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Adaptation of Internet of Things Technology to Measure Energy Consumption Levels to Reduce Ergonomics-Based Work Accidents

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Abstract. *This research focuses on applying Internet of Things (IoT) technology to measure energy consumption levels to reduce work accidents based on ergonomics. Work accidents caused by ergonomic factors, such as physical fatigue and discomfort, can be overcome by understanding and managing energy consumption in the work environment. Comparisons made between IoT-based approaches and traditional methods, such as manual observation and periodic evaluation, are often less efficient and unresponsive to changes in the dynamic work environment. The research methodology consists of three main stages. First, design and implement an IoT system involving intelligent sensors to measure energy consumption and ergonomic factors. Second, real-time data collection by analyzing data using artificial intelligence algorithms. Third, performance comparison between IoT-based and traditional methods through field trials and statistical analysis. The research results are expected to provide new insights regarding the effectiveness and efficiency of IoT technology in managing the risk of work accidents based on ergonomics. Future implications of this research include the potential for widespread use of IoT technology in various industrial sectors to improve worker safety and well-being. In addition, this research can pave the way for developing more sophisticated technological solutions tailored to the specific needs of each sector.*

Keywords: *Internet of things, ergonomic, sensor, Occupational Health and Safety (OHS)*

I. INTRODUCTION

The costs incurred due to work accidents and injuries have become a major concern for many companies. With the development of technology, many prevention and control efforts have been made to minimize the hazards and risks of work accidents. The industrial sector is striving to improve workplace design by addressing mismatches in worker capabilities, workloads, work environments, and human-machine interactions (Häikiö et al., 2020). Work accidents can be prevented by minimizing and implementing appropriate actions and methods, particularly through the development of information technology. Therefore, implementing a work accident prevention strategy can provide significant economic benefits, reducing the costs of handling accidents and the impact on production levels.

Ergonomics seeks to balance work and its characteristics. In some cases, there may be conflicting conditions on the production floor, where workers must produce high-quality products while paying attention to work safety. Nevertheless, many studies have demonstrated the positive impact of applying ergonomic principles in the workplace, job design, and environmental and facility design (Athirah & Nurul Shahida, 2019; Cachada et al., 2019; Elvers, 1999; Wasnik & Jeyakumar, 2016). Ergonomics ensures that workers are comfortable in their work environment, which can lead to the production of high-quality products and increased productivity. This can promote worker safety, physical well-being, and job satisfaction (Sari & Berlianty, 2019; Zavareh et al., 2018a)

Most industries in Indonesia pay more attention to repairing machines and equipment than to improving the design of the place or work system. Therefore, many work systems on the production floor are poorly designed (Chen, 2016;

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Russeng et al., 2019). The risk of the existence of ergonomic principles on the production floor, according to (Meo et al., 2020), will have a negative impact on the workforce. A less ergonomic workplace can cause physical and emotional stress, reduce productivity, and result in poor work quality.

The manufacturing company produces furniture and household accessories made of rattan, water hyacinth, or wood. The products produced include tabletops, baskets, home accessories, light furniture, and wooden floor tiles. This manufacturing company applies a make-to-order system to meet the demand for its export products. In the production process, many workers are involved manually. The application of Occupational Health and Safety (OHS) has not been optimal, so the rate of work accidents from year to year always occurs. In 2018, there were 25 accidents, 21 accidents in 2019, and it is recorded that in the last two years, many workers did not come to work due to fatigue, muscle injury, vision, and vision pain. Identification of existing problems caused by an uncomfortable work environment is crucial, and therefore, it is important to measure the level of fatigue, room temperature, lighting, humidity, and production results to make workers comfortable when they work.

