

IoT Based Condition Monitoring System for Spot Welding Machines Using Vibration and Non Contact Voltage Detection

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Abstract— This study developed an Internet of Things (IoT)-based spot welding machine condition monitoring system that integrates an MPU6050 sensor, a non-contact voltage detector, an ESP32, a TFT LCD screen, and the Blynk platform. Vibration acceleration values were calculated based on changes in resultant acceleration relative to the stationary baseline and processed using an exponential moving average. Testing was conducted under normal operating conditions and increased- vibration conditions. Under normal conditions, peak vibration acceleration values ranged from 0.90 to 6.79 m/s², while under increased-vibration conditions, they ranged from 7.10 to 9.15 m/s². The response time of the system components ranged from 0.1 to 0.5 seconds. This system can display data locally and send data to Blynk. However, further validation using reference instruments is still needed to determine the measurement accuracy of the developed monitoring system.

Keywords: ESP32, Internet of Things (IoT), monitoring machine condition, Spot Welding, vibration detection, voltage detection

I. INTRODUCTION

PRODUCTION PROCESSES in today's manufacturing industry rely heavily on machines with high levels of precision and efficiency. One common problem that occurs during machine operation is vibration, which can affect performance stability and accelerate component wear if it occurs excessively over a long period of time [1]. Rotating machinery is typically a source of vibration in industrial settings. Machinery can be damaged if vibration levels are too high. Therefore, to prevent further damage, it is necessary to monitor the machinery using predictive maintenance methods [2]. The data generated can be analyzed to improve and evaluate measurements of the machine's condition, as well as to identify maintenance patterns [3]. To support timely maintenance and the identification of anomalies, weekly data collection on vibration parameters is required [4].

Previous research utilized a portable vibration analysis tool equipped with a VIB 5.436 accelerometer as the primary sensor, along with the online analysis platform provided by the tool, allowing measurement results to be monitored in real time [5].

Another study used a piezoelectric sensor to measure motor vibrations, with an AVR Atmega 8 microcontroller serving as the main controller; the vibration measurement results were then identified via text messages [6]. In single-phase motors, the ADXL 335 sensor is also used to monitor vibration levels [7]. Previous research developed a device to detect vibrations in motors and fluctuations in their loads, using the GY-521 MPU6050 sensor and an Arduino Uno [8]. Another study implemented an Internet of Things (IoT)-based system for detecting and alerting users to bridge damage by using load cell sensors to detect loads. The data is then processed using an ESP32 microcontroller, which also serves as a means of connecting to the Blynk app via Wi-Fi, allowing users to receive real-time notifications. [9]. Vibration detection can be applied not only to motor-driven machines but also to cylinder-driven machines, whether pneumatic or hydraulic. Vibration analysis of hydraulic cylinders used in applications with variable loads and varying boundary conditions. The stick-slip phenomenon between the piston and the cylinder is the primary cause of vibration, which also leads to damage to the sealing materials and reduces the fatigue life and performance of the hydraulic system [10].

Previous research has generally focused on monitoring vibrations in induction motors, pumps, and bridge structures. The implementation of integrated monitoring systems in pneumatic-actuator-based spot welding machines remains limited. Furthermore, most systems only monitor mechanical parameters without integrating indicators of the electrical condition of the machine body. This study developed a device that combines vibration monitoring, non-contact voltage detection, local alarms, and IoT-based monitoring into a single system. In this study, the developed device is equipped with an IoT-based system using the Blynk platform, allowing vibration data to be monitored in real time. The ESP32 is used as the main microcontroller to read and process data from the MPU6050 sensor, then display it on a 2.4-inch TFT LCD screen and send it to the Blynk platform via Wi-Fi connectivity. In addition, this device is equipped with a buzzer and an LED that serve as alarms if vibrations exceed a specified limit, as well as an electromagnetic field sensor on the machine body that uses

a 2N3904 transistor in a Darlington configuration—known as NCV—to ensure safer monitoring of the machine's condition.

