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Design of an automatic drinking water filling system using an IoT-based microcontroller for SME

Perancangan sistem pengisian air minum otomatis dengan menggunakan mikrokontroler berbasis Internet of Things (IoT) untuk IKM

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ABSTRACT

Beverages and other commodities packaged in bottles for small and medium industries (SMEs) generally require a relatively long production time. This process is significantly dependent on the workers' skills to achieve higher production costs and low efficiency. Therefore, this research designed an automated water-filling device for improving and monitoring SMEs productivity in real-time. The system comprises four types of sensors, namely ultrasonic, temperature, TDS (total dissolved solids), and proximity. The ultrasonic and temperature sensors measure the water level and temperature in the holding tank. The TDS sensor measures the value of substances or particles dissolved in the water, while the proximity sensor detects and counts the number of bottles. Sensor readings are displayed on the LCD (liquid crystal display) and can be monitored via a smartphone using the Blynk application. In conclusion, the existing automation system accompanied by an IoT-based monitoring system can help SMEs to check the quality and efficiency of production in real-time.

ABSTRAK

Produk minuman botol atau produk lainnya yang dikemas dalam botol pada industri kecil menengah (IKM) umumnya memerlukan waktu produksi yang relatif lama yang ditentukan oleh skill karyawan. Hal ini dapat berdampak pada besarnya pengeluaran biaya produksi dan tingkat efisiensi produksi yang rendah. Penelitian ini bertujuan untuk membuat alat pengisi air secara otomatis dan dapat dimonitoring secara real-time sehingga dapat menigkatkan produktivitas IKM. Alat ini memiliki empat jenis sensor yang digunakan, yaitu sensor ultrasonik, sensor suhu, sensor TDS (total dissolved solids), dan sensor proximity. Sensor ultrasonik digunakan untuk mengukur level air pada tangki penampung, sensor suhu digunakan untuk mengukur temperatur air pada tangki penampung, sensor TDS (total dissolved solids) digunakan untuk mengukur nilai zat atau partikel yang terlarut pada air, dan sensor proximity digunakan untuk mendeteksi posisi botol dan sebagai penghitung jumlah botol. Hasil pembacaan sensor ditampilkan di LCD (liquid crystal display) dan dapat dimonitoring melalui smartphone dengan aplikasi Blynk secara real-time dengan tingkat akurasi diatas 2%. Dengan sistem otomasi yang ada yang disertai dengan sistem monitoring berbasis internet of things (IoT) dapat membantu pelaku IKM untuk mengecek kualitas dan produktivitas proses produksi secara real-time.

1. Introduction

The need for small and medium-sized enterprises (SMEs) to increase productivity and reduce production costs by replacing manual systems with automated techniques is essential to increase profitability and reduce the time needed for each production cycle (Borah et al., 2022; Jung et al., 2021). According to (Bouhamadi et al., 2019), production automation is the process of replacing coordination tasks previously performed by humans with a computer control system.

Automation, within the scope of industrialization, is the process of significantly reducing the role of human operators from the mechanized system through computers (Paryanto et al., 2014). Automation systems can be carried out in almost all production lines, from receiving goods, manufacturing processes, filling, and packaging to shipping (Abubakar et al., 2020). Currently, most of the industrial automation systems in SMEs still monitor and record production outcomes manually on paper, which is time-consuming (Paryanto et al., 2022). Therefore, it is necessary to combine automation systems with Internet of things (IoT) technology, to ensure production results are monitored in real-time.

At SMEs beverages, the average product filling task is still carried out manually, hence an automated machine is needed to fill and pack liquid products. According to (Nainani et al., 2018), there is an increase in the use of automation in the bottle-filling industry. This technology requires using a Programmable Logic Controller (PLC) or a microcontroller such as Arduino, which is the main control in the production system of large industries. PLC is used as digital computer to automate industrial activities (Liton Ahmed et al., 2019).