The presence of IoT technology brings many changes in efforts to prevent work accidents in the work environment (Corichi-Herrejón et al., 2021). In fact, work accidents can be caused by internal factors such as worker behavior, lack of understanding, and unpreparedness or negligence of workers, and external factors such as conditions, ecosystems, and work equipment. IoT technology, as mentioned by (Baron, 2020), requires sensors to collect data on both internal and external factors contributing to work accidents. Sensors are attached to devices often used by workers, such as hands, helmets, watches, as well as Personal Protective Equipment (PPE) and others.

The data generated from the installed sensors will produce data on body conditions such as heart rate, saturation, room temperature, humidity, and lighting. Every change in body condition and work environment will be recorded in real time and sent to the server via the internet. This allows the monitoring center to mitigate the potential for work accidents caused by working environmental conditions. The dataset is analyzed by machine learning with specific algorithms. The result will be a prediction of the real conditions of physical workers and the work environment, serving as a reference for supervisors to take preventive measures to avoid work accidents.

Based on the problems mentioned above, the question arises: Can we design an Internet of Things-Based Occupational Health and Safety (OHS) management system with real-time web-based monitoring? The approach used is ergonomics, a socio-technical approach from the top to the lowest level, applied to holistic system design to optimize the system and ensure its harmonious operation (Berlianty & Rachmawati, 2021; Iridiastadi, 2021; Kleiner, 2002)

II. RESEARCH METHOD

IoT has emerged as a transformative force in advancing intelligent system technology, encompassing systems with the capability to think, communicate, and conduct knowledge-based analyses (Corichi-Herrejón et al., 2021; Zavareh et al., 2018b). In an IoT-enabled environment (Balog et al., 2019), a system incorporates sensors connected to a server through the internet, enabling the transformation of physical systems in the real world into counterparts in cyberspace. Three integral components play a crucial role in IoT, namely control, visualization, and interconnection. The control segment employs sensors to detect conditions or circumstances, with the collected data subsequently visualized by the visualization component. Interconnection is essential to facilitate the process of effecting changes (Singh et al., 2020).

IoT System Design

This study gathers heart rate, room temperature, humidity, and lighting information. The data will be sent through an Internet of Things (IoT) system, which will process it to

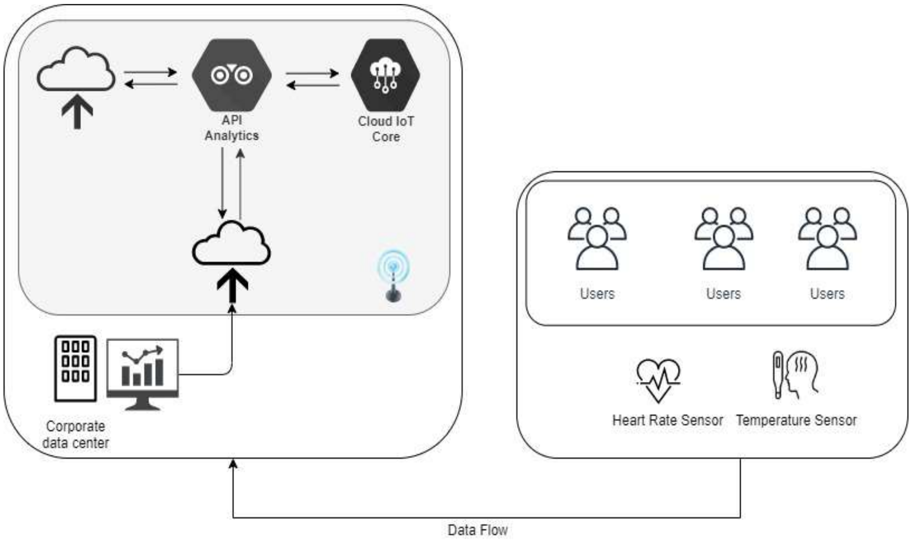


Figure 1. IoT Ergonomic System Design

provide real-time information. To measure energy consumption, we need primary data like heartbeats or pulses, which will be sent by the IoT system and processed for real-time results. Temperature and humidity data will be sent to the server using the MQTT connection protocol. A relay acts as a controller for turning sensors on and off. The control relay receives commands from the server using the MQTT connection protocol. The server's job is to receive, store, and process sensor data and send commands to the control relay using the Node-RED platform. You can see the system diagram in Figure 1.

