Internet of Things based architecture for additive manufacturing interface

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Abstract: The traditional process of selecting 3D printers and monitoring printing statuses manually has presented a big flaw in the additive manufacturing system as it requires physical interaction between the machines and humans. In this paper, a solution to zero physical interaction to additive manufacturing units is proposed. The objective is achieved by using the saturated IoT technologies. Webserver will be used to create a webpage to upload the file, approval, and check the printing status. A server will be used to store the files, slicing software, files queuing system and to store temporary information of the manufacturing units' status. Cameras on multiple 3D printers will be used as sensors to monitor the project progress visually. The proposed system is implemented and verified in the Additive Manufacturing Laboratory at Taylor's University Malaysia.

Keywords: additive manufacturing units; 3D printing; online printing; printer managements; cloud printing; printing networking; IoT printer; printing monitoring; heat monitor.

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Xudong Chen received the BEng in Mechanical Engineering and MEng in Electrical Engineering from the National University of Singapore, Singapore in 2015 and 2018 respectively. He is currently working toward a master's degree in Computer Vision at Carnegie Mellon University. He has been working on the research and development of IoT systems in drones and autonomous vehicles. His research interests include autonomous system localisation and navigation, computer vision and deep learning.

1 Introduction

Additive manufacturing unit or commonly called 3D printer was innovated way back at 1986 by Charles Hull (Matias and Rao, 2015). Since then, a lot of improvements have been made to its original product and it has become a feature to differentiate each and every 3D printer available on market nowadays (Dimitrov et al., 2006; Kruth et al., 1998). Also, it has proven to be the most disruptive technology in this current 21st century by multiple sources (Mohr and Khan, 2015; Jackson, 2014; Karlgraad, 2015; Lipson and Kurman, 2013; Ratto and Ree, 2012; Yang et al., 2019; Fidan et al., 2019).

This paper is to discuss the next feature that can be integrated to any available 3D printer which can elevate the system to a whole new level which is to make it available to manufacture and monitor it online. The aim of this product is to minimise 3D printer dependency on human assistance, which currently is critical in most additive manufacturing units in the market. The Additive Manufacturing Lab in Taylor's University Malaysia is selected as a case study with high volume 3D printing jobs. The 3D printing jobs require constant monitoring to ensure expected printing result. As shown in the flowchart in Figure 1, the user's (in this case, the students) journey to print his/her work is troublesome and highly depends on their successful finding the authorised person in order to move into the next stage or procedure of the printing process. Figure 2 shows an example of failed 34 hours' worth of 3D printing process as the printing job is not monitored closely

To address this specific shortcoming, an idea has come as a solution. By taking the advantage of millennium age, there is saturation of IoT technologies available to solve these challenges.

The monitoring part for the proposed project is depends on the old technology, CCTV and taking it to the next level, IP Camera. CCTV enables user to monitor their surrounding from a screen monitor while IP Camera enables user to monitor it world-wide, providing there is an internet connection. Also, this technology was used widely across the world and plays an important role in a smart home system. Whether it is used to monitor the pet at home, the security or even the backyard of the home, this technology clearly been helpful for people to carry their daily life. Hence, it is being used in this system proposed.

Most of the additive manufacturing units nowadays come with temperature sensor to measure the temperature of the extruder and the bed. The temperature details can be obtained and shown to the user on any device alongside with physical progress video obtained from USB camera. Taking the advantage of this ready technology, a cloud based or IoT solution was introduced to manage the system. With the high demand for 3D printers around the globe, such as those shown by Gonzalez and Bennett (2014), and Nowlan (2015), this research is clearly paramount. In our proposed system, the overall topology of the system created can be seen as shown in Figure 3.

