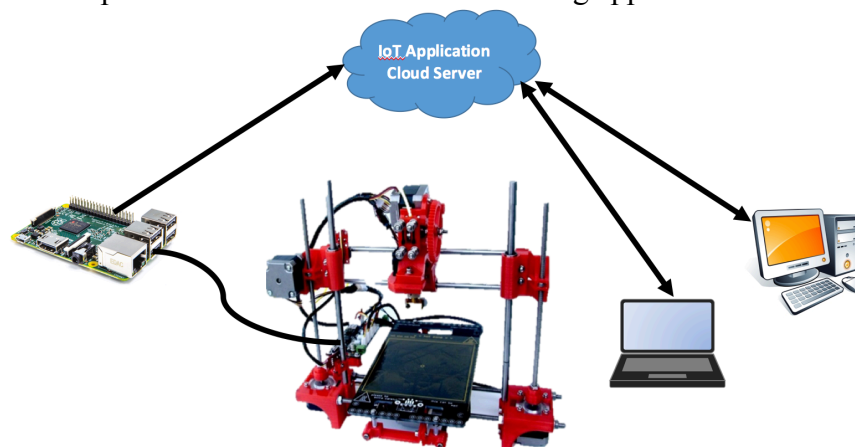

Figure 1 3D Printer with IoT Remote Monitoring Application Layout

There are four major research tasks involved in the project. Task 1 is to upgrade the current 3D printer; Task 2 is to connect the 3D printer to the Raspberry Pi 3 microprocessor; Task 3 is to design and develop the IoT application with ThingWorx composer; and Task 4 is to test the entire 3D printer system.

Task 1: 3D printer refining and upgrading

The following upgrades are completed to make sure the 3D printer can be connected to the IoT platform, and also to improve the robustness of the 3D print.
- Replace both the Arduino Mega and RAMPS 1.4 board with an Arduino RAMBO 1.2G;
- Replace the old thermistors in the heated bed and hot end;
- Replace the cold end assembly;
- Adjust the 3D printer housing in order to add new components (Webcam and LCD monitor)

Task 2: Connect the 3D printer to Raspberry Pi 3B

The 3D printer is connected to a Raspberry Pi 3B microprocessor through an Arduino RAMBO 1.2G board. Raspberry Pi is a credit card-sized single-board computer which can provide basic computing functionalities. It can be used to interact with different hardware (i.e. drive a motor) and software (i.e. web applications). Raspberry Pi 3B is used in this project due to its better connectivity. It has Wi-Fi and Bluetooth embedded. The operating system is Raspbian Jessie.

Task 3: Design and develop the IoT application

The IoT application is developed using Thingworx Composer 7. The Composer is an integrated development environment (IDE) for the creation of ThingWorx applications. Both the data modeling and user interface development aspects of application development are performed using the Composer.

Task 4: System Testing

A detailed Test Plan will be prepared before system testing to make sure that the whole system (including the 3D printer and the IoT application) satisfies all requirements.

The project was planned for 9 months. Figure 2 shows the timeline for the project. Currently the project is in Month 6. The major parts of the IoT application has already developed (as shown in the **Results** section) and tested. Currently, the team is working on refining the application and preparing testing plans.
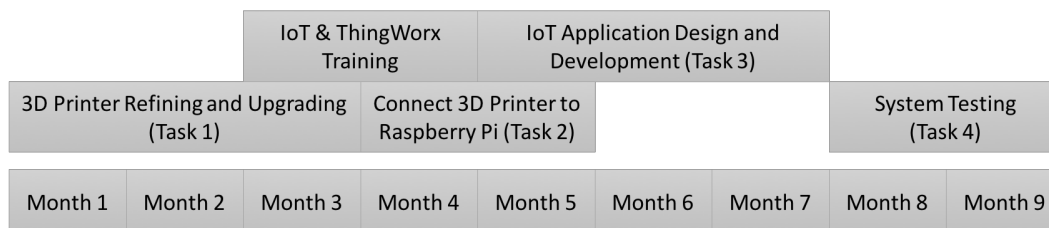
			IoT & ThingWorx Training		IoT Application Design and Development (Task 3)				
3D Printer Refining and Upgrading (Task 1)			Connect 3D Printer to Raspberry Pi (Task 2)					System Testing (Task 4)	
Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9

Figure 2 Project Timeline

Student Assignments and Training

There are four students from four different majors working on the project, and they were assigned into two groups (Group 1 and 2) with two students in each group. Group 1 focuses on upgrading the 3D printer (Task 1); and Group 2 dedicates to connect 3D printer to the Raspberry Pi and design and develop the ThingWorx IoT application (Task 2 and 3). The two groups work together to test the refined 3D printer and the IoT application (Task 4). Even though the students were assigned into two groups, it was expected that all students and mentors worked collaboratively in order to achieve the overall goal of the project. Table 1 shows the students' years, majors, and assigned groups.