The results obtained from the IoT system will be processed using an ergonomic approach, including calculations for energy consumption, fatigue levels, lighting, humidity, and room temperature. These calculations will be shown in real-time, allowing corrective actions if they exceedsafety and ergonomic limits. Primary data comes from interviews and documents from the manufacturing company, while secondary data includes results from sensor data processing at specific locations on the shop floor. We use different data types, like facts, attributes, and knowledge from various sources, especially sensor data from IoT devices at 14 points. However, there were challenges during the COVID-19 pandemic, making it difficult to interact directly with companies in the environment. As a result, collecting data using sensors couldn't provide enough information.

Selection of workers to be installed sensors

An essential aspect of this research lies in selecting worker objects on which sensors will be installed. Initially, the number of employees under normal conditions (before Covid-19) was 241 people. However, due to the COVID-19 pandemic, a policy was implemented that allowed only 50% of the workforce to enter the location. However, for data collection purposes and with the approval of the leadership of the manufacturing company, there were no changes in the workers selected for this study. This decision was made to ensure more precise data collection regarding employees' working conditions during the research period.

The research was conducted at a metal foundry company with an observation period of two months, every Monday to Friday, during regular working hours. Installation of the device and explanations given to workers were carried out over one week to improve their understanding, resulting in more accurate data collection. The research variables include 1) independent variable - Measurement Time, 2) dependent variable - pulse rate, and 3)

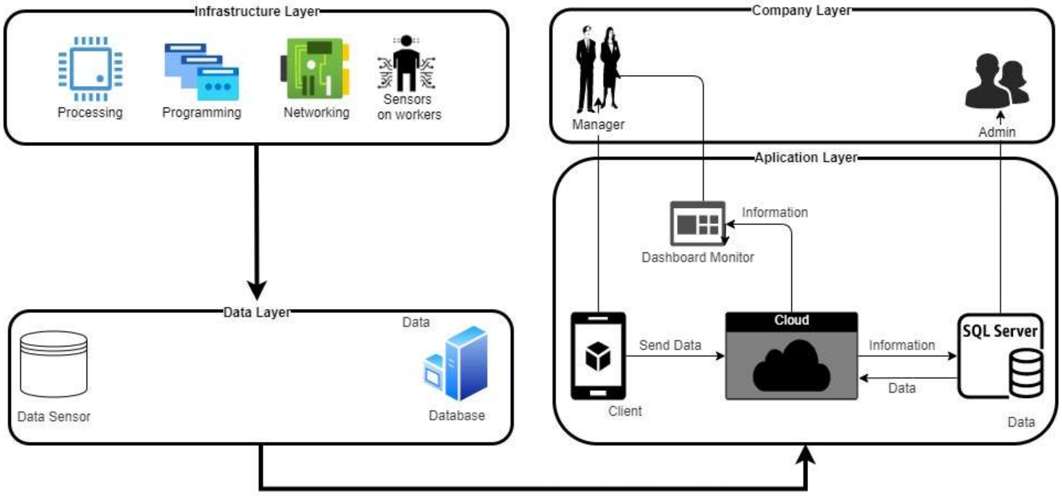


Figure 2. System architecture design

confounding variables, including a) factors that cannot be controlled, such as work attitude, body size, psychological condition, health condition, and age, and b) controlled variables such as gender and workload because the workers sampled have the same gender and workload.

Component Requirements

To meet system requirements, various hardware is required, including sensors, microcontrollers and interconnections. Sensors are essential in reading parameter values such as pulse rate, temperature, humidity, and lighting. Sensor selection is based on its ability to read data accurately and adapt to surrounding environmental conditions, ensuring it meets the specific needs of the connected peripheral.