II. METHOD

This study employs system design and development methods to create a monitoring device for spot welding machine conditions. The research stages include system design, hardware and electrical circuit design, program development, device assembly, sensor calibration, functional testing, and data collection and analysis. The system is designed to monitor mechanical vibrations based on three-axis acceleration measurement obtained from an MPU6050 sensor and detect AC electric fields using a non-contact voltage (NCV) sensor. Data is processed by an ESP32, displayed on a 2.4-inch TFT LCD, and transmitted to the Blynk platform via a Wi-Fi network. A buzzer and LED are used to alert the user when the system detects conditions that exceed the threshold. Figure 1 illustrates the research stages, from component preparation through the testing and data analysis processes.

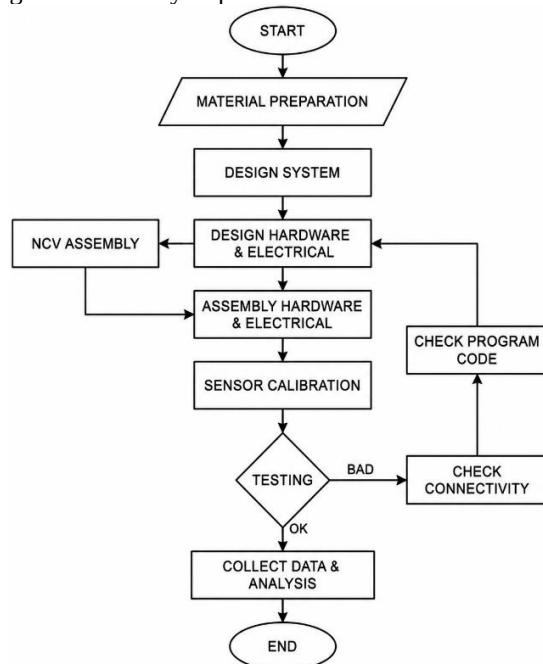


Figure 1. Flowchart methodology

A. Research Object and Test Condition

The subject of this study is a Prevail PW-C1500J spot welding machine used in the thermostat spot welding process. The machine uses a pneumatic actuator with a normal operating pressure of 2 ± 1 bar. The machine supply voltage is 220 V, with a power frequency of 50/60 Hz. Testing was conducted under two conditions: normal operating conditions and increased-vibration conditions. Under normal operating conditions, the pneumatic pressure was maintained at approximately 2 bar. The increased-vibration condition was simulated by adjusting the pneumatic pressure to 3 bar. Although this value is still close to the upper operating range of the machine, the pressure increase produced a stronger pneumatic actuator impact during the welding cycle, resulting in higher vibration responses. This condition was used to evaluate the ability of the monitoring system to detect increased vibration without causing permanent

damage to the machine. The test was conducted in accordance with safety procedures.

B. Design Block Diagram System

As shown in Figure 2, the monitoring system consists of an MPU6050 sensor, an NCV sensor, an ESP32, a TFT LCD, a buzzer, an indicator LED, a calibration button, a reset button, and the Blynk platform. The MPU6050 sensor is used to measure acceleration along the X, Y, and Z axes. The NCV sensor is used to detect the presence of an AC electric field without direct contact with the machine's surface. The ESP32 receives and processes data from both sensors. The processed results are displayed on the TFT LCD and transmitted to the Blynk platform via a Wi-Fi connection. When the vibration value exceeds the threshold or the NCV sensor detects an AC electric field, the ESP32 activates the buzzer and LED as an alarm.

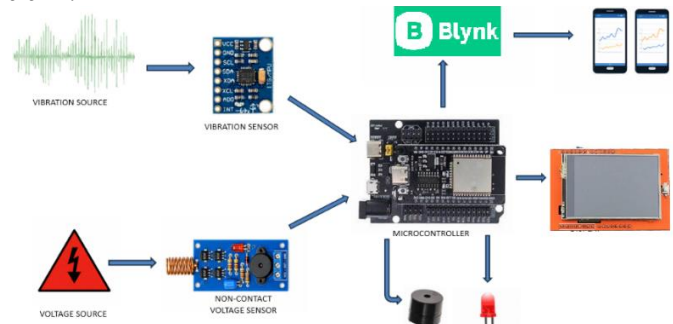


Figure 2. System block diagram for monitoring device

C. Electrical and Hardware Design

TABLE I
MAIN COMPONENTS OF MONITORING SYSTEM

No	Component	Type/Spec	Function
1	Microcontroller	ESP32 Devkit V1	Read sensor and transfer data
2	Acceleration sensor	GY521 MPU6050	Measures vibration acceleration
3	Display	2,4-inch TFT LCD	Displays measurement result
4	NCV detector	2N3904 transistor	Detect AC electric fields
5	Alarm	Buzzer and LED	Provides warning
6	Calibration button	Push button	Runs calibration
7	Reset button	Push button	Clears alarm status
8	IoT platform	Blynk IoT Platform	Remote monitoring