Table 1 Team Members

Student	Year	Major	Group
1	Sophomore	Mechanical Engineering Technology	1
2	Senior	Mechanical Engineering	1
3	Junior	Computer Engineering	2
4	Junior	Electrical Engineering	2

Students in both groups took basic trainings on IoT and ThingWorx platform, including the three PTC IoT series course [4], and an online training course on application development with ThingWorx Composer. These trainings help the students to understand fundamental ideas of IoT and its potential impacts on business, technology and everyday life. Students in Group 2 went through more advanced trainings to be well prepared for the application design and development tasks. These trainings were delivered through a project to develop a predictive weather application with ThingWorx and Raspberry Pi [5,6].

Results

The system block diagram was shown in Figure 3. The center of the system is the Raspberry Pi 3B with Raspbian Jessie. It is the host of OctoPrint which is used to control the 3D printer and collect temperatures of the heated bed and hot end, and the Thingworx client which is for the IoT application. The 3D printer board (RAMBo 1.2G), the Webcam (Logitech C170), and the LCD monitor (Adafruit TFT Display) are also connected to the microprocessor.
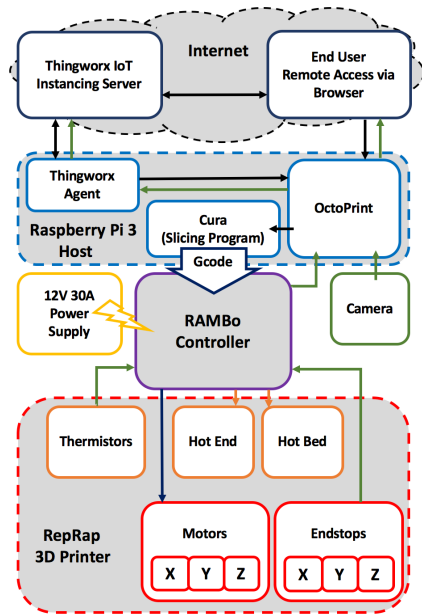
Figure 3 System Block Diagram

The IoT application interface is shown in Figure 4. There are three tabs on the interface: Monitor, Tasks, and Video. The Monitor tab covers the major monitoring capabilities. It is divided into three sections (Figure 4). The left section shows the printer status including busy, offline, available or error. There are also two buttons which are used to pause/resume and abort the monitoring process. The middle section displays the printing progress in percentage and the detailed status of the current task. It also has a video box that can show the live video recorded at the printer. The right section provides the temperature information. The gauge color can change when the temperatures exceed their limits.
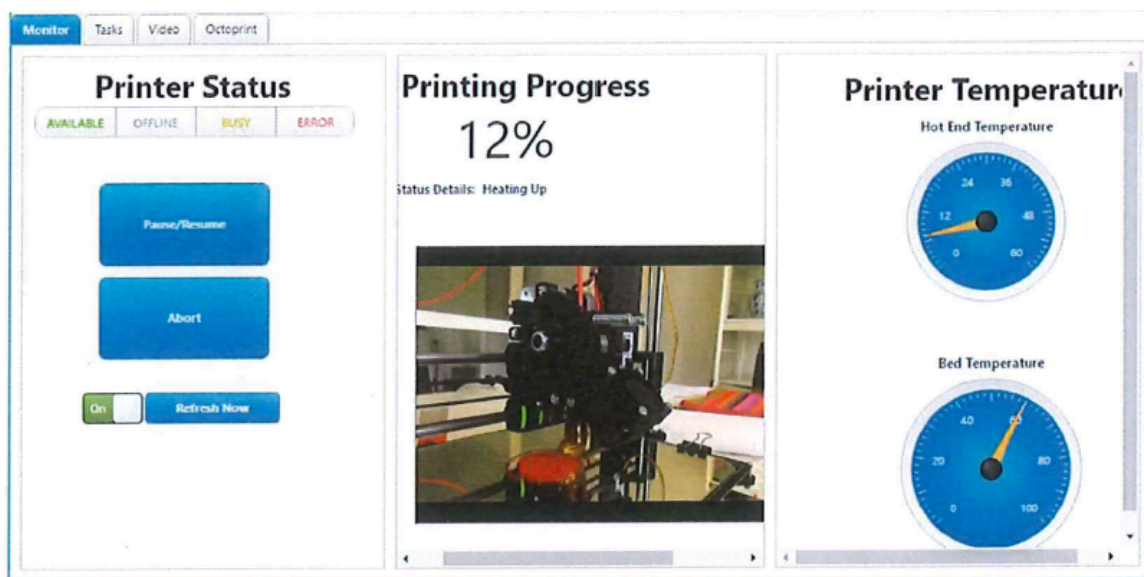