The microcontroller system is equipped with digital interface (I/O), ADC, and I2C pins for smooth integration with various peripherals. The microcontroller operates on a 5-volt power supply to meet the needs of each sensor. The coding program was developed using Arduino IDE. To meet these specifications, the microcontroller chosen was the Arduino Uno module. The selection of the Arduino module was based on several factors, including cost-effectiveness, broad development environment, open-source nature, availability of various functions that simplify programming, and an interface capable of supporting each sensor. Effectively..

Design Development

The system architecture design consists of four layers: the architecture layer, the data layer, the application layer, and the Business layer. This application is focused on measuring temperature, humidity, noise, and light parameters in the Smart shop floor environment.

Architecture Layer. This layer is responsible for formulating the overall structure and framework of the system. It provides the foundation for the subsequent layers and ensures that the system architecture is organized and scalable.

Data Layer. The data layer handles the storage, retrieval, and management of data. In the context of this design, this layer facilitates the reception and storage of data from temperature, humidity, noise, and light sensors.

Application Layer. Positioned above the data layer, the application layer serves as the intermediary between the user interface and the data layer. It manages the flow of data, executes business logic, and plays a crucial role in processing data from temperature, humidity, noise, and light sensors.

Business Layer. At the topmost layer is the Business layer, encapsulating the core business logic and rules governing the system. In this research context, it oversees the processing of data from temperature, humidity, noise, and light sensors using a validation model, ultimately generating supervision recommendations based on predefined criteria.

The operational flow within this architecture involves the measurement of temperature, humidity, noise, and light parameters by sensors embedded in the client application. This data is then transmitted over the internet to the application server. Upon reaching the server, the received data undergoes comprehensive processing using a validation model. This model applies predefined criteria to ensure the accuracy and reliability of the data.

The outcome of this processing is a set of supervision recommendations systematically stored in the database. These recommendations provide valuable insights into the implementation of Occupational Health and Safety (OHS) on the Smart shop floor.

To facilitate easy access and interpretation of these recommendations, an intuitive dashboard is employed within the system. This dashboard provides users with a user-friendly interface to view and analyze monitoring recommendations efficiently. The structured presentation of information on the dashboard enhances the overall user experience and enables prompt decision-making based on the real-time OHS data collected and processed by the system.

Physical Workload Assessment

Assessing workers' physical load involves calculating heart rate, serving as a benchmark for workload determination. It is established that as the workload increases, so does the energy consumption. The evaluation of workers is executed by appraising the energy expended during work, which is assumed to correlate with oxygen intake (beats per minute). This measurement adopts the Kilbon approach, as outlined in the cardiovascular strain method with the 10 beats approach by Huda and Suwandi (2018), expressed through the following equation:

$$Pulse\ (beats/minute) = \frac{10\ Beats}{Calculation\ Time} x60 \qquad (1)$$

Then calculate the Reverse Heart Rate (HR Reverse) which is expressed in a percentage that can be calculated using the formula (Iridiastadi, 2021; Nurmianto et al., 2021) as follows:

$$\%\ HR\ Reverse\ = \frac{DNK-DNI}{DN_{max}-DNI} x100 \qquad (2)$$

where:

DN_{max} = (220 – age) for male and (200 – age) for female
DNI = average pulse rate before work
DNK = average pulse rate at work

Based on the increase in DNK compared to DN_{max}, the cardiovascular load value can be determined as follows.

$$\%CVL\ = \frac{100x\ (DNK-D\quad)}{DN_{max}-DNI} \qquad (3)$$

From the results of the calculation of the % CVL, it is then compared with the classification that has been determined in (Nurmianto, 2003) as follows:

Table 1. Classification of Light Weight Workload Based on % CVL

% CVL	Classification % CVL
< 30 %	No fatigue
30 % - 60 %	Repair needed
60 % - 80 %	Work in short time
80 % - 100 %	Immediate action needed
> 100 %	No activity allowed

