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Implementing i4.0 Tech to Engineering Systems Lab for Smart Manufacturing Learning

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Abstract

Managing the manufacturing input such as designs, energy, and raw stock to sustainably operate machinery systems demands real-time data that can be used to control the process and can result in not only economic improvements but contribute to friendly environmental outcomes. The complexity of manufacturing systems and the need for interchangeability presents an ideal environment to implement smart manufacturing technologies with the goal of sustainability. Manufacturing engineering in an educational classroom is a good place to guide through and examine the shift to smart industrial systems using elements of industry 4.0 (i4.0), industrial internet of thing (IIoT), digital cloud, dashboards, data collection and processing along with integrated sensors. In this paper, the authors present a smart manufacturing engineering course developed and implemented. A summary of two offerings of this course is briefly described. It provided high engagement for students that has been observed through the learning process interactions. It also provided a platform to implement IIoT, digital cloud, and real-time data collection to help with the detection of unplanned events and behavior. The setup also provided tools for fast correction response and documentation.

1. Introduction

Sustainably managing input resources such as energy, material, and other supplies to operate friendly environmental production will result in not only economic improvements but also a slowdown and reduction in natural resource utilization [1]. Interoperations' complexity of a manufacturing system makes sustainable workplans are not easily applicable due to the difficulty of observing the moving data and information from operation to another, and changing operation paths depending on the product design and requirements. During the run state when the interoperation elements are integrated, it becomes highly complicated to use traditional approaches to observe conditions and sustainably respond [2]. Several sustainable procedures have been reviewed, analyzed, and technologically evolved to smart manufacturing level in terms of a real-time control systems can intelligently mange resource and take correction actions when needed. Educational manufacturing engineering is a typical place to guide through and examine these solutions with ability to shift to smart industrial systems using elements of industry 4.0 (i4.0). Industrial internet of thing (IIoT), digital cloud, dashboards, data collection and processing with integrated sensors. i4.0 is one of the main elements of connecting machines and devices into one network where data can be shared and collected remotely and processed in real-time [3] and [4]. The data exchanging can be used to improve and monitor processes, maximize efficiency, and implement machine learning, while also helping with early detection of falling quality and other degradations. Two important areas of i4.0 are IIoT and the cloud. IIoT refers to the connection of machines, devices, with sensors using a network and an IIoT gateway. IIoT gateways are physical devices that users are interested in integrating to implement monitoring and permitting to allow data from all devices to be shared in real-time. This data integration can be used for i4.0 purposes. The data is shared through the physical gateway and generally stored in the cloud. The cloud allows the data to be monitored by other users and machines in real-time and remotely. The data can be used to track various conditions of the machines, compute profits and losses, efficiencies, and many other important physical measurements of the process. If one of the measurements that is being monitored reaches a certain preset limit, the user can be notified through the use of rules and data/alarm subscriptions using MQTT and other similar tools. Any value that is being measured and shared with the cloud can have rules applied to it. There are a variety of rules that can be used such as static, dynamic, statistic, counts, or individual [5], [6], and [7]. Figure 1 illustrates input manufacturing resources and outcomes of typical production setup, and the place of manufacturing interoperations where the invisible layer of integrated elements needs to be monitored.