Based on Table I, the ESP32 DevKit V1 is used as the control center to read and process sensor data and send measurement results to the Blynk platform. The GY-521 MPU6050 is used to measure three-axis acceleration for machine vibration monitoring, while the 2N3904 transistor-based NCV circuit is

used to detect the presence of an AC electric field. The measurement results are displayed on a 2.4-inch TFT LCD. The buzzer and LED serve as alarms, while the calibration and reset buttons are used to initiate the sensor calibration process and clear the alarm status.

Figure 3 shows the electrical circuit and component configuration of the monitoring device.

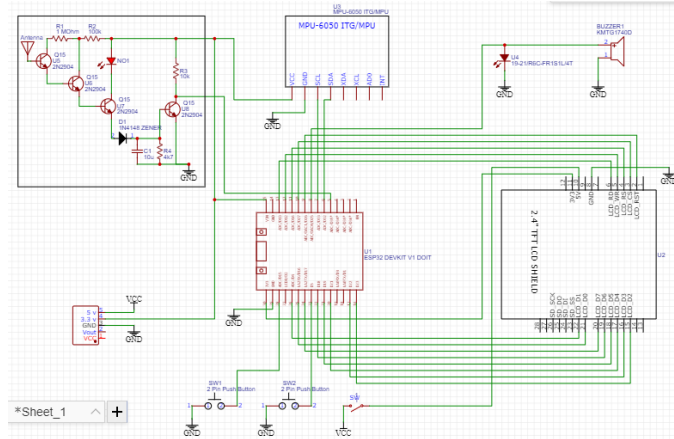


Figure 3. Electrical diagram and sensor configuration

Figure 4. Shows the entire circuit housed in a box measuring approximately $180 \times 100 \times 70$ mm. On the front of the box are a TFT LCD, indicator LEDs, a calibration button, and a reset button. The box is designed to protect the circuit and facilitate operation of the device.

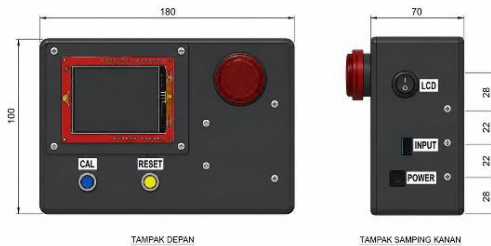


Figure 4. Hardware design of the monitoring device

D. Non Contact Voltage (NCV) Design

The NCV sensor is designed using a 2N3904 transistor arranged in darlington configuration. The NCV detector does not directly measure the current flowing through the machine body. Instead, it detects the alternating electric field generated by an object having an AC potential difference relative to ground. An energized object and the sensor antenna form a small parasitic capacitance, C_p . The displacement current induced in the antenna can be approximated by;

$$I_{ind} = 2\pi f C_p V_{RMS} \quad (1)$$

where f is the AC frequency and V_{RMS} is the voltage of the energized object. For example, assuming a parasitic capacitance of 1 pF, a voltage of 220 V, and a frequency of 50 Hz, the induced current is approximately 69 nA. If the parasitic capacitance increases to 5 pF because the antenna is positioned closer to the object, the induced current increases to approximately 346 nA.

Because the induced current is very small, the signal is amplified through the darlington 2N3904 transistor stages. The amplified signal charges the 1–10 μ F capacitor connected to the base of the output transistor. Together with the 4.7 k Ω resistor, this capacitor produces a time constant ranging from approximately 4.7 to 47 ms, which helps stabilize the detection signal. When the output-transistor base voltage reaches approximately 0.65 V, the transistor turns on and pulls the output voltage to a LOW logic level. Without a detectable AC electric field, the output transistor remains off, and the 10 k Ω pull-up resistor maintains the output at a HIGH logic level. Therefore, a LOW output indicates the presence of a sufficient AC electric field, whereas a HIGH output indicates that the detected field is below the circuit threshold.