Qing et al. (2018) designed and implemented an automatic machine to fill bottles with liquids using PLC control. However, this system is quite expensive and usually used for large-scale industries.

This led to the design of the Arduino system by Sidik and Ghani (2017) to measure volume when filling water, which comprises a solenoid valve used to open and close the water channel. The experimental results showed that the processing system is time-consuming, hence it is unproductive. Faimeed et al. (2022) also developed a control system for automatic bottle filling using Arduino Uno. However, the design to close the bottle was conducted manually, which increased costs and production time.

This research aims to create an automation system for SMEs beverages with real-time monitoring features based on IoT. The novelty is perfecting existing designs to ensure control and monitoring systems are carried out remotely without errors (Liu et al., 2021). This design is very suitable for SMEs, which require flexibility in working hours and workers' skills. It will enable the production process to run smoothly with minimal costs and increased productivity.

2. Research method

2.1. Fabrication of component *wiring*

Component *wiring* is important in developing automation systems and monitoring water filling. Understanding component *wiring* will make it easier to design and connect electronic components to *the microcontroller*. The component *wiring* in this study was developed using *Fritzing software* and components of Arduino Mega, as shown in Figure 1.

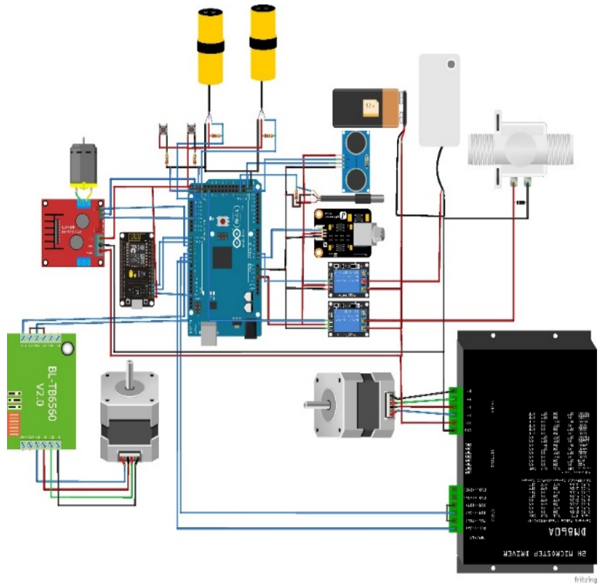

Figure 1. Wiring diagram of the automation system and monitoring of water filling.

2.2. Tools and Materials

The tools and materials used to create an automatic drinking water-filling monitoring system are software and hardware. The software includes Arduino IDE (Integrated Development Environment), SolidWorks, Fritzing, and the Blynk IoT Application. The following is a list of hardware used in the design and development process:

- Laptop
- Arduino Mega
- Esp8266
- Water Temperature Sensor
- *Proximity* sensor E18 D80nk
- TDS sensors
- Ultrasonic Sensors
- DC motors
- Stepper Motors
- L298n drivers
- Tb6560 drivers
- Tb6600 drivers
- LCDs 20x4
- *Power Supply & cable*.

2.3. Mechanical design

The mechanical design consisted of making conveyors, stepper motor stands, conveyor belts, and stands for DC motors designed using SolidWorks software. Tool design starts with designing a prototype using this software, which makes it easier to create designs according to their specifications. The process of manufacturing a 3D design was done sequentially. Furthermore, the parts were merged by opening the assembly on the SolidWorks menu, as shown in Figure 2.