Figure 1 The current standard of procedure for 3D printing in Taylor's University

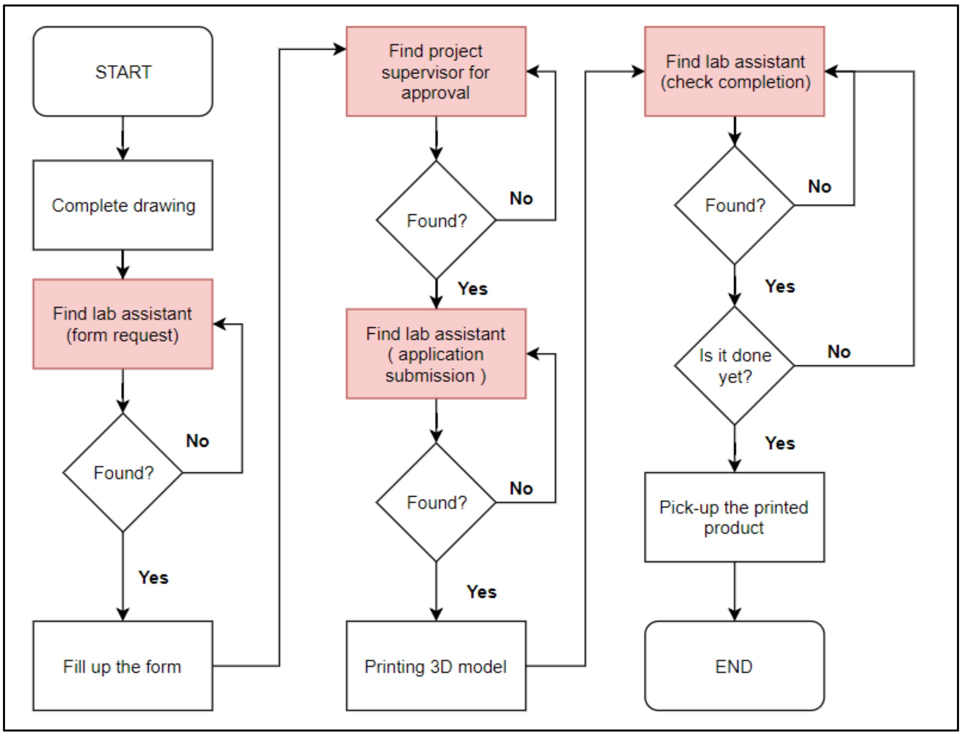


Figure 2 Failed printing process due to absent of monitoring system

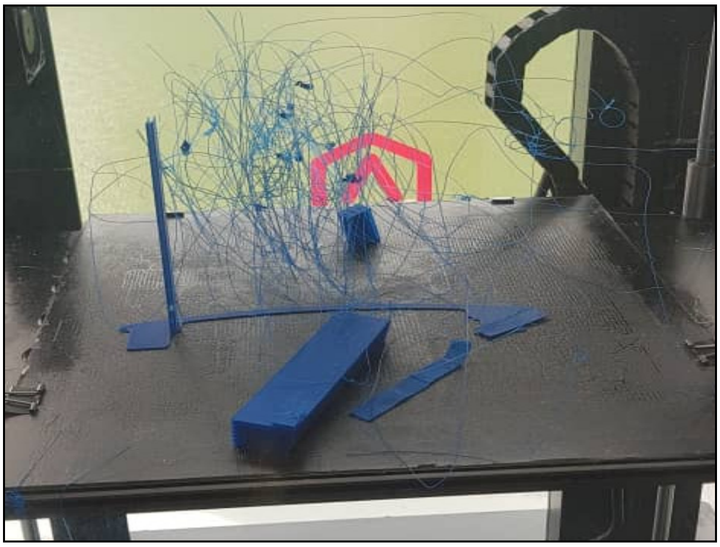
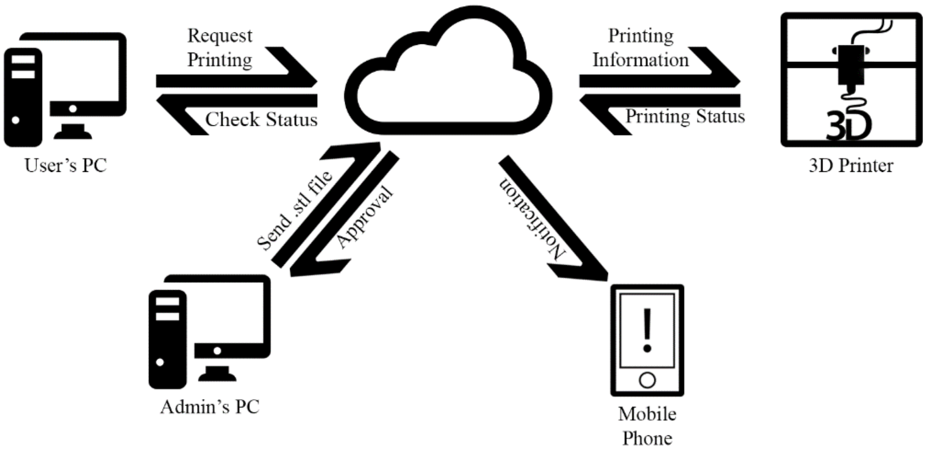