The detection result should be interpreted only as an indication that the object is energized by an AC voltage. It does not directly prove the magnitude of the load current, leakage current, or actual voltage. The detection sensitivity is influenced by the antenna distance, parasitic capacitance, insulation thickness, grounding condition, and environmental noise. Figure 5 shows schematics diagram of NCV detector.

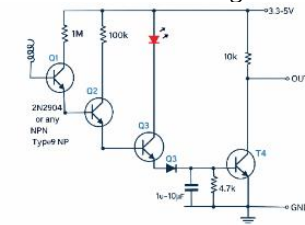


Figure 5. Non-Contact Voltage (NCV) detector schematic design

E. Vibration Acceleration Measurement

Although the spot welding machine remains fixed at its installation position, the pneumatic cylinder and electrode move downward and upward during each welding cycle. When the electrode contacts the workpiece, the impact produces small transient oscillations in the cylinder and machine structure. These motions cause changes in velocity over time and therefore generate acceleration that can be detected by the MPU6050. In this study, vibration is represented by its acceleration response in m/s^2 , which indicates the intensity of the mechanical motion and impact. This value is different from vibration frequency in hertz, which represents the number of oscillation cycles per second. Since the system does not perform frequency-domain analysis, such as a Fast Fourier Transform, the vibration frequency is not calculated in this study.

The MPU6050 accelerometer measures acceleration along the X, Y, and Z axes. Because these three axes are mutually perpendicular and machine vibration may occur in more than one direction, the acceleration components are combined into a resultant acceleration using Equation (2).

$$a_{total} = \sqrt{a_{x,i}^2 + a_{y,i}^2 + a_{z,i}^2} \quad (2)$$

Equation (2) is derived from the three-dimensional Pythagorean theorem and is used to calculate the magnitude of the resultant acceleration measured by the MPU6050. In this equation, a_{total}

is the resultant acceleration expressed in m/s^2 , while $a_{x,i}$, $a_{y,i}$, and $a_{z,i}$ are the acceleration components measured along the mutually perpendicular X, Y, and Z axes, respectively. The positive or negative sign of each component indicates the direction of acceleration along its corresponding axis. Each acceleration component is squared so that components with opposite signs do not cancel each other and so that the vector magnitude can be calculated. The square root is then applied to return the result to the original acceleration unit of m/s^2 . Although the pneumatic cylinder primarily moves in the vertical direction, the electrode impact can also transmit mechanical responses to the horizontal directions through the cylinder mounting and machine structure. Therefore, the resultant acceleration is used to represent the overall acceleration magnitude detected by the sensor from all three directions. However, this resultant value only represents the magnitude of acceleration and does not indicate the dominant vibration direction or vibration frequency.

When the machine is stationary, the accelerometer still detects gravitational acceleration, sensor offset, and noise. Therefore, the system performs calibration by collecting 500 samples at a nominal interval of 20 ms. The baseline is calculated using the arithmetic mean,

$$a_{\text{baseline}} = \frac{1}{N} \sum_{i=1}^N a_{\text{total},i} \quad (3)$$

where a_{baseline} is the average resultant acceleration under stationary conditions, N is the number of samples, and a_{total} is the resultant acceleration of the i -th sample. The use of an average value provides a more stable reference than a single sensor reading.

The vibration acceleration indicator is then determined from the difference between the current resultant acceleration and the stationary baseline using

$$a_{\text{vibration},i} = |a_{\text{total},i} - a_{\text{baseline}}| \quad (4)$$

This equation is based on the concept of deviation from a reference value, where the baseline represents the stationary condition and a_{total} represents the current machine condition. The absolute value is used because the system evaluates the magnitude of the acceleration change regardless of whether the deviation is positive or negative.

