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Smart Temperature Monitoring System for Machining Process Using Internet of Things

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Abstract— *Outer surface integrity must be maintained throughout the machining process during the production of metal parts, which need the ability to monitor temperatures in real time. Changes in temperature during the machining process lead to changes in the behavior of the product after work is completed.To achieve quality and productivity criteria, the metal parts manufacturing process requires a continuous and precise temperature measuring and monitoring system by using IOT. An intelligent temperature measurement can be used during machining processes on conventional, non-conventional, and computer numerical control (CNC) machines.*

This paper presents a performance analysis of a temperature measuring system for machining process applications via Arduino IDE. In this proposal, a temperature monitoring system based on Arduino is used. The system would utilize an: MLX90614 infrared thermometer sensor" to measure the temperature of the workpiece during machining processes.

The methodology's aim is to use the smart manufacturing model to measure and monitor the arising temperatures throughout the machining process in order to build a new tool path rapidly and efficiently. The placement of a non-contact infrared "MLX90614" temperature sensor allowed measuring of the average cutting temperature as well as the maximum cutting temperature. The data acquisition process was carried out using the "Xampp" Control Panel software, which communicated with the ESP32 "microcontroller" board using the Arduino IDE program. Experiments were carried out, so that the temperature of the cutting, which was measured, was recorded, and the results of the experiments were analyzed.

Index Terms: *Smart Manufacturing, Internet of Things, MLX90614 Infrared Temperature Sensor, Machining Parameters.*

I. INTRODUCTION

The productivity, quality, and overall economy of machined parts can be significantly influenced by specific processing parameters. The parameters encompassed are tool life, wear, surface finish, part accuracy, cutting force, material removal rate, and cutting temperature (on the tool and workpiece) [1]. Humans may remotely manage and monitor machines using advanced monitoring systems that are equipped with software systems and connected to the Internet. This strategy can be referred to as the "Internet of Things" (IoT). The Internet of Things (IoT) aims to integrate the physical and digital realms by implementing a vast network of networked computer devices that can exchange and analyze data instantly and from any geographical location [2].

However, several potential issues may arise during the machining process, including tool fracture. Free-form surfaces refer to irregularly shaped surfaces created by placing distinct patches together and ensuring continuity at the places of joining, particularly during machining. [3, 4]

Defects may arise in the final product if tool fractures or chips during the cutting process, and this occurrence is commonly attributed to the raising temperature at which the cut is executed. Proceeding

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with the machining process with a hot tool might result in heightened friction between the tool and the workpiece, thus leading to an escalation in power consumption. While heat generation is an inevitable part of the metal cutting process, the high temperature at the cutting tool tip can lead to damage to the tool [5].

Calculating temperature values in manufacturing processes is considered one of the most important variables that must be studied to control manufacturing defects, in milling operations, companies face difficulty in monitoring, transporting, storing, and analyzing temperatures values automatically, as some are forced to use large devices with less accuracy to monitor temperatures, such as Infrared Fusion Fluke Ti400.

In this research, one of the main contributions is to present a working methodology for monitoring, calculating and analyzing temperatures during the machining process using a high-precision sensor (MLX 90614 Infrared thermometer sensor) compared to other temperature measuring devices.

II. LITERATURE REVIEW

In recent times, a multitude of scholars have put forth diverse methodologies and strategies for the implementation of Industry. There is a scarcity of studies documented in the published literature regarding the produced smart model (SM).

Benardos P.G., et al. (2017) provided an overview of IIoT, to look into some practical industrial uses of precision machining, and to make some forecasts about where the field is headed. [2]

B. T., et al. (2018) designed the infrastructure of an Internet of Things (IoT)-enabled production system and tested it out on a small milling machine. The designed manufacturing system is capable of receiving G-Code inputs from the internet via a website and streaming sensor data to the internet. The engineering implementation and underlying philosophy of the system have been discussed. In their study, they assess how practical it would be to use them for factory condition monitoring. These systems represent a fundamental element in making the 'Smart Factory' a reality. [6].