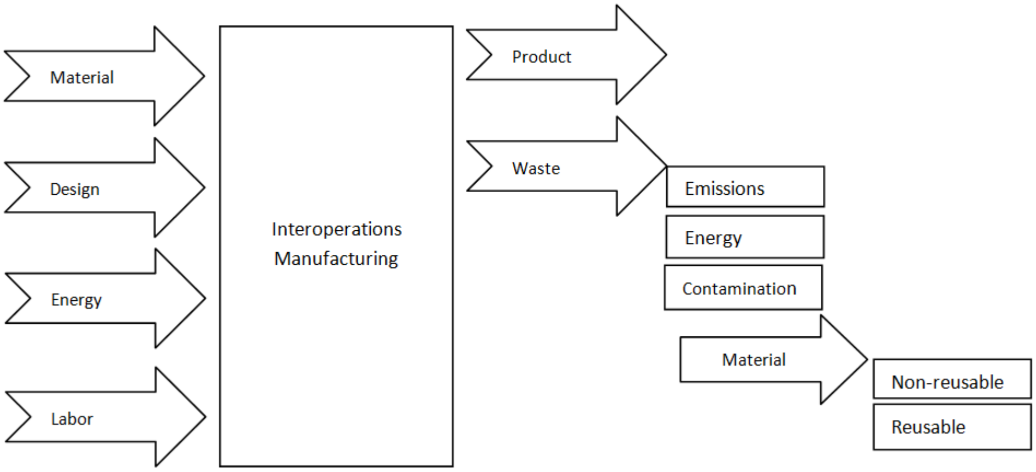

Figure 1: Input Resources and Outcomes of Production System

Since environmental changes and shortages of natural resources became alarming [8], the relationship between the complexity of interoperating elements and unsustainable manufacturing procedures needs to be analyzed and, engineering sustainability becomes highly needed to be involved in curriculum engineering courses [9]. Understanding the technologies and hands-on practice become critical for a successful career in manufacturing engineering. Therefore, education curriculum needs to be formed to prepare students to meet the challenges of advanced intelligent manufacturing industries [10]. In this paper, an innovative empirical methodology based on i4.0 technologies has been developed to be used to create sustainable procedures to the interoperations of manufacturing systems. Implementing IIoT and digital cloud to the curriculum to provide real-time detection of unplanned behavior, fast correction response, and system data documentation for the analysis will help in understanding manufacturing operations. The methodology is to build a fully connected field of processes in order to remotely and in real-time observe the production data exchange needed for the experimentation, analysis, and validation. This will enable in the selection of the most applicable procedures to be used in operating real-world manufacturing.

In addition to reducing the production cost, results are expected to be as follows: significantly reducing CO_2 and other environmental contaminations, high energy savings, decreasing raw material waste and avoiding labor power overlapping. It is also expected to reveal hands-on knowledge that future industries need. This paper has been organized as follows; section 2 included experiments methodology used to apply and examine the idea, section 3 is the result analysis, and section 4 closes the papers by drawing a set of conclusions.

Experimentation Methodology

Implementing i4.0 technologies to 3D printing process of Fused Deposition Modeling (FDM) is used in this paper to observe real-time monitoring and controlling in addition to the automation of the interoperational processes. The current 3D printing requires users to be on-site in order to upload and start the print, change the print file, and monitor the operations. Figure 2 shows the standard procedure to 3D print a SolidWorks design. The operation is also not a continuous cycle; when the part is finished, the door is required to be opened before the part is removed, then the door needs to be closed before starting a new print job. The project objectives was to monitor and control the 3D printer in real-time, and to fully automate the FDM process. To accomplish these objectives, the analysis considered performance factors to determine a baseline and a measurement to evaluate the improvements. OctoPrint (a software tool) was then used to remotely upload the part with the gcode that was previously exported.   The file was uploaded to OctoPrint, and it was then able to be printed directly to the 3D printer. OctoPrint allowed user to view the actual printing results that were previously observed using the standard 3D printing process. Figure 3 shows the 3D printing remotely using OctoPrint. The time the users take for interaction with various aspects of the process was collected and recorded. These included: how long it takes to open the door, how long it takes to remove the part, and how long it takes to close the door. (Note the door that is magnetically attached to the 3D printer is physically removed to open and provide access and is then put back to the printer for it to proceed to the next print job. For safety reasons the printer will only function when the door is closed).