Values below 0.15 m/s^2 are treated as sensor noise and set to zero. The vibration data are subsequently filtered using the exponential moving average equation,

$$EM A_i = \alpha a_{\text{vibration},i} + (1 - \alpha) EM A_{i-1} \quad (5)$$

where $EM A_i$ is the current filtered value, $a_{\text{vibration}}$ is the current vibration value, $EM A_{i-1}$ is the previous filtered value, and α is the smoothing coefficient. In this study, α is set to 0.30, meaning that the filtered output consists of 30% of the current measurement and 70% of the previous filtered value. This weighted-average method is used to reduce short-term fluctuations while maintaining the system's response to changes in machine vibration.

In this study, the acceleration-based vibration indicator refers to the absolute deviation of the resultant acceleration from the

stationary baseline after noise suppression and exponential moving average filtering

F. Program Algorithm

The program begins by initializing the MPU6050 accelerometer, TFT LCD, NCV input, buzzer, control buttons, Wi-Fi connection, and Blynk platform. Communication between the ESP32 and MPU6050 is performed through the I²C protocol. The raw 16-bit acceleration data from the X, Y, and Z axes are converted into m/s^2 using the MPU6050 sensitivity scale of 16,384 LSB/g for the $\pm 2g$ measurement range. The resultant acceleration is then calculated from the three acceleration components.

The calibration and alarm-reset buttons are configured using the internal pull-up resistors of the ESP32. This configuration keeps the input pins at a stable HIGH level when the buttons are not pressed and prevents floating inputs that may cause false button detection. When a button is pressed, the corresponding pin is connected to ground and read as LOW. In contrast, the NCV output is configured as a standard digital input because the NCV circuit already uses an external pull-up resistor. A LOW NCV output indicates the detection of an AC electric field.

During calibration, the system collects 500 resultant-acceleration samples at a nominal interval of 20 ms while the machine is stationary. The average value is stored as the stationary baseline. During operation, the current resultant acceleration is compared with this baseline. The absolute difference is used as the raw acceleration-based vibration indicator. Values below 0.15 m/s^2 are considered sensor noise and set to zero. The data are then filtered using an exponential moving average with a smoothing coefficient of 0.30.

A vibration event begins when the filtered acceleration value reaches 0.50 m/s^2 . During the event, the program stores the highest filtered value as the peak vibration acceleration. When the peak value reaches or exceeds the empirical alarm threshold of 8.0 m/s^2 , the vibration alarm is activated. The vibration and NCV alarms use a latched mechanism, meaning that the warning remains active until the operator presses the reset button. The buzzer produces an intermittent warning at 300 ms intervals, while the TFT LCD displays the vibration value, NCV status, alarm status, and Wi-Fi connection status.

The WiFiMulti function allows the ESP32 to connect automatically to one of several registered Wi-Fi networks. Measurement and alarm data are transmitted to the Blynk platform every two seconds through virtual pins. The transmitted data include the peak vibration acceleration, NCV condition, and alarm status. Therefore, the system supports both local monitoring through the TFT LCD and remote monitoring through the Blynk platform.

Data is sent to the Blynk platform every two seconds. Virtual pin V1 is used for the vibration value, V2 for the NCV status, V3 for the alarm status, and V4 for recording the vibration value. The buzzer sounds at 300 ms intervals when excessive vibration, an AC electric field, or both conditions are detected simultaneously. Figure 6 shows the program flowchart for the monitoring system.

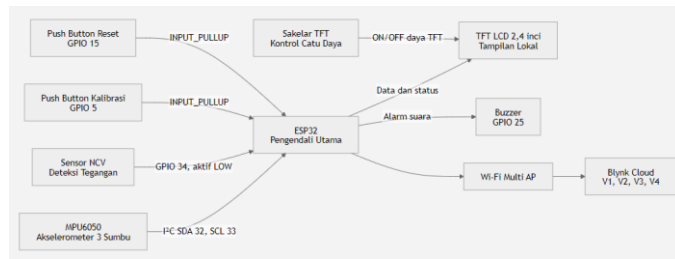


Figure 6. Program block diagram

G. Vibration Acceleration Alarm Threshold

The vibration acceleration alarm threshold is empirically set at 8.0 m/s^2 based on initial system testing. This value is used to distinguish between normal operating vibrations and increased vibrations that indicate abnormal conditions.