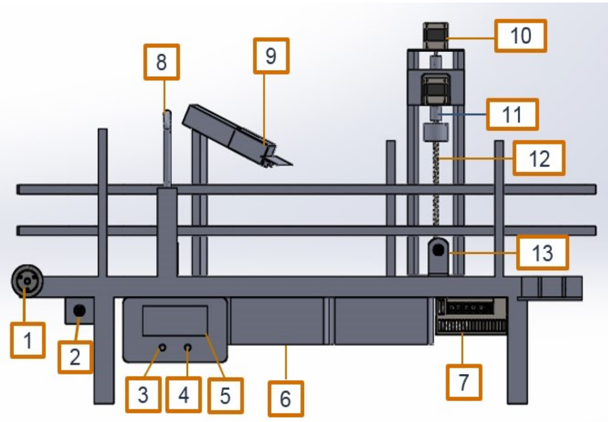

Figure 2. Drinking water filling prototype design.

1. Pulley teeth 40
2. Pulley teeth 16
3. Display
4. On button
5. Off button
6. Electronic box
7. Microcontroller
8. Water fill line
9. Bottle cap holder
10. Stepper motors
11. Bottle cap chuck
12. Lead screw
13. Proximity sensor.

3. Results and discussion

3.1. Design results

Prototype of the automatic drinking water filling device as shown in Figure 3.

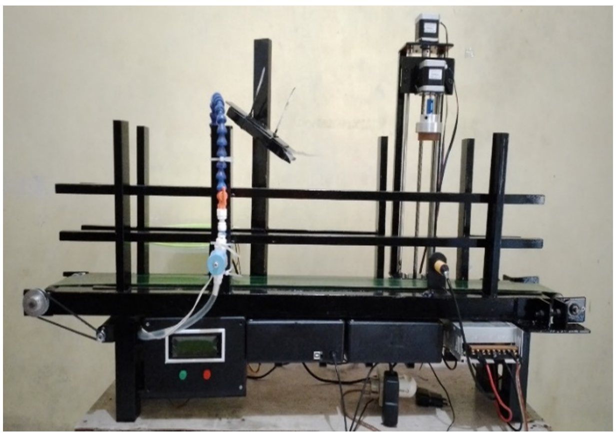

Figure 3. Prototype of an automatic drinking water filling device.

This research was carried out using four types of sensors, namely ultrasonic, temperature, TDS, and proximity. Furthermore, a conveyor system with a 12-volt pump and a solenoid valve was used to move water from a holding tank to a bottle using the solenoid valve. This tool functions as a drain to prevent water from returning to the holding tank due to gravity. Meanwhile, a stepper motor, such as a linear actuator system, was used as the propulsion to tighten the bottle cap, as shown in Figure 3.

3.2. Testing of the HC-SR04 ultrasonic sensor

Ultrasonic sensors are used to measure the water level in the holding tank by putting obstacles at a distance of 2-24 cm according to the tool's dimensions of the sensor testing results are compared with a certain distance, as shown in Table 1.

Table 1.
Comparison results of ultrasonic sensor testing with distance.

No	Testing (cm)		Measurement difference (cm)	Error
	Distance	Ultrasonic sensor		
1	2	2	0	0%
2	4	3	1	25%
3	6	5	1	17%
4	8	8	0	0%
5	10	10	0	0%
6	12	12	0	0%
7	14	14	0	0%
8	16	16	0	0%
9	18	18	0	0%
10	20	20	0	0%
11	22	22	0	0%
12	24	24	0	0%
Average				3.47%

The test results are then used to calibrate the proximity sensor to obtain an error of 0%.

3.3. DS18B20 temperature sensor testing

The temperature sensor calibration uses the linear regression method as the ultrasonic in accordance with the temperature calibration standard. The calibration is carried out by immersing the digital thermometer and temperature sensor in water at 20-31^{o}C. The results of the initial calibration are shown in Table 2.

The calibration graph equations are entered into the temperature sensor program, as shown in Figure 4. Furthermore, the measurements were retaken to determine the difference before and after calibration, as shown in Table 3.

Table 2.
Comparison results of DS18B20 sensor readings and digital thermometers.

