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# Transformation of Industry 3.0 CNC Machines to Industry 4.0 Machines: Sensor Selection and Integration

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***Abstract*—This paper focuses on selection of appropriate sensors for transforming existing CNC machines to Industry 4.0 machines. Retrofitting old machines with sensors is necessary to enable the machines toward industry 4.0. Although a lot of work related to sensor application in the machining process has been published, this way of machine transformation is still a problem as the process involves sensor integration and design complexities related to mountings. The present work proposes a framework for converting Intelitek Promill-8000 machine to Industry 4.0 machine to provide real time data like feed rate, tool position, tool vibration, cutting forces etc. The data collected from sensors is transmitted by a server and stored in a database which can further be used to create dashboards and digital twins. This paper discusses the selection of required sensors, creating fixtures, designing mounts for proper placement for each sensor for converting Intelitek Promill-8000 machine to IoT based machine. An optimal approach for reducing the overall number of sensors required is proposed. The web database created with the data obtained from the transformed machine is presented.**

***Index Terms*—Sensors Integration, Industry 4.0, Database**

## I. Introduction

CNC machines are key elements in any manufacturing industry. They were started a few decades back with the Industrial revolution 3.0. With the evolution of technology, the part varieties and demand for high quantities of each part is increasing. Due to this every plant is expected to perform with high efficiency and the need for real time monitoring of the machines is increasing. This led to the development of Industrial revolution 4.0. Based on this, new machines are developed with smart and intelligent features such as smart sensors, cloud connectivity and real time diagnosis[1]. The machines with these features are usually costly and can not be affordable for small and medium scale industries which are equipped with CNC machines. The existing CNC machines available with these industries have to be upgraded to meet the demand. The major components that play a key role in the upgradation process are incorporating smart sensors onto the machine, cloud connectivity and real time data monitoring. The present paper focuses on addressing the sensor integration part for converting CNC machines to a cyber-physical system or Industry 4.0 machine. Sensors play a crucial role in factory automation in making the system intellectual. Different types of sensors are available as per the suitability and applications. The recent rise of sensor systems in industrial demonstrations showcases their exceptional capacities. Sensors link multiple devices and systems and enable various machines to communicate and to track systems or equipment at each facility [2]. There are different types of sensors which can range from very simple to complex [3]. Sensors initially contributed much to the smart systems in the medical field. Sensors were used in various medical applications such as patient monitoring, diagnosis, and treatment. For example, sensors are used in wearable devices that monitor a patient's vital signs such as heart rate, blood pressure, and oxygen levels [4] and smart pills with sensors are used to diagnose conditions such as colon cancer and Crohn's disease [5]. Over the years, the manufacturing industry has seen a significant transformation, and sensors have been an integral part of that transformation. With the emergence of Industry 4.0, the role of sensors in manufacturing has become even more important. Today, sensors are used in every aspect of the manufacturing process, from product design to delivery. For example, thermocouples and resistance temperature detectors (RTDs) can now be used in a wider range of temperatures, from cryogenic temperatures to high-temperature applications [6]. Also, the accelerometers and gyroscopes can be used to measure vibration and orientation [7], while proximity sensors can detect the presence or absence of objects [8]. Overall, sensors have become essential tools in modern manufacturing, allowing for more precise control over processes, greater efficiency, and improved quality control. A smart temperature measurement and monitoring system for the manufacturing process of metal parts is necessary to meet quality and productivity requirements. Agus Sudianto et al. developed an Arduino based temperature measurement system, to capture the workpiece temperature during machining of Aluminum Alloy (AA6041) and data was compared with the Fluke Ti400 infrared thermometer [9]. Hanan et al detected water level in a container using HR-SC04 ultrasonic sensor [10]. Song-Eun KIM et al monitored smart healthcare to provide convenient services to users without smart devices, where the author used an MPU6050 accelerometer sensor to calculate the number of footsteps and calorie consumption. The calorie consumption can be measured using the derived steps and the user's body weight [11]. X.Y. Zhang et al developed a Wi-Fi based Arduino Uno board that has been selected to collect and store the data in a database. Around sixty two thousand samples of sensor data is collected during the entire experiment process, each sample containing eight different signals, acquired from piezoelectric sensors, three axis acceleration sensors and three phase power sensors, and stored in a Big Data database [12]. Sachin S. Kamble et al proposed an IoT-based approach to retrofit existing CNC machines to Industry 4.0 standards [13]. V. Balaji et al developed an infrared sensor-based smart manufacturing system for Industry 4.0. and discussed how infrared sensors can be used for a range of manufacturing processes, such as temperature sensing, machine condition monitoring, and quality control [14]. T. Lins et al discussed the use of various sensors in manufacturing, such as force sensors, torque sensors, and vibration sensors, to optimize the production process and ensure product quality [15]. P. Gupta et al., discussed the use of sensors for real-time monitoring of production processes, enabling predictive maintenance and reducing downtime [16]. Various researchers showcased the implementation of various sensors and automation techniques in different industries to improve process efficiency and productivity. These works have contributed significantly to the field of industry 4.0, which is characterized by the integration of cyber-physical systems and data-driven decision-making processes. The present work focuses on the transformation of CNC 3.0 machines to 4.0 machines through incorporating smart sensors onto the machine to integrate the data with the cloud. Not much research has been progressed in this field and needs to be explored to upgrade the CNC machines to cyber physical systems. While the previous works have implemented sensor systems in different industries, this work specifically addresses the challenges of transforming existing CNC machines to Industry 4.0 machines. This work aims at real-time machine monitoring and data storage by selecting appropriate sensors and integrating them onto the Promill 8000 machine. The approach taken in this work can serve as a guideline for other industries looking to upgrade their existing manufacturing systems to meet the demands of Industry 4.0.