The system reports a 'Normal' status when the peak vibration acceleration value is below 8.0 m/s^2 and a 'Vibration Exceed' status when the peak vibration acceleration value reaches or exceeds 8.0 m/s^2 . This threshold value is an initial empirical value. Therefore, further testing with a larger amount of data and a wider variety of machine conditions is still needed to evaluate the accuracy of the threshold value.

H. Testing Procedure

Testing was conducted to ensure that every part of the system functions as intended. The tests included :

1. MPU6050 sensor readings.
2. Sensor calibration process.
3. NCV sensor response.
4. Value display on the TFT LCD.
5. Buzzer and LED response.
6. Functionality of the calibration and reset buttons.
7. Wi-Fi connection.
8. Data transmission to the Blynk platform.

The MPU6050 sensor was mounted on the pneumatic cylinder of the spot welding machine. The sensor position was maintained throughout the entire testing process to allow consistent comparison of readings. Testing was conducted under two conditions: normal operating condition and increased-vibration condition. In the normal condition, the pneumatic pressure was maintained at approximately 2 bar. In the increased-vibration condition, the pneumatic pressure was adjusted to 3 bar to simulate a higher actuator impact during the welding process. Each condition was tested 20 times. The recorded parameters included peak vibration acceleration values, NCV sensor status, and system alarm status.

Peak vibration acceleration values below 8.0 m/s^2 were classified as 'Normal,' whereas values reaching or exceeding 8.0 m/s^2 were classified as 'Vibration Exceed.'

I. Response Time Testing

Response time testing was conducted to determine the time required for each part of the system to produce an output after receiving an input. The components tested included the MPU6050, NCV sensor, TFT LCD, buzzer, LED, reset button, calibration button, and data transmission to Blynk.

Response time is measured from the moment a sensor or button receives input until a status change appears on the TFT

LCD, alarm, or Blynk dashboard. The average response time is calculated using Equation (6).

$$\bar{t} = \frac{1}{n} \sum_{i=1}^n t_i \quad (6)$$

Test parameters include vibration levels, NCV status, alarm status, button response, and data consistency between the TFT LCD and the Blynk platform.

III. RESULT AND DISCUSSION

A. Non Contact Voltage (NCV) Detector

Figure 7 shows a non-contact voltage (NCV) circuit successfully assembled using a 2N3904 transistor on a through-hole PCB. Initial testing was conducted by bringing the sensor antenna close to an AC power source without direct contact. When an AC electric field is detected, the indicator LED lights up and the sensor output can be read by the ESP32.

These results demonstrate that the NCV circuit can indicate the presence of an AC electric field. The sensor produces a digital output indicating either a "safe" or "danger" status. This circuit is not intended to quantitatively measure voltage levels or leakage current.

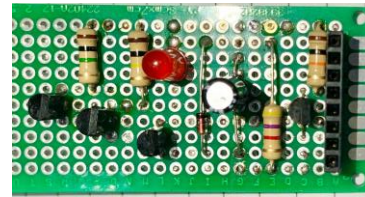


Figure 7. Non-Contact Voltage (NCV) detector assembly result

B. Prototype Assembly Result

The monitoring system prototype was successfully assembled and housed in a protective enclosure. The enclosure was used to protect the electronic components and make the device easier to operate during testing. The front panel of the device features a 2.4-inch TFT LCD, indicator LEDs, a calibration button, and a reset button. The TFT LCD displays vibration readings, NCV status, alarm status, and Wi-Fi connection status. The calibration button is used to set the MPU6050 baseline value when the machine is at rest, while the reset button is used to stop the buzzer and clear the alarm status after a warning condition occurs. The buzzer and indicator LEDs provide local warnings when vibration exceeds the threshold or when the NCV sensor detects an AC electric field. Based on initial testing, all interface components functioned as designed, including the display, buttons, buzzer, and indicator LEDs. Figure 8 shows the assembled monitoring system prototype..