In determining energy consumption (Nurmianto, 2003; Saeidifard et al., 2018) determined by calculating using the following equation:

$E = 1{,}80411 – 0{,}0229038\ X + 4{,}71733 \cdot 10^{-4}\ X^2$

where:

E = Energy (Kcal/minute)
X = Heart rate/pulse (beats/minute)

III. RESULT AND DISCUSSION

Application testing will be conducted on the developed system and devices to ensure a robust application. Four testing processes have been implemented, commencing with the evaluation of data reading capabilities, followed by testing signal transmission, validating the process of transforming sensor data into the database and concluding with the assessment of the visualization process..

Testing of Data Retrieval Device

This test aims to verify the data capture device's proficiency in capturing data and transmitting it to the device. A procedure performed on a data capture device involves a series of sequential tasks. The first circuit focuses on outdoor temperature readings, followed by the second through fourth circuits, which are used to read indoor and production floor temperature sensors. The fifth array is intended to read worker heartbeats, which are then sent to the device gateway.

Data Transfer Test

Testing was conducted to assess the optimal data transmission capability from the sensor to the gateway. The underlying assumption is that the distance between the monitoring room and the workshop is 710 meters. This testing phase specifically evaluates the transmitter signal strength and available bandwidth. The results show a transmit power of 26 dB and a bandwidth of 32,000 bits per second..

Testing Data Delivery to Database

This test is carried out to ensure the time interval required for data reception from the device gateway to the database server. The test results show that the average time for sending data from the gateway device to the database is 0.57 minutes.

The Process of Visualizing Data on the Web Interface

Key findings from the three-week trial involving 42 workers in designated testing rooms have revealed exciting insights into the complex dynamics of worker wellbeing. From this observation period, data from sensors recorded 5 workers experiencing fatigue. This fatigue determination is derived from a comprehensive data set, including heart rate, room temperature, lighting, and humidity metrics. The correlation of these factors underscores the significant influence of age, heart rate, and work environment comfort on employee energy consumption levels, as explained in Figure 4. The results of this trial provide a different understanding of the various elements that impact worker vitality and energy levels in the monitored environment.

This research is to carefully validate the system's suitability developed with the objectives determined initially. The inspection process primarily focuses on checking the web interface's functionality, ensuring alignment with the predefined design and intended purpose. This comprehensive way of testing requires a thorough evaluation of all tasks within the web interface, and the results unequivocally confirm that each function operates exactly as intended.

The hardware implementation phase involves carefully manufacturing the complete system hardware components, with the Arduino Uno microcontroller module serving as the control centre. Microcontrollers are intricately connected to sensors and data transmission systems, forming a cohesive sensor node unit. Simultaneously, the gateway server node deftly receives the data sent by the sensor nodes and stores it in a dedicated database, thus forming a strong foundation for system functionality.

On the software side, the implementation is divided into two components: the software on the microcontroller and the gateway server. Programming for the microcontroller system was carefully created using Arduino, and the results validate the sensor's proficiency in generating data, an important aspect shown in Figure 3. Careful attention to software development ensures smooth operation and accuracy of the entire system.

The integration of three critical components—Arduino, MQTT, and API—was completed through the Freed Node program. The program provides a browser-based editor, facilitating seamless interaction between various nodes in the palette with just one click runtime. This collaborative strategy serves as a linchpin, ensuring hardware and software components' cohesion and operational effectiveness. Successful implementation of this approach