## II. Architecture for Transforming Industry 3.0 to 4.0 Machines

To transform Industry 3.0 machines to Industry 4.0 machines, the CNC machines have to be equipped with various sensors which can collect machine data that can be transferred further to the cloud. The architecture of the sensor data acquisition for transforming a CNC machine to Industry 4.0 machine is shown in the Figure Fig.1. Sensors mounted in various locations such as machine table, machine spindle and at other parts of the machine to get information related to the machine as shown in Fig.1. All the data acquired is transferred to the Data Acquisition System (DAQ) or an embedded computer. The DAQ system converts the analog signals from the sensors into digital signals that can be read by a computer. The data received in embedded computers is further transferred to the cloud database to enable real-time monitoring from a remote location.

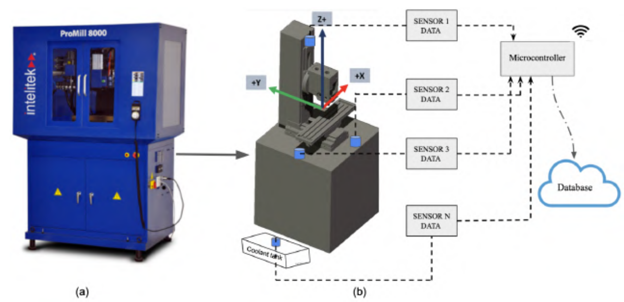



Fig. 1. (a). Promill 8000 before sensor integration (b). Proposed method for the transformation of existing industry 3.0 machine to industry 4.0 machine.

## III. Sensor Selection and Integration

Transformation of an Industry 3.0 machine to an Industry 4.0 machine requires careful consideration of the sensors that will be integrated into the system. Many factors such as hardware and software compatibility with machines, size and accuracy etc., are necessary to be considered while selecting the sensors. The selected sensor must be cost effective, ease of maintenance, long life and continuous operation. The environment in which the sensors are used such as extreme temperatures, humidity, dust, or vibration is also crucial. In such cases, sensors with protective casings may be required to ensure durability and reliability. The present work aims at incorporating sensors on Intelitek Promill 8000 for real time monitoring. In the Intelitek Promill 8000 machine, the existing software is unable to retrieve essential data such as coolant level, coolant temperature, spindle temperature, spindle current, door status, tool position, tool wear, and cutting speed. To obtain some of these parameters accurately, appropriate sensors are selected. Once the sensors are integrated on the machine, data needs to be acquired and stored. To enable sensor data acquisition, Raspberry Pi (Rpi) is selected as it is a small, affordable, and versatile computer as it can be used to both collect and process data. The General-Purpose