Figure 8. Implemented prototype of monitoring device

C. Function Test Result

TABLE II
RESPONSE TIME OF MONITORING SYSTEM

No.	Process Stage	Average Respon Time
1	MPU6050	0.1 s
2	NCV Detector	0.2 s
3	TFT LCD	0.1 s
4	Buzzer & LED alarm	0.2 s
5	Data transfer to cloud	0.5 s
6	Reset button	0.2 s
7	Calibration Button	0.2 s

Table II shows the results of response time testing for each component of the monitoring system. The MPU6050 sensor and TFT LCD had the fastest response time, at 0.1 seconds. The NCV sensor, buzzer, alarm LED, reset button, and calibration button had an average response time of 0.2 seconds. Meanwhile, the process of sending data to the Blynk platform took the longest, at 0.5 seconds. These differences are influenced by the communication process via the Wi-Fi network and the internet connection.

Overall, the system's response time ranges from 0.1 to 0.5 seconds. These results indicate that the system can be used for real-time monitoring of machine conditions.

D. System Integration Result

As shown in Figure 9, the monitoring device is mounted on the spot welding machine. The MPU6050 sensor is positioned on the pneumatic cylinder so that vibrations during the welding process can be detected. The sensor's position is maintained throughout the testing, as any change in position could affect the measurement values.

The NCV sensor is used to detect AC electric fields near the machine's surface. Data from both sensors is processed by the ESP32, then displayed on the TFT LCD and transmitted to the Blynk platform. The buzzer and LED activate when vibration levels reach the alarm threshold or when the NCV sensor detects an AC electric field.

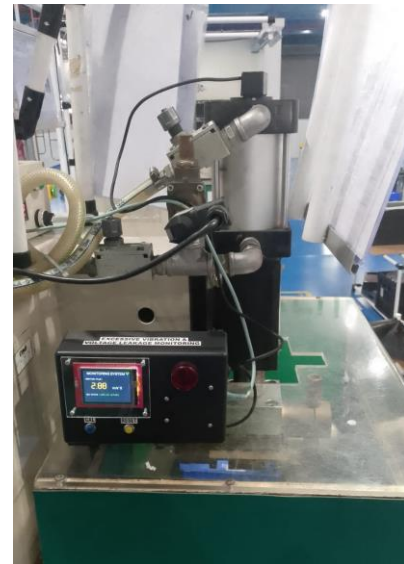


Figure 9. Monitoring device integration on spot welding machine

E. Vibration Data Result

TABLE III
VIBRATION DATA UNDER NORMAL OPERATING CONDITIONS

No.	Peak Vibration Acceleration (m/s ²)	NCV Status	Alarm
1	5.44	Safe	Normal
2	1.40	Safe	Normal
3	6.79	Safe	Normal
4	2.78	Safe	Normal
5	1.18	Safe	Normal
6	3.89	Safe	Normal
7	5.93	Safe	Normal
8	3.02	Safe	Normal
9	3.76	Safe	Normal
10	0.90	Safe	Normal
11	6.20	Safe	Normal
12	5.32	Safe	Normal
13	5.30	Safe	Normal
14	5.60	Safe	Normal
15	6.10	Safe	Normal
16	4.21	Safe	Normal
17	2.89	Safe	Normal
18	3.30	Safe	Normal
19	4.28	Safe	Normal
20	5.50	Safe	Normal

Table III shows the measurement results under normal conditions. Based on 20 tests, the peak vibration acceleration values ranged from 0.90 to 6.79 m/s². The mean peak vibration acceleration was 4.19 m/s², with a standard deviation of 1.76 m/s².

All vibration acceleration values under normal conditions were below the alarm threshold of 8.0 m/s². The system displayed a "Normal" status in all tests. The NCV sensor also indicated a "Safe" status, indicating that no AC electric fields were detected on the machine's surface.

Table IV presents the vibration acceleration measurement results under increased-vibration conditions. In this test, the pneumatic pressure was adjusted from the normal setting of approximately 2 bar to 3 bar. The increase in pneumatic pressure produced a stronger actuator impact during the welding cycle, which resulted in higher vibration values compared with the normal condition.