L. Ta. (2019) introduced a novel approach to identify the most effective surface milling parameters by examining variations in cutting forces and the stability of the tool path. Subsequently, these parameters are utilized to generate astute tool paths that satisfy precise geometric criteria. The Paper proposed method’s merits are showcased by its application to specific circumstances pertinent to industrial environments. Empirical evidence shows that using process simulations in tool path planning and production can greatly decrease the overall cycle time of 5-axis milling. [7]

A case study was conducted by S. A., et al. (2020) to assess the effectiveness of an arduino-based temperature measurement system used in a milling operation. This study created a temperature measuring device using an Arduino microcontroller board and “MLX90614 infrared thermometer sensor”. A comparison was conducted between the data collected from infrared fusion using “Fluke Ti400” and data collected from this system during milling, the “MLX90614 infrared thermometer sensor” improves temperature measurement by seamlessly integration and synchronizing with Microsoft Excel. [8]

Andy L., et al. (2022) Conducted research to investigate the possible impact of cutting parameters, such as cutting speed, depth of cut, and feed rate, on the temperature at the tip of the cutting tool. The impact of flank wear on cutting tool temperature will thereafter be assessed by comparing the temperatures of a pristine tool and a deteriorated tool. “MLX90614” series infrared temperature sensor is connected to “NodeMCU ESP8266” development board equipped with a Wi-Fi module to create a sensor system that measures temperature using the Internet of Things technology. Initially, the system is programmed using

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the Arduino IDE software. Subsequently, the system is connected to the "BLYNK" application on mobile devices, enabling the visualization of real-time temperature data during the turning process. The temperature of the cutting tool tip rises in direct proportion to both the cutting speed and the depth of the cut. [1]

Yap H., et al. (2022) develops an affordable predictive maintenance system that incorporates an Internet of Things. This system will be able to forecast the state of cutting tools and determine the optimal time for tool replacement. The primary goals are to ensure product quality and maximize the lifespan of tools. Additionally, it is contemplating the inclusion of enhancements to the outdated traditional machine. This study employed a novel instrument exhibiting no signs of flank wear alongside a conventional instrument displaying flank wear of 0.51mm. The MLX90614 temperature sensor, which uses infrared technology and does not require physical touch, was used to detect both the average and maximum temperatures during cutting. The temperature during the cutting process was measured, and the results were examined. [9]

III. PROPOSED SYSTEM COMPONENTS

The components of the proposed system are explained in Table I, where the proposed system consists of Hardware & Software as illustrated below:

TABLE I. PROPOSED SYSTEM COMPONENTS

HARDWARE	SOFTWARE
ESP32 "Microcontroller Module"	Operation System Windows
MLX 90614 Infrared Temperature Sensor	Arduino Application (V 1.8.19)
Power Supply Wi-Fi	PHP File.
Router	SQL File.
Jumper Wires	"XAMPP Control Panel" Application (V 3.2.4)
Bread Board	
Serial Port Wires	
Box	

IV. ESP 32 MICROCONTROLLER MODULE

The "ESP32 Micro – Controller Module" development board is a comprehensive platform specifically created for the development of ESP32, an enhanced iteration of the widely-utilized ESP8266. The ESP32, like the ESP8266, is a "microcontroller" with built-in Wi-Fi functionality. However, it also has support for Bluetooth low-energy (BLE), BT4.0, and Bluetooth Smart, as well as 28 I/O pins. The ESP32's robust capabilities and adaptability render it an optimal choice for assuming the role of the central processing unit in the forthcoming IoT endeavor. [10]

The ESP32 is specifically designed for use in mobile devices, wearable electronics, and applications related to the Internet of Things (IoT). The device incorporates advanced features such as precise clock gating, several power modes, and dynamic power scaling, which are all essential for low-power operation. For example, in a case where a low-power IoT sensor hub is being used, The ESP32 series is offered in both chip and module form. The user's text is "[11]". The essential elements of ESP32 Arduino are shown in Table I, while the description of ESP32 Arduino is depicted in *Fig. 1*.