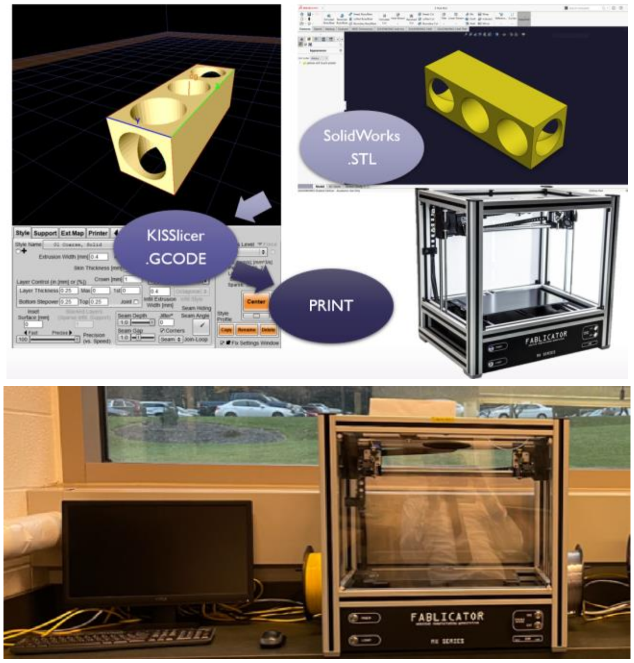

Figure 2: Manufacturing Procedure of 3D Printing Using FDM Process.

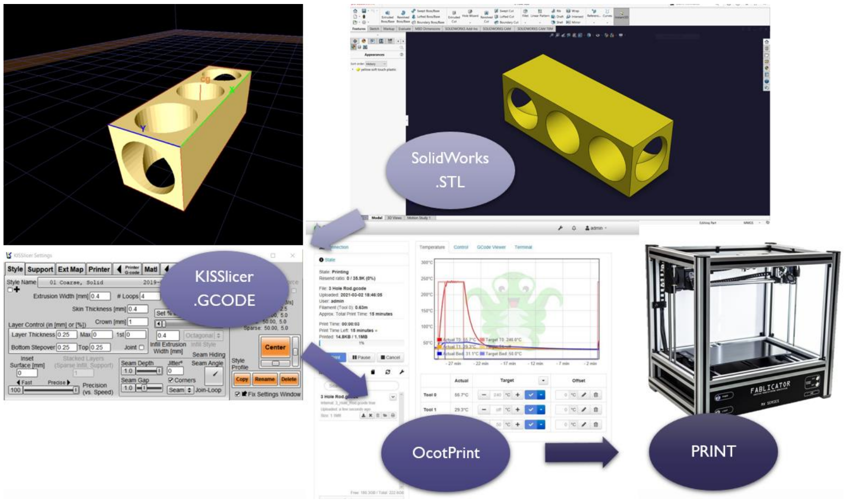

Figure 3: Remotely 3D Printing FDM process via OctoPrint.

The interoperation pattern to be analyzed to intelligently automate 3D printing process with i4.0 technology, is shown in Figure 4. The interoperational pattern shows the procedure that is needed to print the part and is independent of whether the part was printed directly from the FDM 3D printer (Fablicator interface window) or if OctoPrint was used. After the user starts the print, the bed and nozzle heat up to the temperature defined in the slicer based on the material being used. The print starts after the bed and nozzle are up to temperature. After the print completes, the bed and part needs to cool down. Once the part is cooled down, the door needs to be opened, and the part is ready to be removed. Once the part is removed, the door can be closed, and a new print can be started.

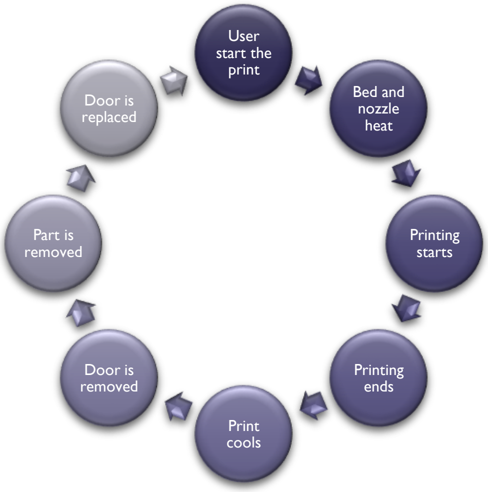

Figure 4: 3D Printing FDM interoperation Pattern.

