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Design of a Sensor System to Digitize Manual End Milling Machine to Collect Machine Data

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Abstract

In the manufacturing system, machines and manufacturing data are becoming more closely linked. In order to collect manufacturing data, there have been many new technologies that are in line with the Industrial Revolution 4.0 to replace existing systems and machines. The objective of this study is to design a sensor system that can collect and stream machine data from an end milling machine to generate a manufacturing report. A prototype of this system was designed using a Raspberry Pi Model 3 B+, PiCamera module, and infrared sensors for installing onto the machine, while Microsoft Azure and Power BI were used to stream and publish the data in a report form. The design was placed onto a milling machine where a machinist had done one milling operation for one workpiece, the sensors collected the data of X-position, Y-position, feed rate, and spindle speed, while deriving the percentage utilization of total time for cutting steps. The end result was a system that was integrated with the milling machine where the critical operation data are collected to produce a manufacturing report that displays the use of the machine. For future studies, different applications for this kind of sensor system can be used to digitize different manufacturing systems. Furthermore, an optimization and standardization testing for this kind of manufacturing system could be set in the future as well.

Keywords

Internet of things, Operation management, Computer vision, Manufacturing.

Introduction

The Fourth Industrial Revolution (IR 4.0) is the current stage of advancement that is currently being undertaken in the manufacturing industry. The goal of IR 4.0 is the use of smart technologies such as Internet of Things (IoT), data mining, cloud computing and many other techniques to enable better visualization of the manufacturing data and analysis. Being a particularly new advancement in technology, many of the technologies are priced very high as a result. There are still many businesses and industries that are still quite sceptical about the impacts that utilizing such monitoring techniques that are offered by IR 4.0 technologies will bring about, particularly in developing countries and in industries that do not yield a high profit margins, it can be very difficult to justify the replacement of their existing manufacturing systems they have in place as the increase in productivity of the new systems may not be enough to make economic sense to replace. As such, is there a way to get the better of two

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worlds? An existing manufacturing system that can be modified so that it has certain IR 4.0 capabilities such as real-time monitoring of various kinds of system data would be an ideal alternative for many small-to-medium enterprises (SMEs). These modifications are made possible using microcontrollers and microcomputers such as the Arduino and Raspberry Pi.

There have been multiple instances of Arduinos and Raspberry Pis being deployed either as sensor systems that collect important environment data. Arduino UNO systems that collected manufacturing data to be sent to a cloud for further processing had been tested within a dental prosthetics factory (Cheng et al., 2018). Whereas use of Raspberry Pi in monitoring a photovoltaic plant which was decentralized in real-time also shows its capability as a medium to improve an existing in ways that do not need to replace and scrap existing systems in place (Pereira et al., 2018). The Raspberry Pi has capabilities to send sensor data to cloud services such as Microsoft Azure to be published into Business Intelligence (BI) tools such as Microsoft Power BI that is scalable and user-friendly (Rifat, 2018). Comparing between the 2 choices of Raspberry Pi and Arduino, the Raspberry Pi acts better as a tool for cloud communication as well as being easily compatible with various kinds of modules available, its camera module, the PiCamera has also found applications for smart surveillance camera systems (Abaya et al., 2014) and it can run computer vision modules such as OpenCV for real time image processing capabilities (Dziri et al., 2016).

In this study, a manual end milling machine that is controlled by operator is modified in a modular way to enable use data of the machine to be logged and published in the form of a report. This report will show how much time an operator has spent on the cutting of a single work part, the RPM of the spindle, percent of time the cutting tool is engaged in cutting steps, and displaying the variation of X and Y-positions of the headstock with respect to the worktable.

Methodology

The end milling machine has two points that will have data being collected, the top of the headstock where the spindle is exposed and the LCD that shows the X-position, Y-position, and feed rate (FR) of the work piece. Figure 1 shows the flow chart of this research.