No	Measurement (°C)		Measurement difference (°C)	Error
	Digital	Sensors		
1	20.10	18.5	1.60	7.96%
2	21.10	19.75	1.35	6.40%
3	22.40	21.25	1.15	5.13%
4	23.00	22.00	1.00	4.35%
5	24.00	23.25	0.75	3.13%
6	25.20	24.75	0.45	1.79%
7	26.20	26.50	0.30	1.15%
8	27.70	27.50	0.20	0.72%
9	28.40	28.25	0.15	0.53%
10	29.00	29.00	0.00	0.00%
11	31.80	32.25	0.45	1.42%
Average				2.96%

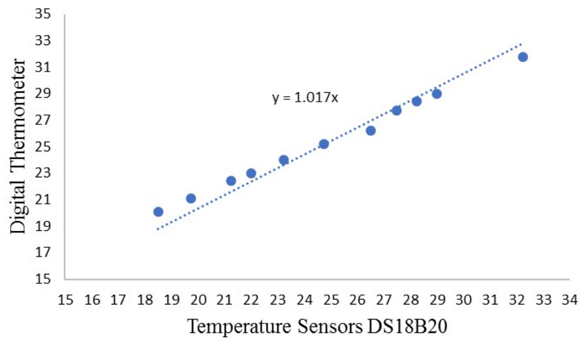

Figure 4. DS18B20 sensor calibration graph.

Table 3.
Comparison test of BS18B20 temperature sensor and digital thermometer.

No	Measurement		Measurement difference	Error
	Digital	sensors		
1	20.10	19.58	0.52	2.59%
2	21.50	20.85	0.65	3.02%
3	22.10	21.61	0.49	2.22%
4	23.00	22.63	0.37	1.61%
5	24.20	24.15	0.05	0.21%
6	25.10	25.17	0.07	0.28%
7	26.10	26.19	0.09	0.34%
8	27.20	27.20	0.00	0.00%
9	28.10	28.22	0.12	0.43%
10	29.00	29.24	0.24	0.83%
11	31.00	31.53	0.53	1.71%
Average				1.20%

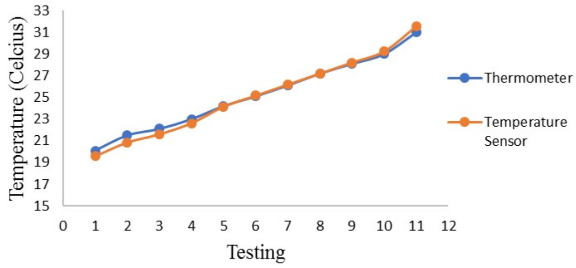

Figure 5. Graph of comparison of temperature sensors and digital thermometers after calibration.

Table 3 shows that there is no significant difference in the sensor and digital measurement values. The highest difference is 0.65, with an average error of 1.2%. Furthermore, the comparison chart in Figure 5 shows no significant difference, hence the sensor is more accurate, with an initial average error of 2.96%, which dropped to 1.2% after calibration.

3.4. TDS sensor testing

TDS and TDS-3 sensors were used to measure three water samples. First, the TDS sensor calibration process was carried out by comparing the measurement values of the sensor and TDS-3 with the results presented in tables and linear graphs using Ms. Excel. After creating a linear graph, an equation was obtained, which was entered into the TDS sensor program. Table 4 is the result of the TDS and TDS-3 sensor measurements.

Table 4.
TDS sensor test results and TDS-3 meters.

No	Measurement		Measurement difference	Error
	TDS meters (ppm)	TDS sensors (ppm)		
1	41	39	02	5%
2	124	100	24	19%
3	126	104	22	17%
4	129	114	15	12%
5	146	129	17	12%
6	154	140	14	9%
7	186	143	43	23%
Average				14%

After creating a calibration graph, a graphic equation was obtained and entered into the ultrasonic sensor program. Furthermore, the measurements were taken again to determine the differences before and after calibration. The following is a table of test results after calibration.

Table 5 shows that the highest difference is 3 ppm with an average error of 2%. The comparison chart after calibration shows no significant difference. Initially, an average error of 14% was obtained, and after calibration, it dropped to 2%, hence the sensor is more accurate.