TABLE I
SENSOR SELECTION CRITERIA

| Sensor usage | Sensor used in this work | Other Sensors available | Advantage of using this sensor over general |
|---|---|---|---|
| Distance | HCR-S04 | Inductive proximity sensor | The HCR-S04 ultrasonic sensor is a ten times cost-effective, non-contact sensor with a wide range of detecting capabilities, making it suitable for various applications, including coolant level measurement, unlike inductive sensors that only detect distance from metal objects. |
| Temperature | MLX90614 | DTH11, LM35 | The MLX90614 non-contact temperature sensor offers accurate temperature measurements without physical contact, at a lower cost compared to the DTH11 and LM35 sensors, which range from $1to5$. |
| Acceleration | MPU6050 | ADXL377, LIS3DH | The MPU6050 is a cost-effective and widely available sensor that offers high performance while consuming low power. Its compatibility with Raspberry Pi makes it a suitable choice for various applications, making it preferable over higher-end accelerometers. |
| Object detection | IR Sensor | Stereo Camera, inductive proximity sensor | IR sensor modules provide a cost-effective solution with user-friendly interfaces, easy integration, and real-time monitoring capabilities. They are significantly cheaper than inductive sensors and offer rapid feedback. Additionally, IR sensors have a compact size compared to larger and more complex Stereo Cameras, making them a practical choice for various applications. |

Input/Output (GPIO) pins of Rpi are used to interface with sensors. These pins can be configured to read analog or digital signals from the sensors and convert them into usable data for analysis. Temperature sensors, accelerometers, ultrasonic sensors and infrared sensors are mounted on the machine to collect the required data.

### *A. Sensor mounting for coolant and spindle temperature*

The MLX90614 is selected to calculate the coolant and spindle temperatures in the Promill 8000 machine. It is an infrared sensor that can measure temperature without physical contact with the object being measured. This makes it useful for measuring the temperature of objects that are difficult to access or that may be moving. It is a popular sensor in industrial and commercial applications due to its accuracy, ease of use, and low cost. The MLX90614 sensor can measure temperatures in a wide range from -70°C to +380°C where there is a less possibility that the spindle temperature of the machine can go beyond this range. The sensor mounted on the coolant tank of the Promill 8000 is shown in Figure Fig. 2. The data wires from the sensor are directed to Rpi.

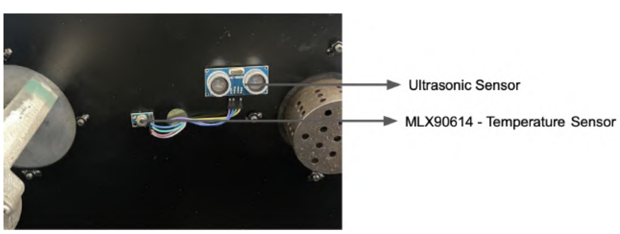



Fig. 2. MLX90614 measuring coolant temperature

### *B. Sensor Mounting for Finding Door Status*

An IR sensor module is selected to get the door status of the machine. It typically uses an IR emitter and receiver pair to detect the presence of an object. The receiver then sends an output signal to a microcontroller or other device to indicate the presence or absence of the object. The IR sensor is placed in front of the door to detect door status as shown in Figure Fig. 3.

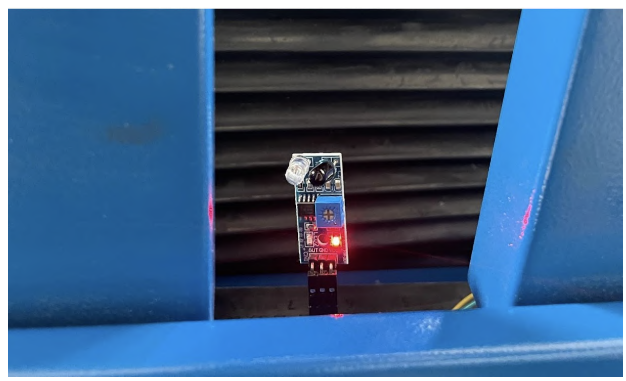


Fig. 3. IR sensor indicating the door status

### *C. Sensors Mounting for Coolant Level and Tool Position Measurement*

Ultrasonic sensors are used to detect the distance of an object by sending high-frequency sound waves and measuring the time it takes for the sound waves to bounce back after hitting an object. They are commonly used for distance measurement in robotics, automation applications. They can also be used to measure the level of liquids in tanks, pipes, and other containers. A particular type of sensor named HR-SC04 is selected for its accuracy and range of measurement. It is a non-contact sensor and can measure from small centimeters to meters. Many sensors are placed at different locations to gather the required data.

Three ultrasonic sensors are placed in the Promill 8000 to get the three-axis position of the tool. Two sensors are placed facing the bench in perpendicular directions to get all the bench movements in X and Y direction. Similarly, another sensor is facing the machine column to get the tool motion in Z-direction as shown in Figure Fig. 4 to get the three-dimensional position of the tool. Another ultrasonic sensor is placed inside the coolant tank to measure the coolant level as shown in Figure Fig.1.