TABLE IV
VIBRATION DATA UNDER INCREASED-VIBRATION CONDITIONS

No.	Peak Vibration Acceleration (m/s ²)	NCV Status	Alarm
1	7.80	Safe	Normal
2	8.12	Safe	Vibration Exceed
3	8.98	Safe	Vibration Exceed
4	7.50	Safe	Normal
5	9.15	Safe	Vibration Exceed
6	8.20	Safe	Vibration Exceed
7	8.20	Safe	Vibration Exceed
8	8.04	Safe	Vibration Exceed
9	7.89	Safe	Normal
10	8.21	Safe	Vibration Exceed
11	8.22	Safe	Vibration Exceed
12	7.10	Safe	Normal
13	8.80	Safe	Vibration Exceed
14	8.90	Safe	Vibration Exceed
15	7.14	Safe	Normal
16	7.21	Safe	Normal
17	8.70	Safe	Vibration Exceed
18	8.21	Safe	Vibration Exceed
19	8.34	Safe	Vibration Exceed
20	8.90	Safe	Vibration Exceed

Based on Table IV, the vibration acceleration values under increased-vibration conditions ranged from 7.10 to 9.15 m/s², with a mean value of 8.18 m/s² and a standard deviation of 0.62 m/s². Compared with the normal condition, the vibration acceleration values increased after the pneumatic pressure was adjusted to 3 bar. This result indicates that changes in pneumatic pressure affect the vibration response of the spot welding machine during operation. Of the 20 tests conducted under increased-vibration conditions, 14 resulted in a “Vibration Exceed” status, while six tests still resulted in a “Normal” status because their peak vibration acceleration values remained below the 8.0 m/s² threshold. These six values were 7.80, 7.50, 7.89, 7.10, 7.14, and 7.21 m/s². The NCV sensor continued to indicate a “Safe” status throughout all tests.

F. System Performance Discussion

The system did not generate any false alarms during the 20 tests under normal conditions. Under increased-vibration conditions, the system successfully detected 14 out of 20 tests, while six tests were still classified as normal. Based on the predefined test-condition labels and the empirical 8.0 m/s² threshold, the classification performance achieved a sensitivity of 70%, specificity of 100%, and accuracy of 85%. An alarm threshold of 8.0 m/s² effectively prevents false alarms under

normal conditions. However, this threshold is unable to detect increased-vibration conditions with vibration acceleration values between 7.10 and 7.89 m/s². Therefore, the threshold value needs to be evaluated through testing with a larger dataset and a wider range of machine conditions. Testing using a reference vibration meter is also necessary to assess the accuracy of the MPU6050 sensor readings.

TABLE V
PERFORMANCE OF THE VIBRATION DETECTION SYSTEM

No.	Performance Parameter	Result
1	True Positive	14
2	False Negative	6
3	True Negative	20
4	False Positive	0
5	Sensitivity	70%
6	Specificity	100%
7	Accuracy	85%

Table V summarizes the system’s performance based on the classification results for normal and increased-vibration conditions. The system achieved a sensitivity of 70%, a specificity of 100%, and an accuracy of 85%. Six instances of increased-vibration conditions were not detected because their vibration values were below the alarm threshold of 8.0 m/s².

IV. CONCLUSIONS

This research successfully developed an Internet of Things-based condition monitoring system for a spot welding machine using an ESP32, MPU6050, non-contact voltage detector, TFT LCD, buzzer, LED indicator, and Blynk platform. The system can monitor machine vibration based on acceleration measurements obtained from the MPU6050, display measurement results in real time, transmit data through a Wi-Fi network, and issue an alert when the peak vibration acceleration reaches the empirically determined threshold of 8.0 m/s². The mean peak vibration acceleration under normal operating conditions was 4.19 m/s², with values ranging from 0.90 to 6.79 m/s², whereas under increased-vibration conditions, the mean was 8.18 m/s², with values ranging from 7.10 to 9.15 m/s². Of the 20 tests under normal conditions, all were successfully identified without triggering any false alarms, while under increased-vibration conditions, the system was able to detect 14 out of 20 tests.

Based on these results, the system has a sensitivity of 70%, a specificity of 100%, and an accuracy of 85%. In general, this device can be used as an early-warning monitoring system to help technicians identify increased machine vibrations, although there are still some increased-vibration conditions that remain undetected because their values fall below the alarm threshold.

For future research, testing should be conducted with a wider variety of data and machine conditions; the MPU6050 sensor readings should be compared with those from a calibrated vibration meter; the alarm thresholds should be reevaluated; and the system should be developed to include multiple warning levels, data history storage, and additional sensors capable of

more accurately measuring voltage or leakage current.

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