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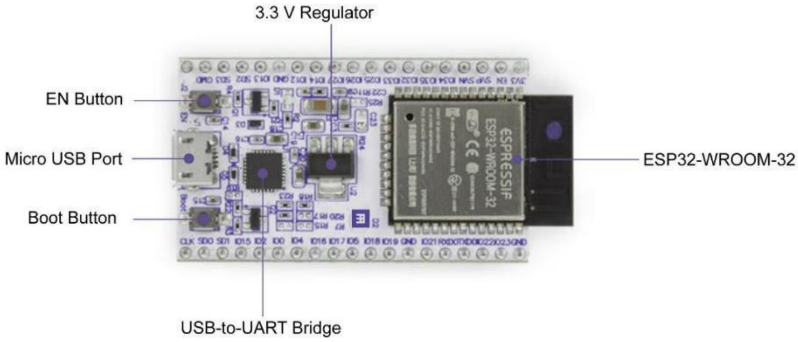

FIG. 1. ESP32 ARDUINO MICRO-CONTROLLER BOARD [10].

TABLE II. KEY COMPONENTS OF ESP32

Components Key	Description
ESP32-WROOM-32	"A module with ESP32 at its core."
EN Button	Reset Button
Boot Button	Button for downloading. Activating Firmware Download mode can be achieved by pushing the Boot button and thereafter pressing EN, allowing for the downloading of firmware over the serial port.
USB-to-UART Bridge	Enables the conversion of USB to UART serial to facilitate communication between the ESP32 and PC.
Micro USB Port	Universal Serial Bus (USB) interface. The power supply for the board and the communication interface between a computer and the ESP32 module.
Regulator of 3.3 V	Transforms 5 volts provided by the USB into the required 3.3 volts to power the ESP32 module.

V. INFRARED TEMPERATURE SENSOR

The MLX90614 is a "Melexis-manufactured" infrared thermometer designed for precise noncontact temperature readings.The thermometer achieves a high level of precision and resolution because to its low noise amplifier, 17-bit ADC, and power DSP unit. The thermometer employed is precalibrated at the manufacturer and features a digital Pulse Width Modulation (PWM) and System Management Bus (SMB) output.

The 10-bit PWM is configured to consistently transmit temperature readings ranging from -40 to 125 °C, with a precision of 0.14 °C [12]. The pin function of the MLX90614 is displayed in Table II, while the pin description is illustrated in *Fig. 2*.

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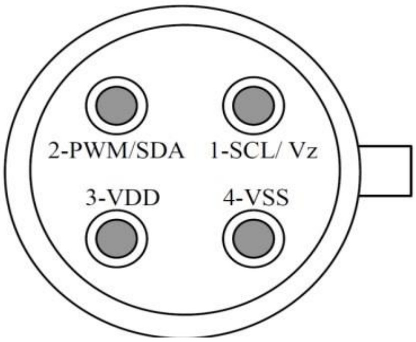


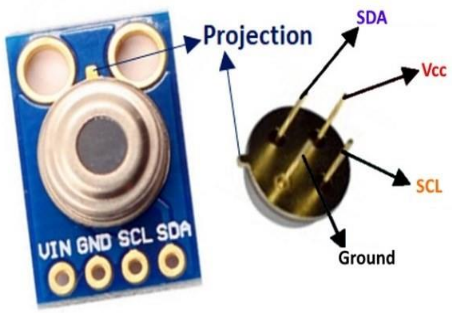
FIG. 2. PIN DESCRIPTION OF MLX90614 (TOP VIEW).

TABLE III. PIN FUNCTIONS OF MLX90614. [12]

Pin	Type Size (pts)	Appearance
1	SCL	Serial Clock Input
2	PWM/SDA	Data In/Out
3	VDD/VIN	External Supply Voltage
4	VSS/GND	Ground

The MLX90614, seen in *Fig. 3*, utilizes emissivity and radiation to estimate the temperature of an item without direct touch. Emissivity is a numerical value that quantifies the efficiency of an item in emitting infrared light relative to an ideal black body. The MLX90614 utilizes this radiation to determine the temperature of the item. During the production process, "MLX90614 is calibrated" using a black material with an emissivity of 99.9%, which is equivalent to an emissivity value of E = 1. Table III provides a comprehensive overview of the specs for the MLX90614 infrared thermometer.