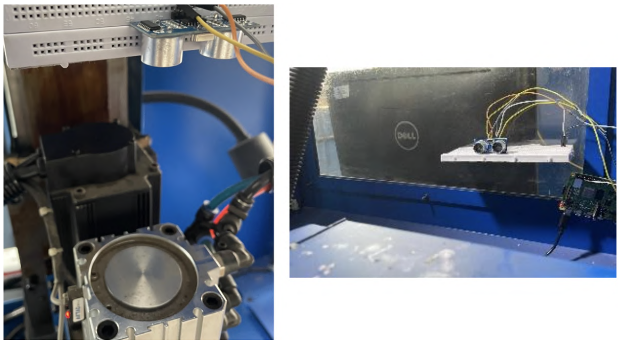


Fig. 4. Mounting of Ultrasonic Sensor for detecting the tool position along X,Y and Z directions

### D. Sensor Mounting for Spindle Power Consumption

WCS 1700 sensor is used to measure the current passing through a wire.The sensor uses the Hall-effect principle to detect the magnetic field generated by the current flowing through a conductor. This sensor is clamped to the spindle wire as shown in Figure Fig. 5, to calculate the spindle power. The spindle power data helps to check the fluctuations in the power requirements for different work materials and can detect the low voltage currents. Energy required for machining a job can be calculated using power data obtained over a period of time by integrating. Data for components can be stored and analyzed at a later stage for design of the product.

Fig. 5. Mounting of WCS1700 for detecting Spindle Power Consumption.

### E. Sensor for Cutting Tool Feed Rate Change

The MPU6050 sensor is placed on the 2-axis bench of the milling machine as shown in Figure Fig. 5, which senses the acceleration of the table in two directions. In this kind of milling machine, the workpiece moves while machining, hence the bench acceleration can help to get the tool feed rate change. The MPU6050 is a popular 6-axis motion tracking device that combines a 3-axis gyroscope and a 3-axis accelerometer in a single package. This sensor tracks the motion accurately at low cost.

Fig. 6. MPU6050 to measure cutting speed

## IV. Results and Discussions

In the context of this paper, the data required for monitoring different parameters in CNC machines is successfully achieved by a combination of sensors and a data processing platform. The collected data is then sent to a central processing unit, in this case, a Raspberry Pi, which serves as the hub for data processing. As shown in Fig. 7, the real-time data from the sensors is displayed on the Rpi screen.

The tool and coolant temperature that is being sensed by the MLX90614 temperature sensor is shown in Fig. 7.

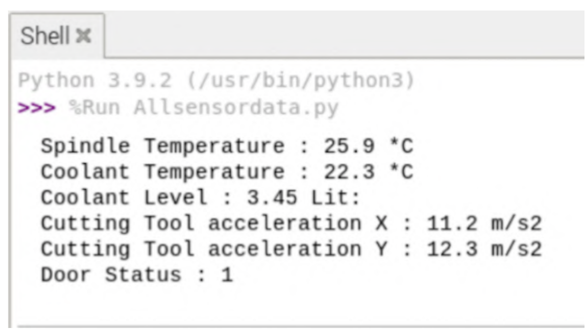



Fig. 7. The coolant and tool temperature from sensor data that is being read by Raspberry Pi.

The number “1” is a binary result from the IR sensor, where it displays 1 when the door is closed and 0 when the door is open. The bracket having three numerical values, from the ultrasonic sensor indicates the x, y and z position of the tool respectively. Cutting speeds are obtained from the MPU6050 accelerometer sensor, where the bench feed rate changes or accelerations are detected. A database is used to store the data collected from the sensors, which is critical for analysis and decision-making. Firebase real-time database is used in this case, which provides a scalable and reliable platform for storing and accessing real-time data. This database has unique keys, IDs which are updated using the algorithm written in python and executed in Raspberry Pi. A library called Pyrebase is installed on the raspberry pi OS to interact with the Firebase database.