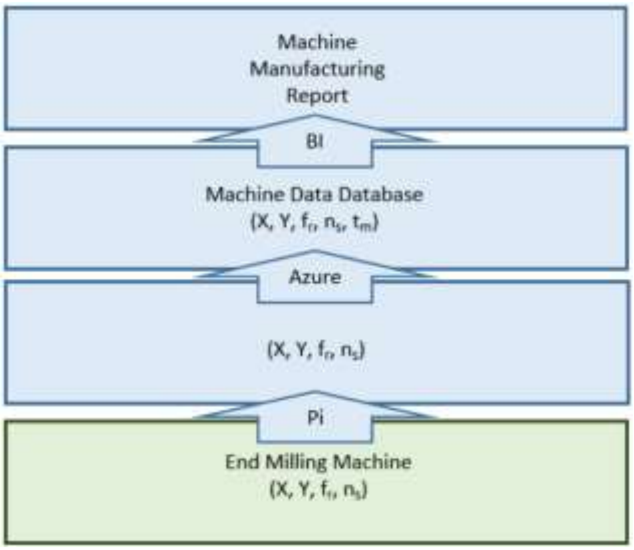

Figure 1. Flow chart of the prototype

For this study, a Raspberry Pi Model 3 B+ is used as the extension to be added onto the end milling machine for collecting, processing, and streaming the data onto Microsoft Azure (Microsoft, 2018). Data on the spindle speed (n_s) is collected via infrared module, whereas a PiCamera module is used to capture data on the LCD. OpenCV is used as a medium to process each frame that is taken by the PiCamera feed and the values of X, Y, and FR (Rosebrock, 2016). To determine the start of the machining cycle, an external circuit that is connected to the Raspberry Pi is also setup to allow the machinist to signal to the Pi that a machine operation is about to begin (Rototron, 2016). The circuit consist of a push button and 1 red and 1 green LED. When the program for data collecting is launched, the red LED is turned on and the green LED remains off, signalling the program for collecting data is on standby. Pressing the push button will turn the red light off and the green light on, it is from this moment on where the PiCamera and infrared sensor is activated and begins to pull data in from the machine, a new variable that keeps track of the total time (t_m) that has passed is also started. Once the machining cycle has ended, pushing the push button again will turn off the green LED and the red LED will come back on, at this point the PiCamera and infrared module will be turned off, the t_m variable will also stop counting the total number of seconds that have passed. After 3 seconds since pressing the push button, the red LED is turned off signalling that the program has been terminated smoothly. Figure 2 shows the connection of the system that was installed onto the end milling machine.

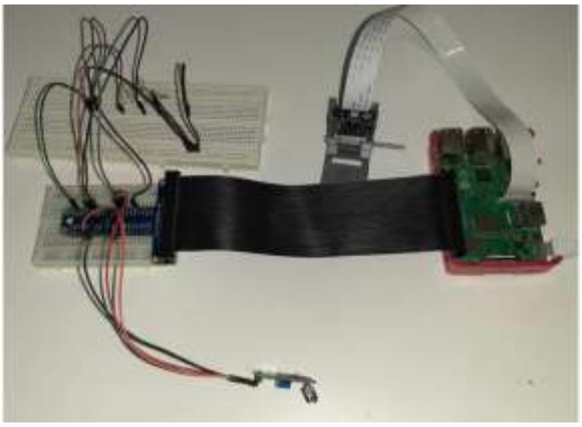

Figure 2. Setup of the system

As a means of measuring the percentage of time the cutting tool is engaged in cutting, there is a rule that has to be followed by the users of the end milling machine set by the technicians in charge. To ensure that there is no damage onto the machine and the workpiece, users of the machine have been advised to not exceed a FR of 10 displayed on the LCD, hence using this relation, a variable is created that counts the number of times in each frame where the value of FR is below 10 and above 0 and divided by the number of total frame collected for that cycle, by doing so, a new variable called percent utilization (utl) is created which shows a value between 0 to 100 that represents the percentage of the total time of the machine cycle where the cutting tool is in contact with the workpiece. To stream all these variables onto the cloud, Microsoft Azure IoT Hub and Stream Analytics has to be setup before the data can be passed over onto Microsoft Power BI to be published.

Results and Discussion

A machining process is done on the end milling machine and the sensor system is kicked off to begin recording the use pattern of the milling machine. A screenshot of the resulting machine data report is shown in Figure 4 as follows.

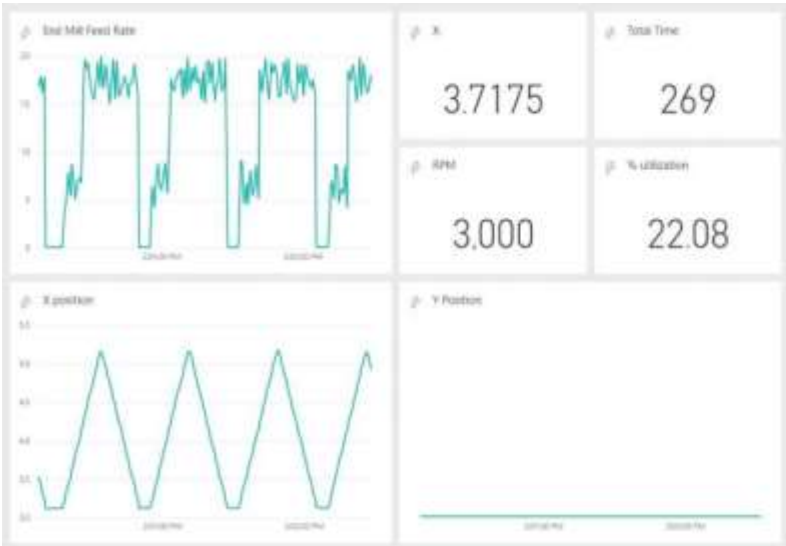

Figure 3. Report Generated for one work cycle

Referring to Figure 4, information on the period of the machine cycle can be deduced as follows:

i. Total time displayed on the screenshot is 269, this shows that the machining cycle has been running for 269 seconds. This is derived from the t_s variable being collected by the Raspberry Pi.

ii. The value of % utilization displayed in the report shows 22.08, this is derived from the utl variable being collected by the Raspberry Pi. Multiplying this percentage with the Total Time will yield the amount of time that FR has been between a value of 10 to 0, which is the theoretical time the cutting tool is engaged with the workpiece.

iii. We see that the X position is varying in a regular pulse like pattern with intermittent peaks and flat-lines. The flat line implies that during that period there was no movement of the X-position, which is further confirmed when we see that the flat lines in the X position and Feed Rate coincide with one another. This flat line represents a pause in the machining process, where it can be assumed that the machinist is adjusting the depth of cut for the next pass by turning the dial that controls the height of the worktable.

iv. From the line chart formed by the Feed Rate, we can see that there is a regular pattern to the formation of the line with slight variation. We see that the line will rise and stabilize at a value that is slightly below 10 before spiking above values of 10 and the sharply declining back to 0 for a few moments before the pattern repeats itself again. We can see that the curves of X and FR are synchronized, this means that by comparing the region where the curves of X and parts of FR that show value range below 10, we can estimate that the total length of the workpiece being cut is from value of X from 3 to 4.5, which means that the workpiece's dimension in length is approximately 1.5 inches.

v. The End Mill Feed Rate curve shown in the report shows that there is approximately one-fifth of the time where the feed rate is between the values of 0 to 10, which is consistent with the value that is shown by the % utilization variable.
vi. The window of Y Position shows a flat line throughout the cycle so far, this shows that the machinist has only moved the worktable in the X direction only.
vii. It is also shown that the pattern of highs and lows in FR are consistent, this implies that the machinist has conformed to the rule set by the technician where the value for FR must not exceed 10 when cutting the workpiece. Any spikes in the zones where the FR is expected to be below 10 is a possible indication of premature damage to the cutting tool, the milling machine or workpiece that is resulted from human error.

It is evident that there has been useful information that can be extracted from the report generated. The choice of using a PiCamera to capture data on the LCD is chosen over plugging in the Raspberry Pi directly into the LCD's sensors is that this would require the building of libraries that would be able to read the sensor data directly from the existing sensors on the milling machine, moreover the LCD would then be unavailable for the machinist to monitor his/her feed rate when operating the machine. PiCamera paired with OpenCV already has built-in libraries that can process the data from images of the LCD, hence it is a more flexible alternative. This implies that the system could have the flexibility to be repurposed for other applications in the same setting as the user would desire when compared to using alternatives for collecting data such as data loggers which are very application-specific. Hence, Raspberry Pi with its additional modules could act as a more economical alternative with its wide range of potential applications and versatility.

With that, the originally traditional end milling machine now can have its machining data being sent to cloud services displayed in real-time, the machinist does not have to be retrained significantly as the operating procedure is fundamentally unchanged. Without a doubt there would be discrepancies between a machine built in with IoT abilities and one that is just added with sensors, this design is not proposed as a means to eliminate the need for brand new manufacturing systems but an alternative to those who seek for solutions that offer minimal change to the status quo at the manufacturing system while still providing IR 4.0 capabilities.

Conclusion

The goal of this study was to design a system that can capture and stream the milling machine data to be published in the form of a report that shows various parameters throughout the period the machine was in use. A simple system that displays the time taken for single milling operation and the percentage time of cutting steps was published onto Microsoft Power BI Dashboard. This study represents a larger group of studies that aims to use microcomputers and other types of modifications to existing manufacturing systems so that it is IR 4.0 compatible. With microcomputers becoming increasingly more affordable and robust, it is beginning to find useful applications in different fields, particularly in manufacturing where there are still many different features that could be used in this sector that are yet to be fully realized. Future studies should aim towards finding more applications in different manufacturing settings, application of data mining and machine learning as classifiers and prediction models within these systems is also a field that has plenty of potential.

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