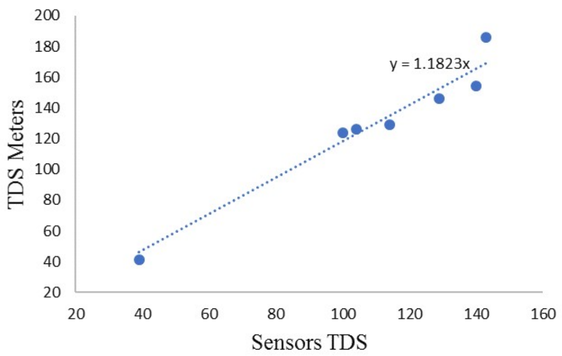

Figure 6. TDS sensor calibration graph.

Table 5
Test results of the TDS sensor and TDS-3 meter after calibration.

No	Measurement		Measurement difference	Error
	TDS meters	TDS sensors		
1	41	43	2	5%
2	124	122	2	2%
3	126	129	3	2%
4	129	127	2	2%
5	146	142	4	3%
6	154	155	1	1%
7	186	186	0	0%
Average				2%

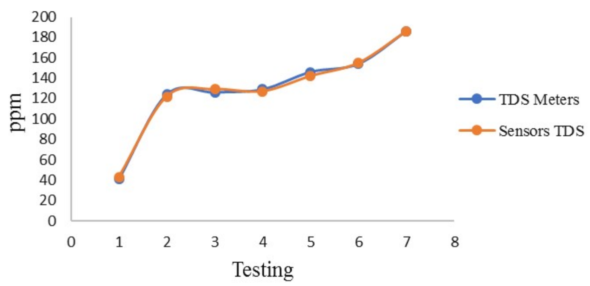

Figure 7. Graph comparison of TDS sensors and TDS-3 meters.

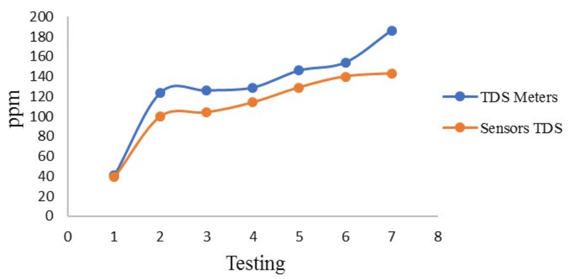

Figure 8. Graph of comparison of TDS sensors and TDS-3 meters after calibration.

3.5. Stepper motor testing

The test was carried out on a stepper motor that moves up and down the bottle cap, which functions as its cover under loaded conditions. Furthermore, tests were conducted 10 times to determine the stability of the time and distance traveled on the leadscrew threaded rod with a rotational speed of 73.125 rpm. The results are shown in Table 6.

Table 6.
The results of testing the stability of the *stepper motor* down motion.

Test-to-	Distance (cm)	Time (s)	*Stepper* motor Speed (RPM)
1	4.4	4.91	73.125
2	4.4	4.91	73.125
3	4.4	4.91	73.125
4	4.4	4.98	73.125
5	4.4	4.71	73.125
6	4.4	4.78	73.125
7	4.4	4.97	73.125
8	4.4	4.9	73.125
9	4.4	4.84	73.125
10	4.4	4.84	73.125

Tables 6 and 7 show that the up and down distance traveled by the stepper motor does not change but remains at a distance of 4.4 cm. Therefore, it can be concluded that the stepper motor works stably at a distance of 4.4 cm, with a difference of 10 trials. However, this does not affect its performance because the error is influenced by the examiner, who uses a cellphone stopwatch as a timer, leading to delay at the start or end.

Table 7.
The results of testing the stability of the stepper motor for the upward motion.