There are a variety of rules that can be used to monitor and keep the FDM interoperation patten functioning. With data stored in the cloud, cloud based computation such as static, dynamic, statistic, counts, or individual can be carried out. When the measurement exceeds the boundary set by the rule, a notification email will be sent to the subscribed users of the rule. The email contains the details the users needs and these include subject, message, recipients, rule, and notification interval. These all can be configured when a subscription is created/edited. Selected control rule needs to be based on the collected data from the field. A multiple function sensor called Cross Domain Development Kit (XDK); Bosch's smart sensor, has been implemented as an external agent to gather the desired data and provide the control rules creation. XDK has an array of sensors that can be used, and has Wi-Fi and Bluetooth capabilities, a rechargeable battery, and microcontroller functionality (MCU) and includes programming ability. Physical variables that was collected for this paper include the acceleration to measure the door position (open/closed) and the printing noise to monitor the state of the 3D printer. SMi4.0 platform (shown in figure 5.) has been developed for interconnecting devices, an external agent to assist in monitoring the process on the cloud, and OctoPrint to connect and monitor the 3D printer. Figure 5 shows the users view of theSMi4.0 platform. The administrator view is different and has not been shown here as it is not relevant to the paper.

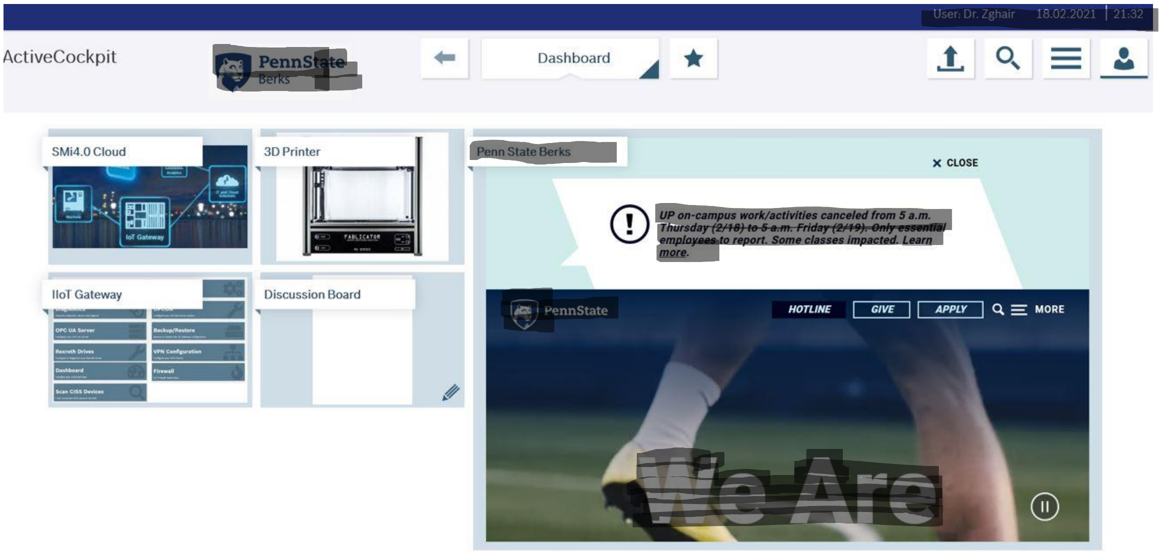

Figure 5: Smart Manufacturing for Industry 4.0 Platform (SMi4.0) (Blackened area to conceal identity for review purposes)

2. Results Analysis

The XDK is mounted to the door with the X-axis aligned to the motor of the 3D printer for collecting data. The results of acceleration measurements using the XDK showed that the Y-axis and Z-axis changed based on the orientation of the door when it was opened or closed. The data is shown in Figure 6, where the Y-axis data points are the purple dots, and the Z-axis data points are the grey dots.. The figure can be accessed from the SMI4.0 platform where the data was collected, processed, displayed in the dashboard and could help with monitoring. Data in figure 6 shows when the door is closed, the acceleration in the Y-axis increases and the acceleration in the Z-axis decreases. This is the opposite when the door is opened. The team was able to apply a rule to these values to notify the users when the door was opened and when the door was closed. Streamed data was used initially to determine threshold values for setting the rules on the digital cloud and dashboard.