In their practical studies, the researchers focused on using the MLX 90614 Infrared Thermometer senso to monitor temperatures because of its high accuracy in calculating temperatures and its small size compared to other device like Infrared Fusion Fluke Ti400.



MLX90614 INFRARED TEMPERATURE SENSOR

Infrared Fusion Fluke Ti400

FIG. 3. MLX90614 INFRARED TEMPERATURE SENSOR & INFRARED FUSION FLUKE TI400.

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VI. THE IMPLEMENTATION & ANALYSIS

The IoT training system for a smart manufacturing model is a new platform design shown in *Fig. 5.* The BOM (Bill of Material) is listed previously as hardware and software. There is a set of sensors that can be linked with the smart model designed and programmed to read, record, and monitor the data extracted from the infrared temperature sensors (MLX90614).

In this paper, a smart manufacturing model was designed that contains an ESP32 Arduino and an MLX90614 sensor, with specifications shown in Table IV, to read temperatures during the operation process. The purpose of designing this model is to transfer the extracted data during the operation process to another methodology designed on a central computer to monitor and analyze the temperature data of the operation process. *Fig. 4* describes the process flow of setting up the temperature sensor MLX 90614.

The aim of the methodology is to re-plan and generate a new tool path that is more optimal than the previous tool path with which the surface was previously operated. An analysis conduct on the temperature data sent by the smart manufacturing model to study the variables that impact the operating process.