Test-to-	Distance (cm)	Time (s)	Stepper motor Speed (RPM)
1	4.4	4.51	73.125
2	4.4	4.45	73.125
3	4.4	4.52	73.125
4	4.4	4.45	73.125
5	4.4	4.51	73.125
6	4.4	4.45	73.125
7	4.4	4.43	73.125
8	4.4	4.46	73.125
9	4.4	4.45	73.125
10	4.4	4.45	73.125

3.6. Testing of DC motors

This test is carried out to determine the DC motor's ability to function properly or improperly. The load used to test the DC motor was obtained from the conveyor belt. The pulse width modulation (PWM) value used as a DC motor speed regulator was carried out in the test range of 50-225.

Table 8.
DC motor voltage test results.

No	PWM rotating speed	DC motor voltage	
		Load	No Load
1	50	0.44 Volts	4.67 Volts
2	100	5.57 Volts	8.56 Volts
3	150	8.22 Volts	9.31 Volts
4	200	9.38 Volts	10.22 Volts
5	255	10.54 Volts	10.74 Volts

Table 8 shows that the greater the PWM value given, the higher the voltage obtained by the DC motor. For a PWM value of 50, the voltage generated by the DC motor without a load is 4.67 Volts, while the one with a load is 0.44 Volts. The test results obtained with and without a load were 10.59 and 10.74 Volts for the maximum PWM value.

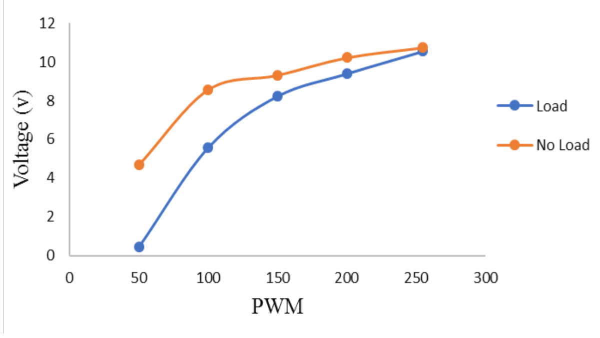

Figure 9. Graph of DC motor voltage comparison.

The voltage comparison graph shows that the load also affects the value of the DC motor. According to the test results, a loaded DC motor produces a lower voltage than when unloaded. This is influenced by its rotational speed because, under loaded conditions, the motor becomes slow. Therefore, the higher the rotation of the DC motor, the greater the voltage generated.

Table 9.
DC motor current test results.

No	PWM Rotate Speed	DC Motor Current	
		Load	No Load
1	50	38 mA	35.8 mA
2	100	101 mA	49.6 mA
3	150	127 mA	52.8 mA
4	200	133.8 mA	61.1 mA
5	255	154 mA	62.9 mA

Table 9 shows the current test of a loaded and unloaded DC motor. For those with a load at 50 PWM, the current generated is 38 mA, while the DC motor without load produces 35.8 mA. These results show an insignificant difference because, at a rotational speed of 50 PWM, the DC motor cannot rotate when loaded to move the conveyor belt. Meanwhile, at the maximum rotating speed of 255 PWM, the current generated with and without load are154 mA and 62.9 mA, which indicates a significant difference.

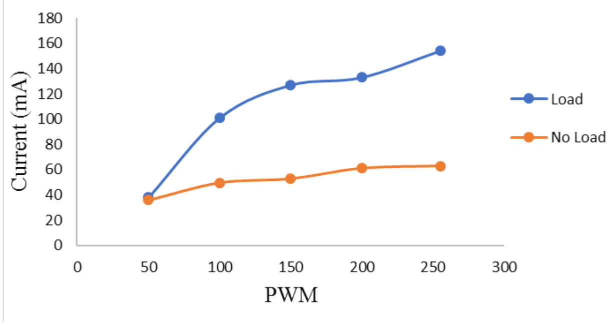

Figure 10. Graph of comparison of DC motor currents.

In Figure 10, the comparison shows that the heavier the load received by the DC motor and the PWM value, the greater the current generated.