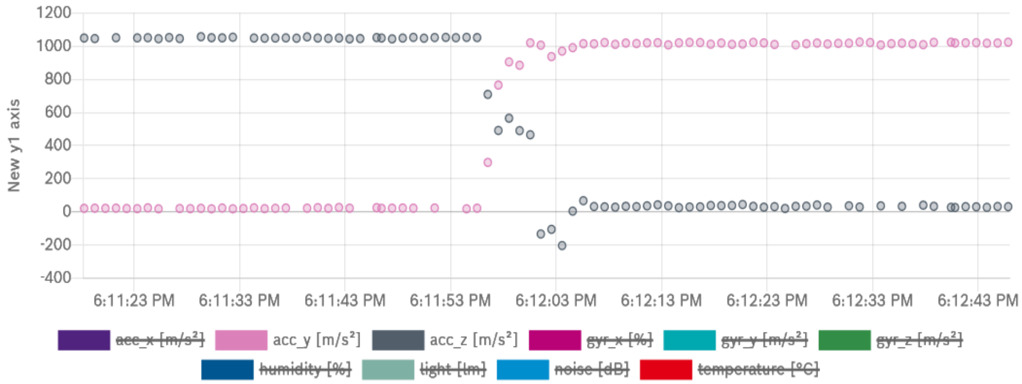

Figure 6: Y and Z axes data stream at the real time of processing

Table 1. and Table 2. shows the data for the two door states; opened and closed. A lower bound of 46m/s^2 was applied to the acceleration in the Z-axis to determine when the door was closed. When the value decreased below 46 m/s^2, the rule was triggered, and all subscribed users to the rule would be notified that the door was closed. Likewise, an upper bound of 50 m/s^2 was applied to the acceleration in the Y-axis to determine when the door was opened.

Table 1: XDK Acceleration Data for the Door Open State

Axis	**Coded Variable (m/s^2)**	**Min Value**	**Max Value**
X	acc_x	18	38
Y	acc_y	15	45
Z	acc_z	982	1011

Table 2: XDK Acceleration Data for the Door close State

Axis	**Coded Variable (m/s^2)**	**Min Value**	**Max Value**
X	acc_x	18	22
Y	acc_y	997	1029
Z	acc_z	14	42

The noise measurement via the XDK was observed to determine the state the 3D printer. There are three states the machine can be in: idle, printing, or print complete. The idle state means the printer is currently not running, the printing state means the printer is currently printing a part, and the complete state means the machine has finished printing a part. Figure 7 shows the printer in idle state and the data values range from 28 to 42 dB. Figure 8 shows the noise of the printer while printing and these values range from 16 to 52 dB. Several experiments have been tried to find a correlation between the noise and the state of the printer but were unsuccessful due to ambient noise in the room, which had an overall effect on the value. It was difficult to observe any patterns between the three states, even while mounting the XDK directly on the motors during the printing state. It is also noticed that the printer bed impacts the door when the printing is complete, which was thought to be measured from the noise value to indicate when the print was finished, however, there is no clear evidence of that event being measured. It was obviously determined that measured noise data has a low frequency and it was not observed by the XDX, therefore, it was ignored.

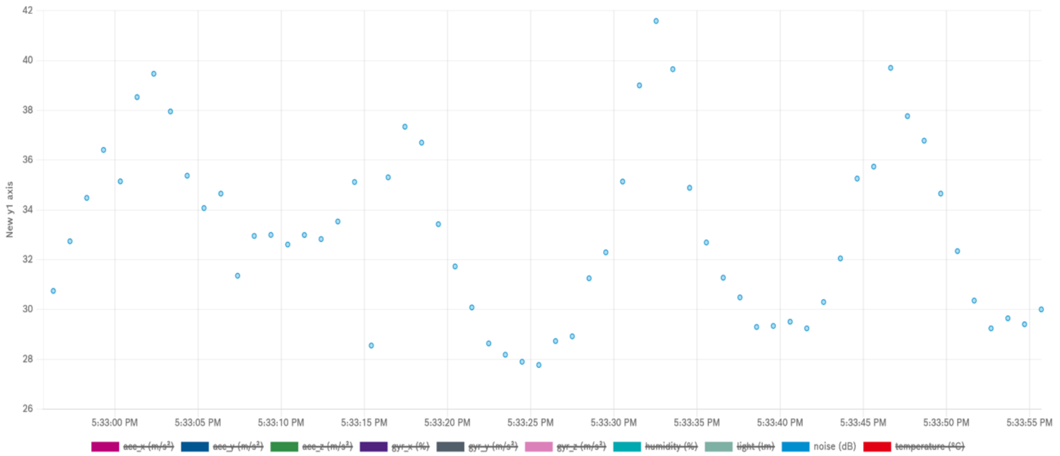

Figure 7: Streamed Noise Data in Idle State.