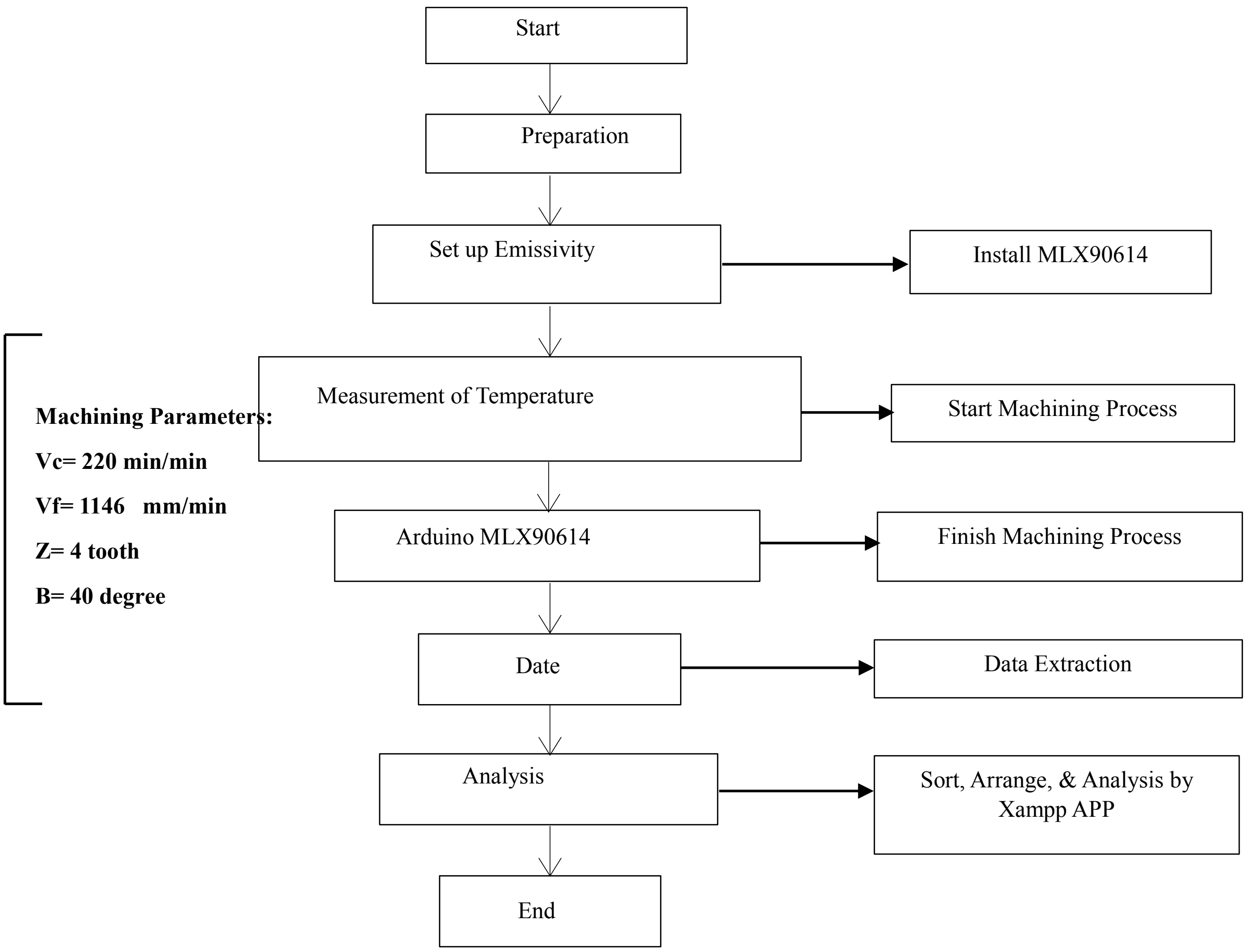

FIG. 4. PROCESS FLOW OF TEMPERATURE MEASUREMENT.

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TABLE IV. DETAILS THE SPECIFICATIONS OF MLX90614 INFRARED THERMOMETER [13]

Attribute	Type Size (pts)	Unit
Ambient Temperature	-40 to 125	°C
Object Temperature	-70 to 380	°C
Detector Resolution	0.02	°C
Versions	Single and dual-zone	
Application	Arduino, SMB compatible digital interface	
Model Number	MLX90614	
Measurement Resolution	0.02	°C
Best Temperature Measurement Accuracy	0.5	°C
Focus Type	Manual	
Version	3 and 5	V
Display Size	LCD 16x2	cm
Weight	< 250	gram

The smart manufacturing model needs a database designed to store and arrange the data extracted from the model and the temperature sensor. “Xampp Control Panel” application facilitates the creation of a database for the purpose of storing, organizing, and transmitting temperature data. “Xampp Control Panel” Programmers can create and test websites locally on their PC without the need of external server access or internet connectivity. This data is then connected to a smart manufacturing model using a PHP file, which enables its integration into a local network. With XAMPP already set up for use, PHP environment and MySQL server should already be ready for action – easily access PHP files using “htdocs” directory in XAMPP for quick use.