Figure 3 Topology of the IoT 3D printing system



2 Related work

2.1 Mobile app development

A new framework to develop the mobile application called PhoneGap was used by both researchers and professionals. This is because it is easier, time saving and cost-effective to develop a mobile application compared to native applications. The validation, reliability and usage of this framework were done by several researchers.

In a research paper studied by Babu et al. (2012) it has been concluded that developing a mobile application using PhoneGap framework shows its portability and versatility to cater for high volume users cross-platform. On the same case, a study case by Heitkötter et al. (2012) has found that PhoneGap is viable with a minor different to a native look and feel. Also, Kontio (2015) has developed a cross-platform mobile application using PhoneGap framework in the author's thesis. The result is that the application can run smoothly on Android, iOS and Windows mobile phones as specified in the requirement.

2.2 IoT applications

Li et al. (2011) have introduced IoT applications which refer to a paradigmatic class of cyber-physical systems with various electronics. They also define the smart community architecture which has high social impact. The authors also present Neighbour Watch and Pervasive Healthcare application which envision a few value-added smart community services.

Stojkoska and Trivodaliev (2016) include a lot of literature reviews of state-of-the-art IoT applications for home and smart grid. The authors come out with a base model of the smart home framework. Also, the current and future challenges of the IoT based solution were discussed thoroughly. Gomes et al. (2018) have also proposed an infrastructure model for smart cities based on IoT big data. In a patented work by Kitada et al. (2004), authors have shown and proved how to manage and provide an optimum system to distribute the printing job task among multiple printer. This can be done as the algorithm set in the printer server automatically calculates the time required job status, technology viability of the printer, and status of the printer. By optimising the printing management network, the research has shown and proved it could solve printing issues such as backlog of print jobs in the queue. As the number of data increases, a management system for resource handling is needed. Kaushik and Vidyarthi (2015) have derived a model for resource management specifically for real-time job using game theory.

Kageyama (2008) has proposed that one dedicated computer should handle the print job queue and process the control for the plurality of printers on a network. The computer also detects any malfunction for the printer units, orders replacement part, and updates the data and programs used by the printer. The system also has notification feature to instruct the user upon failure or completion status.

Also, Ishikake (2006) has created an algorithm called switching unit. It processes the printing request and selects the best and most suitable printer from among the plurality of the printers as user's requirement to carry the job. Also, it stores the history information of each one of the printers available on the network.

For live telecasting, Ito et al. (2018) has proposed a real-time webcast system that was intended to be used in the school classroom setups. It can also be utilised for live video streaming of 3D printers for monitoring purposes.

2.3 Summary

Overall, it has found that the cutting-edge technology, PhoneGap framework has proven to be reliable on numerous study cases and research. However, implementing it with online monitoring and printer management software is still lacking and requires study.

This short literature review has shown one major flaw. The network system used in printer management research is mainly LAN. As its name states, only computers connected locally to the printing network able to queue and monitor the printing status. Hence, the room for improvement for the available system is to put the network itself on a cloud-based technology. This enables users to work, request and manage multiple 3D printers or additive manufacturing units from a click of a button in any part of the world. The security issues can be solved by using a login database that is associated with Taylor's University database. On top of that, there is not much research improving or addressing the management issues for additive manufacturing units.

3 System development

The work done for this project heavily depends on software programming to minimise the usage of hardware integrated to the system. The programming languages used are HTML, JavaScript, Java, RESTful API, networking and PhoneGap app development. Meanwhile, the only hardware required are USB Camera and Raspberry Pi 3, and the temperature sensor for temperature monitoring (Liu et al., 2020).

However, in order to connect two or more printers, copies of OctoPrint system are required to be installed in the Raspberry Pi. Once it is done, a local port of each printer and USB camera are assigned to its respective USB connection port.