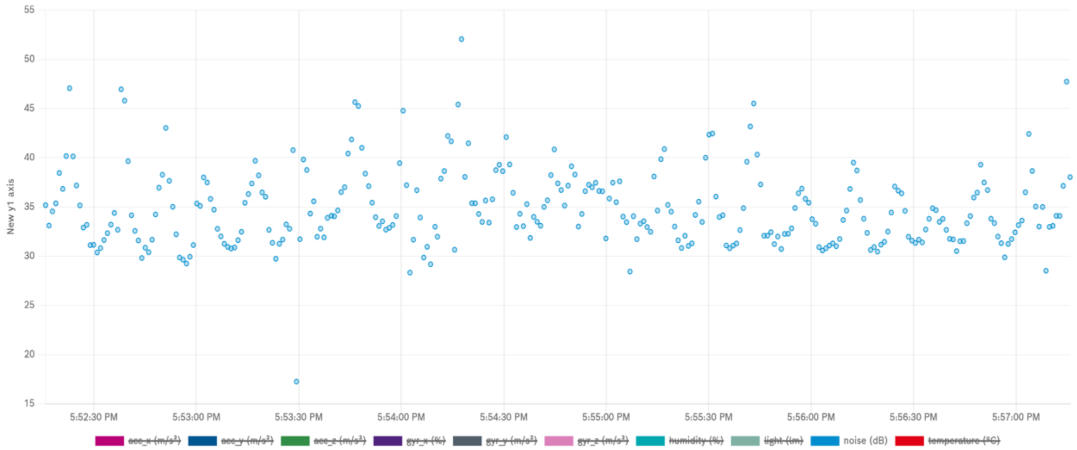

Figure 8: Streamed Noise Data in Printing State.

3. Conclusion

The i4.0 technology is a tool to improve the monitoring of manufacturing interoperation factors such as those that are seen in 3D printer process. Data measurements of the acceleration was used to monitor the position of the door remotely and in real-time. It also was possible to successfully send notifications to the users if the door position changed (opened/closed)in the real-time. Further smart improvements to the 3D printer could involve fully automating the FDM printing process to make it a continuous process. Ability was found to use two motors setup, one to control the door and another to control the part removal. As the motor rotates in one direction, the door would open, and rotation in the other direction would close the door. The door position can be monitored and controlled using the acceleration in the Y and Z axes, which is already determined to be a practical solution. The XDK can be used as an MCU to build a program that uses the internal sensors that control the two setups of motors. Figure 9 shows the smart continuation of the process that can be developed because of using i4.0 technology.