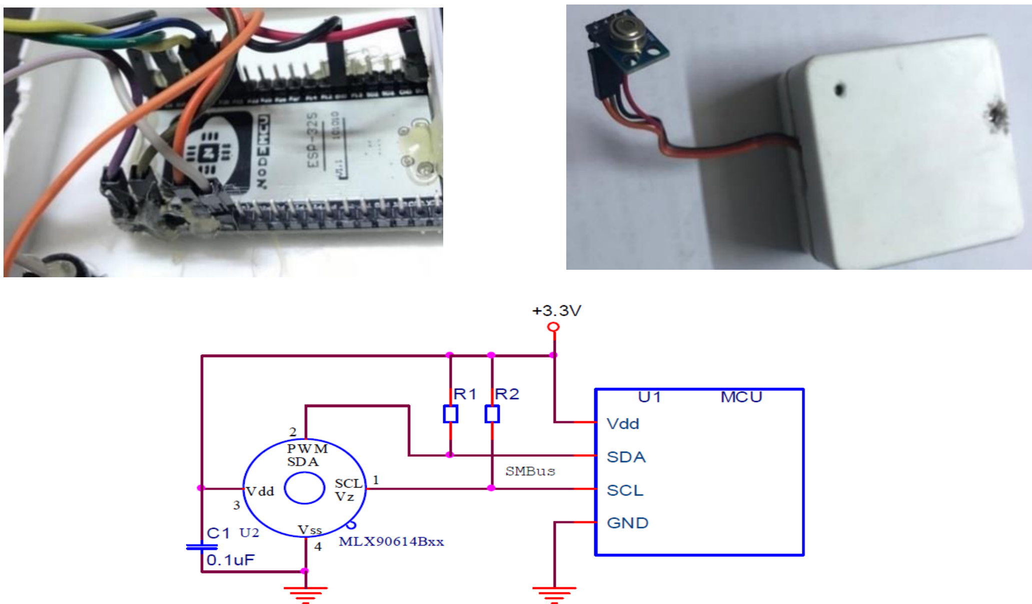

FIG. 5. SMART MODEL (ESP32 ARDUINO & MLX90614 INFRARED TEMPERATURE SENSOR).

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VII. EXPERIMENTAL SETUP

The efficacy of the smart manufacturing model was evaluated during the material machining process see *Fig. 6*. Utilizing the smart model and the MLX90614 Infrared Temperature Sensor allowed for the acquisition of temperature data. The temperature differential is evident in the results, which were obtained after constructing a SQL file database to store and organize the temperature data within the "Xampp Control Panel" application, as depicted in *Fig. 7* and *Fig. 8*.

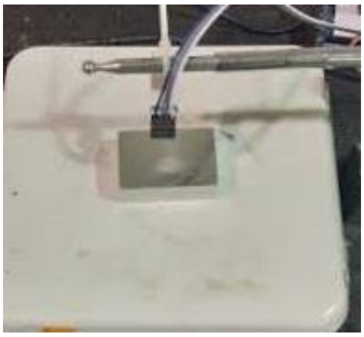
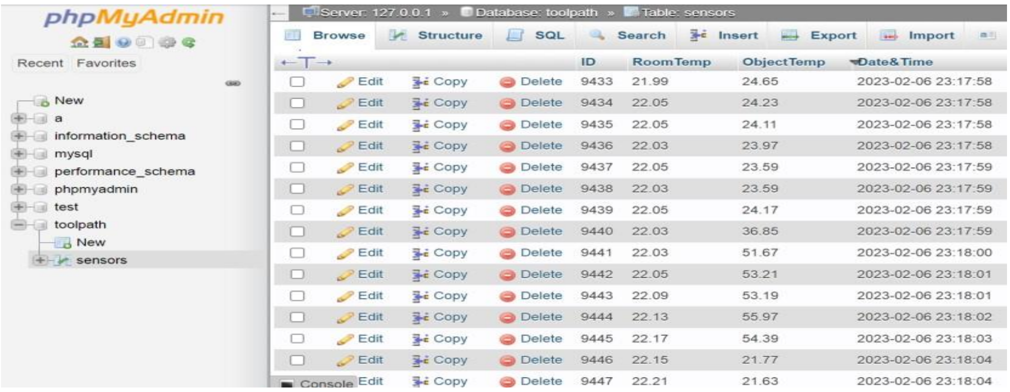
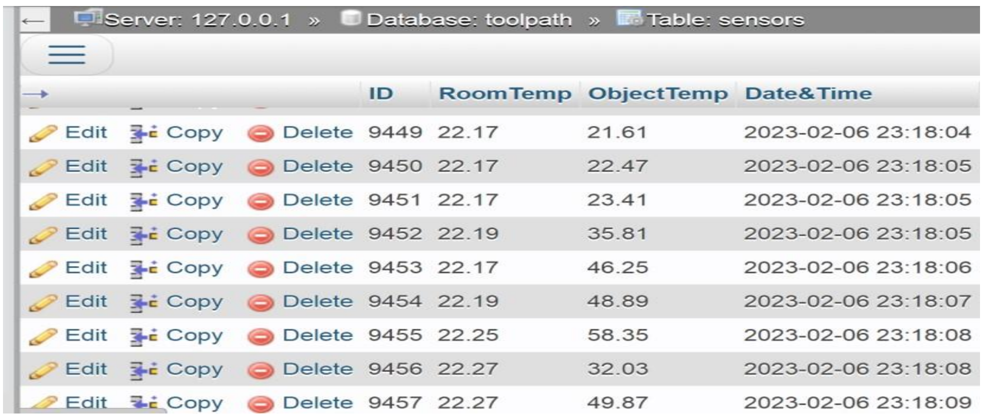


FIG. 6. MLX 90614 DURING MACHINING PROCESS.