Figure 4 IoT Application Interface (Monitor Tab)

The Task tab is used to control the monitoring tasks. It is divided into two sections (Figure 5a). The left section is a group of buttons for New Task, History, Instructions, Schedule Task, and Printer Info. The New Task button leads to another screen which is designed to start a new monitoring task (Figure 5b).
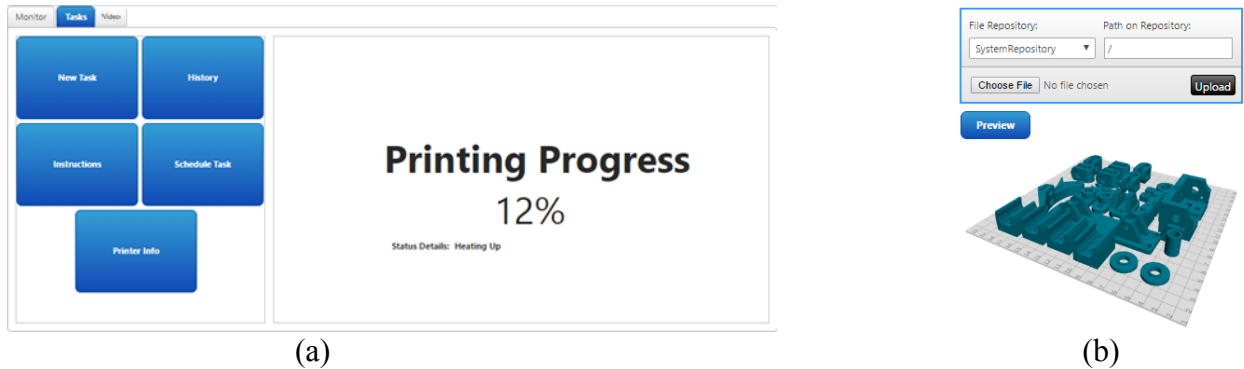

(a)

(b)

Figure 5 IoT Application Interface (Task Tab)

Discussions

This is a multidisciplinary project involving undergraduate students from different engineering backgrounds. Students learn to collaborate with engineers from other disciplines to solve complex multidisciplinary problems. They practice not only their technical knowledge and skills but also improve their communication and project management capability that may be even more important for their future career. The project started with reading the 3D printer documents prepared by the previous team. This task made the whole team aware and better understand the importance of good engineering documentation. They are working on a document that is informative and also easy to read as part of their final deliverables now.

Another benefit for the students is that they have a great opportunity to experience two "big things" (IoT and 3D printing) in current technology world. However, the current project only uses the IoT application to monitor the 3D printer. A future projects focusing on an application that can be used to remote control the 3D printer is under development. Other potential projects include adding supports to mobile devices for the IoT application and remote control multiple 3D printers. These projects will involve more undergraduate students to research projects.

Conclusions

This is an undergoing project, so more data will be collected to support a strong claim of conclusions. However, current results have already clearly show that

1. It is possible to use an IoT application to remote monitor the performance of a RepRap 3D printer.
2. A group of undergraduate students with different academic backgrounds are able to work collaboratively to solve a multidisciplinary engineering problem with proper trainings and supports from mentors.

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