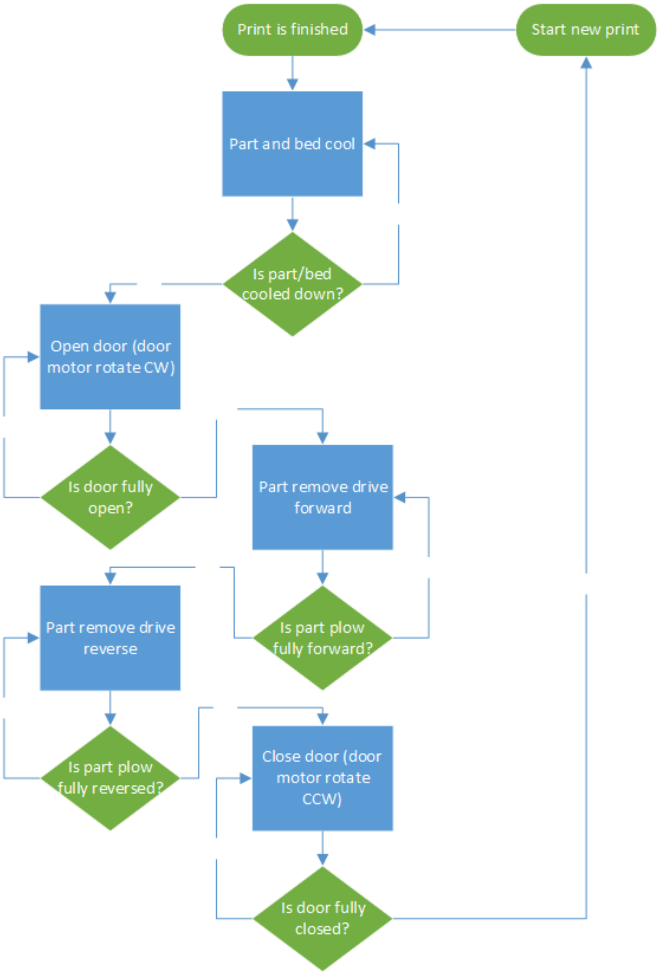

Figure 9: Remotely Real-time Automation Flowchart.

It is possible to isolate the printer in a more quitter room to avoid noise interference to be able to monitor the machine states, and search to find another parameter that correlates with the three states of the machine. Using a dedicated sensor to measure noise could be an alternate solution. Once the states can be determined, these can trigger the process of the door opening, the part being removed, and finally the door closing. Figure 10 shows a rendering of the idea to automate the part removal. The part removal device would be mounted on linear rails similar and parallel to the 12 mm linear rails and linear bearings that the bed is mounted on, and it will normally rest in the rear of the printer position during printing as shown in the figure. Once the door is detected to be fully open, the part remover will be belt driven forward. Then the bed will be fully forward once the print is finished, and this will make the process easier. As the part remover travels toward the open door, the part will be pushed off and out of the 3D printer enclosure. The counts of the motor's encoder will be measured and when the correct number of counts is reached, the part remover will be fully forward. At this point the part remover will move back to the home position. Once the remover is back home, the process is complete, and a new print can be started. This will be a significant development to a traditionally computerized manufacturing systems to be a fully automated smart manufacturing.

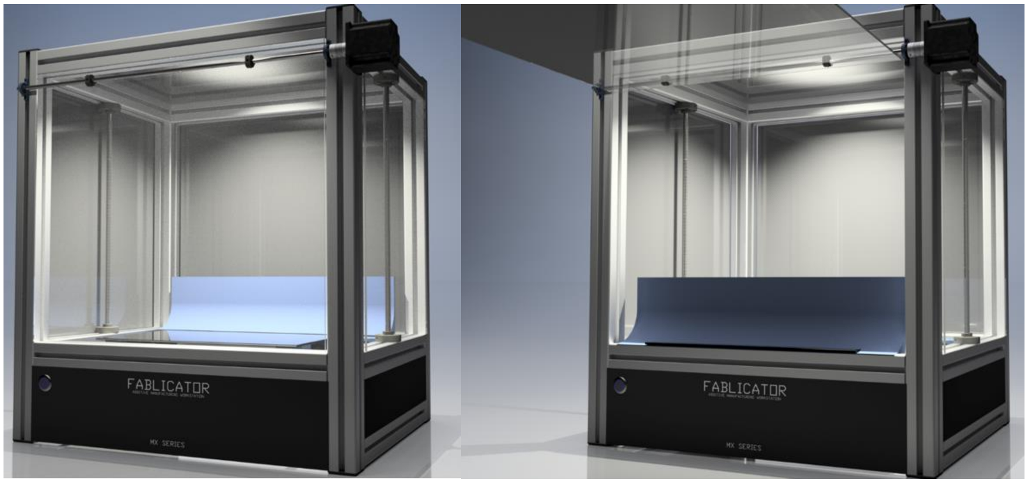

Figure 10: Fablicator Full Automation Mechanism - Door Closed, Part Remover Home, Door Open, Part Remover Forward.

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