			ID	RoomTemp	ObjectTemp	Date&Time
Edit	Copy	Delete	9433	21.99	24.65	2023-02-06 23:17:58
Edit	Copy	Delete	9434	22.05	24.23	2023-02-06 23:17:58
Edit	Copy	Delete	9435	22.05	24.11	2023-02-06 23:17:58
Edit	Copy	Delete	9436	22.03	23.97	2023-02-06 23:17:58
Edit	Copy	Delete	9437	22.05	23.59	2023-02-06 23:17:59
Edit	Copy	Delete	9438	22.03	23.59	2023-02-06 23:17:59
Edit	Copy	Delete	9439	22.05	24.17	2023-02-06 23:17:59
Edit	Copy	Delete	9440	22.03	36.85	2023-02-06 23:17:59
Edit	Copy	Delete	9441	22.03	51.67	2023-02-06 23:18:00
Edit	Copy	Delete	9442	22.05	53.21	2023-02-06 23:18:01
Edit	Copy	Delete	9443	22.09	53.19	2023-02-06 23:18:01
Edit	Copy	Delete	9444	22.13	55.97	2023-02-06 23:18:02
Edit	Copy	Delete	9445	22.17	54.39	2023-02-06 23:18:03
Edit	Copy	Delete	9446	22.15	21.77	2023-02-06 23:18:04
Edit	Copy	Delete	9447	22.21	21.63	2023-02-06 23:18:04

FIG. 7. SAMPLE1 OF MACHINING TEMPERATURE DATA.



			ID	RoomTemp	ObjectTemp	Date&Time
Edit	Copy	Delete	9449	22.17	21.61	2023-02-06 23:18:04
Edit	Copy	Delete	9450	22.17	22.47	2023-02-06 23:18:05
Edit	Copy	Delete	9451	22.17	23.41	2023-02-06 23:18:05
Edit	Copy	Delete	9452	22.19	35.81	2023-02-06 23:18:05
Edit	Copy	Delete	9453	22.17	46.25	2023-02-06 23:18:06
Edit	Copy	Delete	9454	22.19	48.89	2023-02-06 23:18:07
Edit	Copy	Delete	9455	22.25	58.35	2023-02-06 23:18:08
Edit	Copy	Delete	9456	22.27	32.03	2023-02-06 23:18:08
Edit	Copy	Delete	9457	22.27	49.87	2023-02-06 23:18:09

FIG. 8. SAMPLE2 OF MACHINING TEMPERATURE DATA.

From *Fig. 7* and *Fig. 8*, we can see the difference in temperatures during the operation process. This difference is monitored and then analyzed according to the 3D CAD model design. The rise in temperatures means that the operating process passes through complex features (sculpture surface) that

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may contain some complex bends or cavities, which need to study and analyze the influences on the operating process shown in *Fig. 8*. Mostly, these complex features are called free form features; the degree of complexity of these surfaces is high and is called free surface modeling.

VIII. CONCLUSIONS

Current industries offer a wide range of variations, necessitating the creation of manufacturing systems. The Fourth Industrial Revolution has proven its success in achieving this diversity through the development of manufacturing systems and the use of smart tools and technologies such as the Internet of Things, big data, cloud computing, and cyber physical systems.

In this research, a smart model was designed to monitor and analyze one of the important influences on the manufacturing process (operating process temperature) through an infrared sensor (MLX90614). This model succeeded in transferring, storing, and arranging the data required to be processed in another research methodology aimed at re-planning and generating an optimal tool path for the operation process in order to reduce the production cost, improve the quality of operation, and reduce the operating time by choosing the best machining parameters for each feature in the free form surface.

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