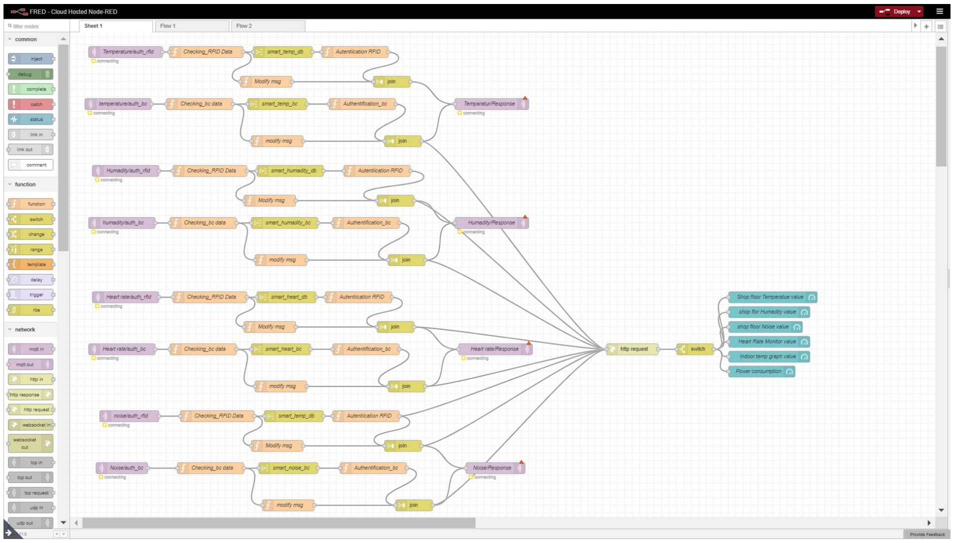
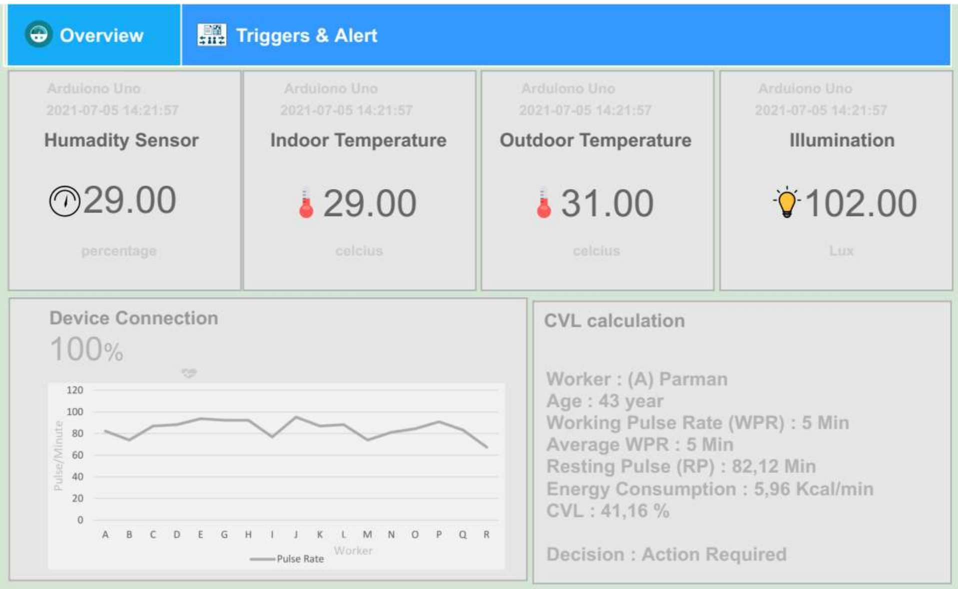


Figure 3. Fred-Node runtime display



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Outdoor Temperature
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Illumination
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Lux

Device Connection
100%

CVL calculation

Worker : (A) Parman
Age : 43 year
Working Pulse Rate (WPR) : 5 Min
Average WPR : 5 Min
Resting Pulse (RP) : 82,12 Min
Energy Consumption : 5,96 Kcal/min
CVL : 41,16 %

Decision : Action Required

Figure 4. User interface display

strengthens the development of functional and goal-oriented systems.

In a 3 week trial involving 42 workers in the testing room, 5 workers were recorded as experiencing fatigue as evidenced by data on heart rate, room temperature, lighting and humidity received from the sensors. This underlines the influence of factors such as age, heart rate and work environment comfort on employee energy consumption, as illustrated in Figure 4. The trial results provide valuable insight into the complex interactions between variables that influence worker well-being and performance. Energy levels in the monitored environment.