3.1 Raspberry server

Raspberry Pi 3 is a mini computer hardware that will be used as a server. With its limited power, a good server can be obtained with a little restrain on number of 3D printer and USB cameras connected, video streaming size and file transfer capacity.

OctoPi is an operation system that are based on Raspbian system. It contains Octoprint software (to manage the printer), mjpeg-streamer module (to stream video) and CuraEngine (to process and stream g-code to the 3D printers). By simply installing it, three most important features can be done.

However, the OS is only as good as its features yet configuration of each one of them will make the system as a whole.

3.2 Temperature sensor

A temperature sensor is essential in the system for a stable working environment. Real-time monitoring of the temperature of the 3D printer is to be developed and published on the server. A built in sensor, PT100 is used in the system for this purpose. A PT100 is a type of sensor which fall into the sensor group of Resistance Temperature Detectors (RTD). It is a platinum based temperature sensor that has the resistance of 100 Ohm at 0 degree Celsius. It is one of the most commonly used sensors in 3D printers and thus it fits well in our system.

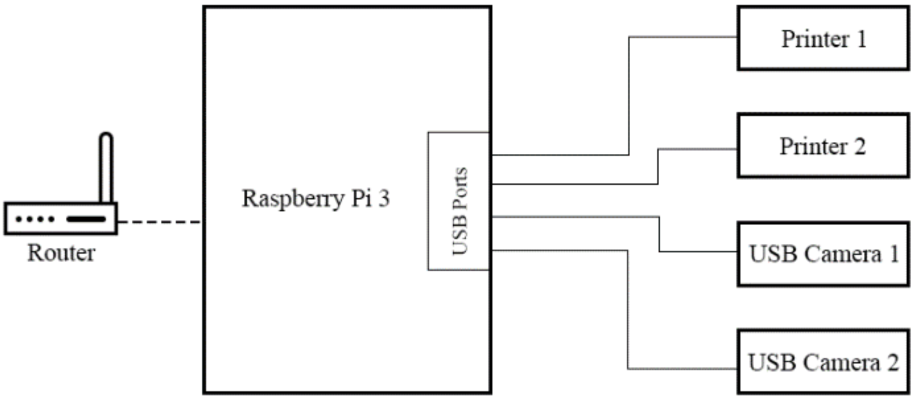
3.3 Network

Network for this system can be categorised into two parts, local area network and wide area network. Local area network can be simplified as the connection between the printer and the server itself. Meanwhile the wide area network enables the server to be accessed by devices from networks outside. The initial connection between the Raspberry Pi, 3D Printers and USB camera is as shown in Figure 4. In order to make Raspberry Pi as a local server, it first must be connected to the local router.

3.3.1 Local area network (LAN)

The connection of multiple printers to Raspberry Pi and being managed by OctoPrint can be challenging as OctoPrint software can only support one printer at a time. To solve this issue, copies of the software were made into the Raspberry Pi. Linux system is then commanded to create multiple OctoPrint. This step enables printers one and two to be accessed by the OctoPrint software at local port 5001 and 5002, respectively. Same case applicable to the USB camera where the local port of each printer is set to 8081 and 8082.

Figure 4 Raspberry Pi three connections in the network of two printers (possible extension to more printers)



Then, each printer profile is connected to the local port number by matching the USB pathway. The corresponding USB pathway can be obtained by plug it in one by one and notice the changes happened by listening to log events. The overall LAN connection is as shown in Figure 5.

3.3.2 Wide area network (WAN)

To enable access of the server for the outside network, i.e. from devices using mobile data internet access, a few changes needed to be made in the configuration file.

First, the WAN address for the router needs to be determined. WAN address acts as an address for the internet to find the router so that it can pass the server information further.

Then, for security issue, a basic authentication and port list for both printers and USB camera need to be programmed in the configuration file. The overall WAN connection can be seen in Figure 6.

Finally, to make it accessible to the internet, port forwarding technique is required. At this step, the router will able to forward the necessary access from the server to the internet. The configuration for this step depends on the router make and model.

3.4 Web service

Another safety precaution for this server is to forward only the necessary info and control to authorised user. It can be done by limiting the feature of OctoPrint and show it on a single webpage. To achieve it, a web hosting is required to host the necessary files as shown in the next section.