3.7. Filling volume testing

This test was conducted 10 times to determine the accuracy of filling drinking water into bottles with a capacity of 500 ml for 30 seconds, which had been entered into the program in the Arduino IDE. The results in Table 10 show that the average error rate, when filled with water, is 1.12%. From these results, the tool has a good level of accuracy because the average error is below 5%.

Table 10.
The results of the water filling test in the bottle.

No	Input volume (ml)	Output volume (ml)	Travel Time (s)	Error
1	500	497	30	0.6%
2	500	495	30	1.0%
3	500	493	30	1.4%
4	500	490	30	2.0%
5	500	497	30	0.6%
6	500	495	30	1.0%
7	500	495	30	1.0%
8	500	490	30	2.0%
9	500	497	30	0.6%
10	500	495	30	1.0%
Average				1.12%

Meanwhile, the bottle filling test result conducted 10 times in 500 ml is shown in Table 11. It can be concluded that a good level of accuracy was obtained with the between the programmed filling time using *a stopwatch* at an error rate of 0.7%.

Table 11.
Comparison of the time of filling the water in the bottle.

No	Filling Result (ml)	Time on program (s)	Filling time (s)	*Error* %
1	500	30	30.22	0.7%
2	500	30	30.36	1.2%
3	500	30	30.3	1.0%
4	500	30	30.2	0.7%
5	500	30	30.02	0.1%
6	500	30	30.14	0.5%
7	500	30	30.16	0.5%
8	500	30	30.16	0.5%
9	500	30	30.23	0.8%
10	500	30	30.17	0.6%
Average				0.7%

3.8. Network coverage test against ESP8266

This test is carried out to determine how far the ESP8266 can capture the network distance to ensure the prototype can carry out its functions properly. This test was conducted with a wifi network from Orbit Telkomsel and carried out in a room with straight conditions without any obstructions. The data graphs were viewed in real-time to determine whether the ESP8266 is connected. The result shows that when the graph displays data in real-time, the ESP8266 is still connected and vice versa.

Table 12.
Wifi range testing against ESP8266.

No	Network coverage distance	Status ESP8266
1	3 meters	connected
2	6 meters	connected
3	9 meters	connected
4	12 meters	connected
5	15 meters	connected
6	18 meters	connected
7	21 meters	connected
8	24 meters	connected
9	27 meters	connected
10	30 meters	connected
11	33 meters	disconnected

The test results in Table 12 show the wifi range of ESP8266 with a distance of 30 meters.

3.9. Testing the response of the Blynk application

The Blynk application was used to determine the response of the working prototype. This test was carried out when proximity sensor 2 counted the number of bottles that had been filled with 500 ml of water.

Table 13.
Blynk response testing.

No	Distance	Blynk's response (second)
1	2 Meters	1.06
2	4 Meters	1.05
3	6 Meters	1.05
4	8 Meters	1.12
5	10 Meters	1.00
6	12 Meters	0.86
7	14 Meters	1.05
8	16 Meters	0.98
9	18 Meters	1.05
10	20 Meters	1.12
Average		1.03

Table 13 shows the response from the Blynk application with an average of 1.03 seconds. From the table, it can be concluded that the wifi distance to ESP8266 does not affect the response of the Blynk application.

3.10. LCD testing

This test was conducted to determine whether the data displayed on the LCD was appropriate. Testing was carried out by comparing the results of the LCD with the Blynk dashboard.

Table 14.
Comparison of LCD with Blynk dashboard.

No	Sensors	LCD display	Blynk view
1	TDS sensors	0	0
2	Water level	88%	88%
3	Temperature sensor	30^{o}C	30^{o}C
4	The number of goods	0	0

The test results in Table 14 show no difference between the values displayed on the LCD and the Blynk dashboard of the sensor data. Therefore, it can be concluded that the LCD is working properly.