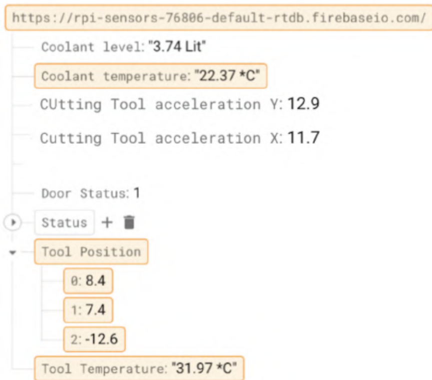
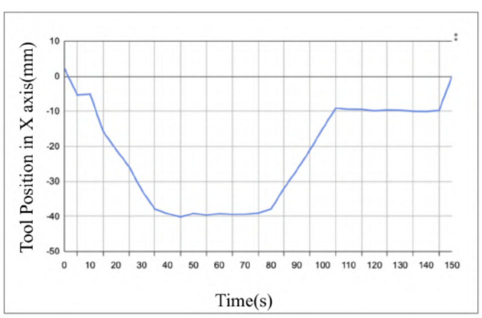



Fig. 8. The data that is pushed to a real-time database in firebase.

All the transferred data is stored in a module called status, and the real-time data is displayed as shown in Fig. 8. This allows the shop-floor manager to have access to the data collected by the sensors in real-time, which is essential for decision-making and quality control. The successful collection and storage of data using sensors and a data processing platform such as Raspberry Pi and Firebase real-time database is a significant step towards achieving the real time monitoring of the Promill 8000 machine status. The use of real-time data provides shop-floor managers with the necessary information to make informed decisions and take corrective action promptly.



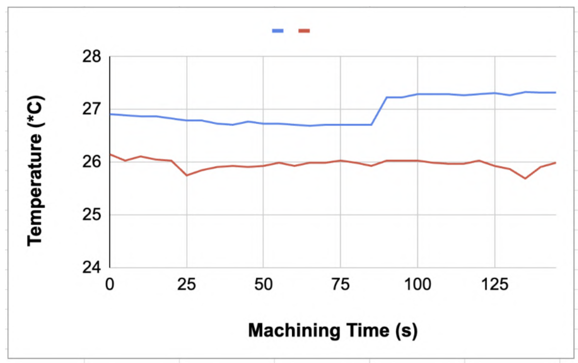

(a)


(b)

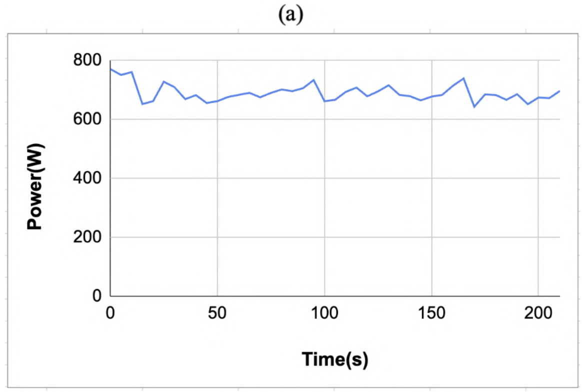
Fig. 9. (a) G- code for machining a wax block. (b) Tool position in X graph with respect to the machining time.

Figure Fig. 9a, shows the data collected from the ultrasonic sensor for the spindle position while machining a wax block. The G code used for the machining of the component is shown in the Figure Fig. 9b. By comparing both the figures Fig. 9a and Fig. 9b, the similarity in motion data from sensor to G code can be observed. The table moves from home position to -40mm, then to -10 mm and to home position. The obtained readings are matching with tolerance of 2 mm. Thus, the position is obtained and transferred to the cloud database to display at a remote location.

The temperature data of the spindle obtained is shown in the Figure Fig. 10a along with ambient temperature obtained from MLX90614. This data will be useful in identifying the spindle condition whether it is overloaded or normal. The data obtained for spindle power calculated using the current sensor data over a period of time is shown in the figure Fig. 10b.




(a)




(b)

Fig. 10. (a) Spindle temperature data obtained from MLX90614 sensor. (b) spindle power data obtained by WCS1700

Thus, the data for various machine parameters are collected using different sensors mentioned and is further transferred to the cloud database to display in the machine tool dashboard which is accessible to the concerned authority.

## V. Conclusions

This paper aimed at sensor integration for converting a CNC machine to Cyber Physical System. To realize this,

- Various sensors are selected for getting the real-time data from the Promill 8000 machine.
- Machine tool data like coolant temperature, door open status, coolant level, tool position and feed rate change are measured in real time using Rpi.
- The data from the embedded computer can be connected with Firebase to store and display the real time data.
- The Promill 8000 machine status can be monitored in real time using a dashboard created using the data obtained from Firebase.

Adding a thermal camera to the machine tool to measure the tool wear will be a good addition for the machine tool condition monitoring in real time. This will be presented in future communications.

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