Figure 5 LAN structure setup

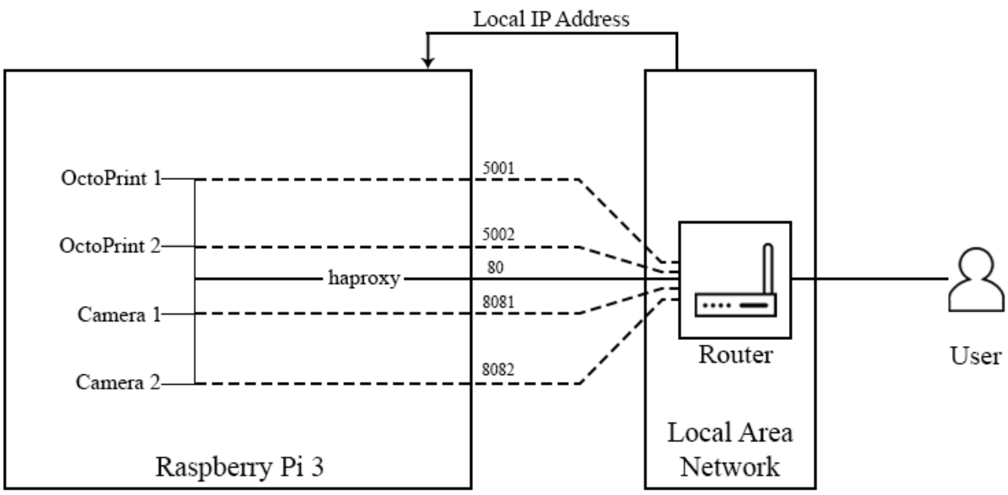
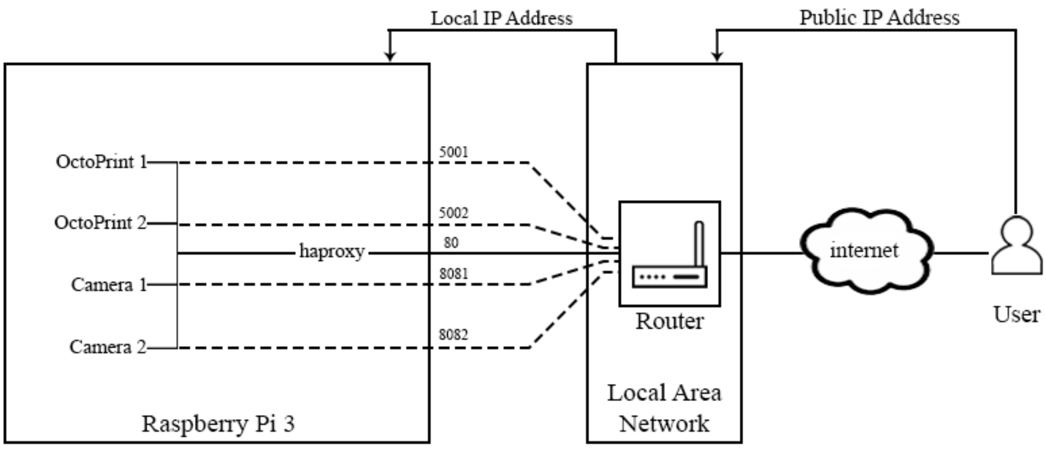


Figure 6 WAN structure setup



3.4.1 *HTML, JavaScript, and CSS*

HTML acts as the skeleton of a webpage. It structures the basic of the webpage and the contents of it. For this system, HTML5 was used as it offers more flexibility in programming and supported by all major web browser. Meanwhile, JavaScript acts as the page transition. For example, to carry out specific function when it is called by the HTML codes. Last but not least, CSS acts as the skin and define the aesthetic of the webpage. For example, the font size, layout sizes and images correspondent to each div group.

3.4.2 *API*

Application programming interface (API) is a subroutine that allows one machine to communicate with the other machine. In this case, it allows the 3D printer to interact with the web service. By using the API, users are able to obtain various information wirelessly from the 3D printer. At the same time, it allows the user to control the 3D printer from distance. For example, the user is able to know the temperatures, job status and also to stop the printing process in case of failure or emergency.

To be able to do this, a XHTML function was written in the JavaScript file. As for authorisation, each printer is equipped with its own unique API-key. It can be obtained from the OctoPrint setting.