3.11. Tool Evaluation

The test results show that each tool component function properly. This tool can automatically fill water in bottles with a volume of 500 ml. Furthermore, it can automatically close bottles using a linear actuator system as an up-and-down drive. Temperature and TDS sensors were also placed in the water storage tank to monitor its quality with another used to count the number of bottles filled with water.

4. Conclusion

In conclusion, this research developed a prototype of a water filling monitoring system using the Arduino

Mega microcontroller. This tool, which comprises four sensors can also be used properly, to fill water automatically. The proximity sensor E18 D80nk is used to detect and count the number of bottles, the ultrasonic sensor detects the water level in the storage tank, while the Ds18b20 temperature sensor measures its temperature. The real-time monitoring system via smartphone with the Blynk application used in this test has an accuracy of less than 2%. This tool has also been successfully implemented to help SMEs become more effective and efficient.

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References

Al Nakib, A., Ahmmad, R., Osman, S., 2018. Design and implementation of PLC based automatic bottle filling. Int. Res. J. Eng. Technol.

Abubakar, A.N., Dhar, S.L., Tijjani, A.A., Abdullahi, A.M., 2020. Automated liquid filling system with a robotic arm conveyor for small scale industries. Mater. Today Proc. 49, 3270–3273. https://doi.org/10.1016/j.matpr.2020.12.923

Borah, S., Kama, C., Rakshit, S., Vajjhala, N.R., 2022. Applications of artificial intelligence in small- and medium-sized enterprises (SMEs). Lect. Notes Networks Syst. 375, 717–726. https://doi.org/10.1007/978-981-16-8763-1_59

Bouhamadi, A., Aboulfatah, M., Sid Ahmed, M.A.O., Mahmoud, M.O.M., 2019. Study of the automatic filling and capping system, using GRAFCET-GEMMA-PLC and winCC flexible. Int. J. Eng. Res. Technol. 12, 736–744.

Faimeed, A., Gajanan, A., Atish, A., Somnath, B., Vishal 5 2 Professor, B., 2022. Automated water bottle filling system. Int. Res. J. Eng. Technol. 1253–1257.

Jung, W.K., Kim, D.R., Lee, H., Lee, T.H., Yang, I., Youn, B.D., Zontar, D., Brockmann, M., Brecher, C., Ahn, S.H., 2021. Appropriate smart factory for smes: concept, application and perspective. Int. J. Precis. Eng. Manuf. 22. https://doi.org/10.1007/s12541-020-00445-2

Liton Ahmed, M., Kundu, S., Rafiquzzaman, M., 2019. Automatic bottle filling system using PLC based controller. J. Adv. Mech. 4, 17–24.

Liu, Y., Ni, Z., Karlsson, M., Gong, S., 2021. Methodology for digital transformation with internet of things and cloud computing: A practical guideline for innovation in small-and medium-sized enterprises. Sensors 21. https://doi.org/10.3390/s21165355

Nainani, S., Rupawate, A., Sayyed, S., Poojary, S., Bodhale, V., Students, U.G., 2018. Automatic Bottle filling system using arduino uno. Int. Res. J. Mod. Eng. Technol. Sci. www.irjmets.com @International Res. J. Mod. Eng.

Paryanto, Brossog, M., Merhof, J., Franke, J., 2014. Mechatronic behavior analysis of a customized manufacturing cell. https://doi.org/10.1007/978-3-319-04271-8_33

Paryanto, D.T., Teknik, F., Diponegoro, U., 2022. Perancangan prototype dan evaluasi alat pemantauan air limbah industri berbasis IoT 24.

Qing, G., Mingda, Q., Jin, X., 2018. Design and implementation of PLC based on BACnet. Mod. Electron. Tech. 41, 38–43.

Sidik, M.H.M., Ghani, S.A.C., 2017. Volume measuring system using arduino for automatic liquid filling machine. Int. J. Appl. Eng. Res. 12, 14505–14509.