This system is comprised of client applications, server applications, and dashboards. The client application, designed for Android smartphones, operates seamlessly. The server and dashboard applications are PHP-based and accessible through the Internet. Specific software is necessary for developing applications within this system.

Table 3. Recapitulation of Workers' Heart Rate Calculations

Worker	Age	Average Working Pulse Rate (WPR) (seconds)		Average WPR (Second)	Resting Pulse (RP) (second)
		8-12 AM	12-16 PM		
A	43	5,0	4,9	5,0	7,3
B	45	5,2	5,0	5,1	8,1
C	45	5,4	5,1	5,3	6,9
D	34	5,7	5,4	5,6	6,8
E	33	5,4	5,1	5,3	6,4
G	47	5,1	4,7	4,9	6,5
H	45	5,4	5,1	5,3	6,5
I	42	5,1	4,7	4,9	7,8
J	41	5,3	5,0	5,2	6,3
K	32	5,9	5,6	5,8	6,9
L	34	5,8	5,4	5,6	6,8

Table 4. CVL classification and Energy Consumption

Worker	Age	Average WPR (minute)		Average WPR (minute)	Resting Pulse (minute)	Average Energy Consumption (Kcal/minute)		%CVL	Classification
		08-Dec	13-16			08-Dec	13-16		
A	43	120	122,45	121,21	82,19	5,85	6,07	41,16	Action Required
B	45	115,38	120	117,65	74,07	5,44	5,85	43,17	Action Required
C	45	111,11	117,65	114,29	86,96	5,08	5,64	31,04	Action Required
D	34	105,26	111,11	108,11	88,24	4,62	5,08	20,33	No Fatigue Occurs
E	33	111,11	117,65	114,29	93,75	5,08	5,64	22,02	No Fatigue Occurs
G	47	117,65	127,66	122,45	92,31	5,64	6,57	37,35	Action Required
H	45	111,11	117,65	114,29	92,31	5,08	5,64	26,58	No Fatigue Occurs
I	42	117,65	127,66	122,45	76,92	5,64	6,57	45,04	Action Required
J	41	113,21	120	116,5	95,24	5,26	5,85	25,39	No Fatigue Occurs
K	32	101,69	107,14	104,35	86,96	4,35	4,77	17,21	No Fatigue Occurs
L	34	103,45	111,11	107,14	88,24	4,48	5,08	19,34	No Fatigue Occurs

The measurement outcomes at each point illustrate the frequency results from sensors to the database. Notably, the input frequency aligns with the output frequency. The measured amplitude registers a decrease to 1.8 V. Summarizing the measurements for each worker using the tool reveals varying heart rate values, as depicted in Table 3.

Upon further analysis using equations (1), (2), and (4) based on the table, calculations are performed to ascertain the percentage of CVL and classify energy consumption. The derived results are then presented in Table 4.

IV. CONCLUSION

In this comprehensive study, we have successfully implemented an Internet of Things (IoT) system specifically designed for measuring the fatigue level of workers, referred to as Ergo-IoT. This innovative system integrates Ergonomics principles to enhance workplace well-being. Each device within Ergo-IoT has demonstrated proficiency in recording and transmitting crucial data points, including pulse, humidity, illumination, and temperature.

The meticulous function testing of the web interface has yielded positive and expected results, affirming the effectiveness of the implemented system. However, recognizing the need for continuous improvement and in-depth understanding, conducting an extended testing process is imperative. This extended testing duration will provide insights into the long-term performance and durability of the tools and allow for a comprehensive evaluation of the system's robustness under prolonged usage scenarios. This step is crucial for ensuring the reliability and sustainability of Ergo-IoT in real-world applications, contributing to the advancement of ergonomic solutions in occupational settings.

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