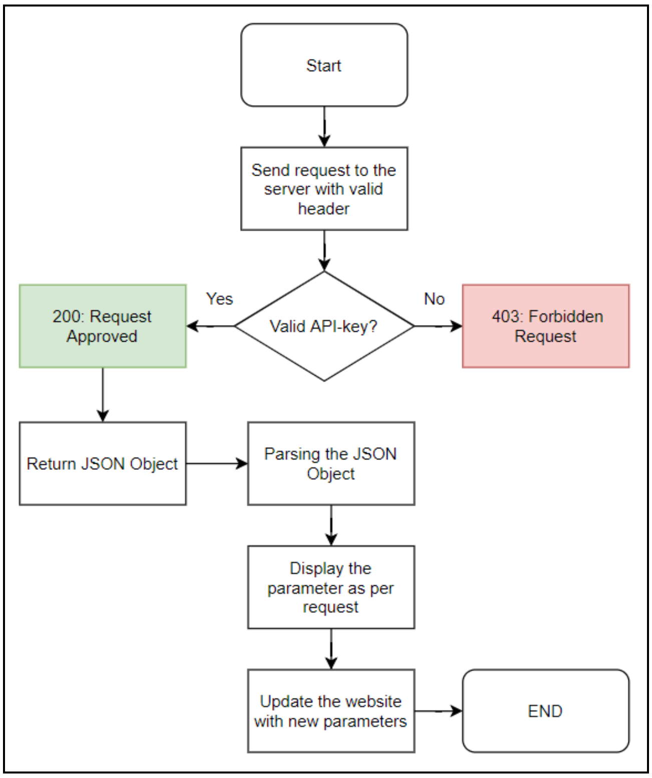
The XHTML function will send a request to the server to retrieve asked data. Then the server will send the data in JSON package. Inside the function, it will parse the JSON data into an object which contains keys and data. At the end of the process, only the suitable data will be filtered down and passed down as value assign to its variable. The flow of the API request can be visualised in Figure 7.

3.5 *Mobile application*

The mobile application was developed by using Monaca. This platform enables users to create a mobile application that is suitable to use on both Android and iOS mobile phone by using a single development environment.

It does support multiple frameworks that work well with each other. However, the same codes used for web service will be used for the mobile application with a different style of layout in order to minimise the usage of RAM and thus increase the loading speed. The programming files were written in HTML, JavaScript and CSS.

Figure 7 RESTful API request flowchart



4 Results and discussion

The results of each component described in the previous sections sum up the result of the total system of IoT based architecture for the 3D printer interface. Each subsystem is seamlessly integrated into the system and thus provides a better manufacturing experience and it can be done from anywhere with internet-connected devices.

4.1 Backend system

The backend system was created to cater the needs for the technical personnel, e.g., the lab technician. The layout and interface of the system while it is idling can be seen in Figure 8. From there, the technician can see the 3D printer's status; whether it is operational, printing or even disconnected away from the system. Also, the technician can drag-and-drop supported 3D files such as *.stl or *.gco to print it. It eliminates the troublesome work needed to transfer the file into flash drives and plug it into the 3D printer.

Other than that, the technician can monitor physically the progress via the video feed and get the temperatures of both the extruder and the bed on the Temperature tab. With it, the fail printing due to lack of monitoring can be reduced substantially. Last but not least, printing information such as printing time, time left and the file name can be monitored.

4.2 Front system (main webpage)

Figure 9 shows the front end of the customised website. This is what the users will see when they are using the website. It shows limited information and limited control for two purposes.

First, it is aesthetically best to create a simple template so that the user's attention will not be disturbed by irrelevant data. By doing so, they are directed to focus on the temperatures and time, so they can react accordingly with the information given. This eliminates the guesswork about the printing's status thus saving time.

Second, in case of emergency, they can directly see the STOP button located at the bottom of the page as it is appealing, striking in bright red colour and scroll-less access by the user. Also, in the same page, the user can request printing of their project on the top right page under the "Request Printing" tab. Likewise, Figure 9 shows the website is currently handling a printing file named gear_x2.gco that was printed using the said system. It shows the reliability and validity of the system.

4.3 Mobile app

The mobile application developed by Monaca IDE can be seen in the Figure 10. It shows the USB camera screenshots as thumbnails where user can click to watch the live progress and obtain other information. The temperature, time left, operating time and file name can be seen on the screen as well indicating that the XHTML call function is working as expected. It does show the same exact information as the website shows. This indicates the PhoneGap framework is reliable.

Also, there is a Stop Printing button at the bottom end of the screen which give the user the ability to stop the whole printing process if there are any issues risen. The Job Finished button is only available to the technician. The main purpose of the button is to tell the machine that the project has been picked out from the printing bed and it acts as a queue for the additive manufacturing unit to start a new printing job if available.

The ability to create the mobile phone applications gives advantage to all three user categories: the administrator (technician), project supervisor and also the student (user). It enables them to check on the printing progress from anywhere at any locations. As it is accessible from anywhere, and login credentials were required in order to avoid any misused and harmful deeds done to the 3D printer.

Figure 8 The backend system UI designed to optimise monitoring for the lab technician

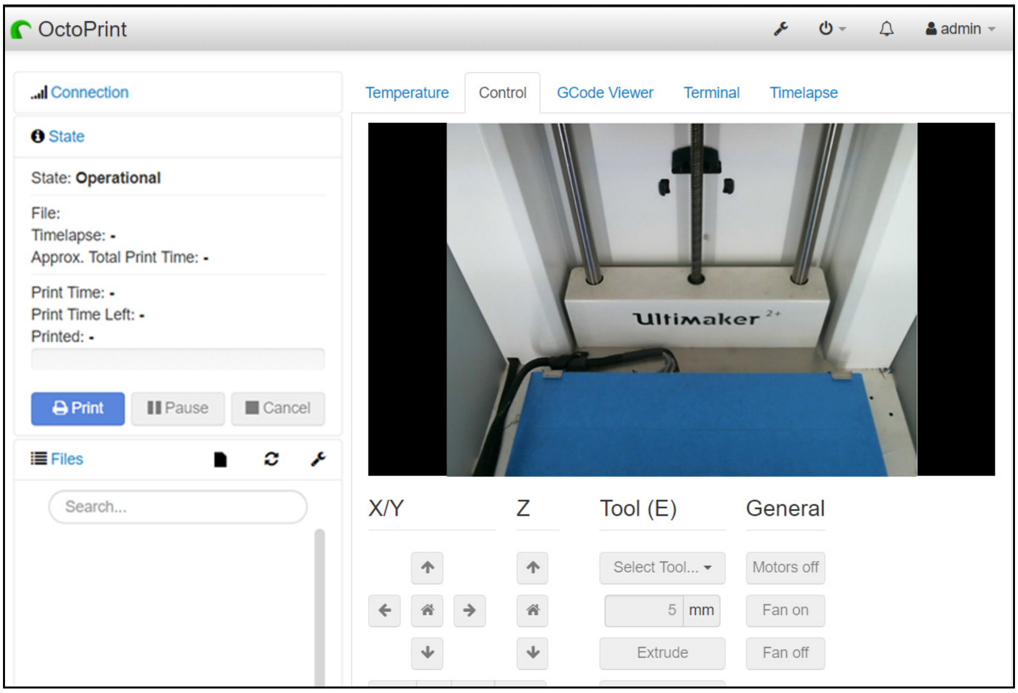


Figure 9 Frontend (webpage) system that can be access by authorised user

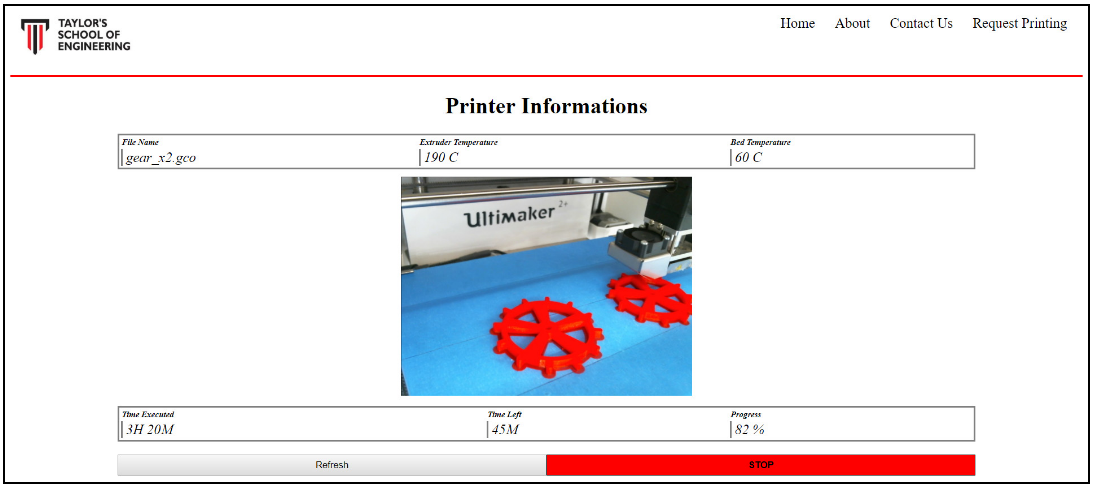
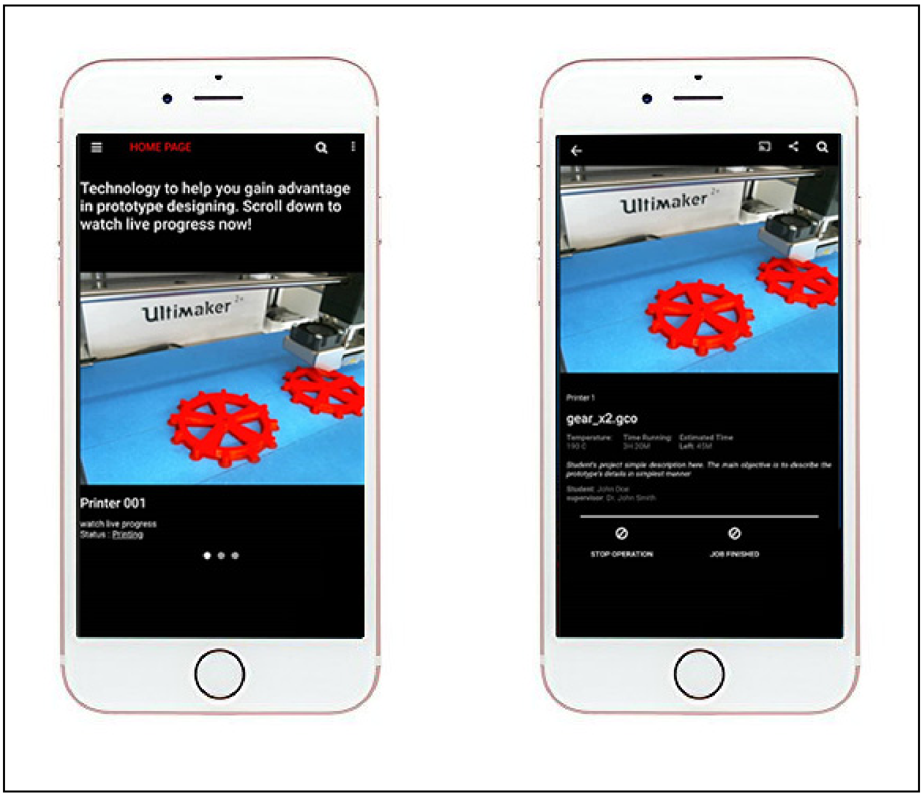


Figure 10 The UI of the mobile app developed using PhoneGap framework



5 Conclusions

In conclusion, the system can be engineered by implementing multiple technologies that are available nowadays. Users can monitor and control the additive manufacturing machine at their fingertips around the world.

It can be done by setting up the Raspberry Pi server, HTML codes for the webpage and JavaScript to control the website functionality. To optimise the camera monitoring, the video resolution can be lower down to 640 x 480 pixels which can lower down the bandwidth and graphic usage. It is not advisable to connect the printer using extension USB hub as it could disturb the gcode streaming which could lead towards defective product.

However, for further development, there should be robot arms that are able to take off the finished product from the printer's bed to other location. Doing this, it enables a total free human interaction while producing a 3D prototype product.

Last but not least, the security for the system should be improved further to avoid exploitation from other party as it can control temperature and extruder's motor. This could lead to arson and permanent damage towards the additive manufacturing machine.

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