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Application of Ultrasonic Sensor and IR Sensor in Automatic Alcohol Hand Sanitizer

Wirote Jongchanachavawat,[1*] Bureerak Sungkongmueng,[1] Chaleedol Inyasri,[1] Ittipat Roopkom,[1] Noppon Mingmuang,[1] Pichamol Putthed,[2] Atiwat Srithammakan,[2] Boonpi Chinowan,[2] Patcharapon Pathomphomma,[2] Peemongkol Kumngern,[3] Suphat Bunyarittikit,[4] and Patchamon Jongchanachavawat[5]

[1]Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University,
38 Moo 8, Chaosamran Road, Nawoong Subdistrict, Mueng District, Phetchaburi 76000, Thailand
[2]Phetchaburi Rajabhat University Demonstration School, Phetchaburi Rajabhat University,
38 Moo 8, Chaosamran Road, Nawoong Subdistrict, Mueng District, Phetchaburi 76000, Thailand
[3]Triam Udom Suksa Pattanakarn Suvarnabhumi School,
199 Soi Romklao 17, Khlong Sam Prawet Subdistrict, Lat Krabang, Bangkok 10520, Thailand
[4]School of Architecture, King Mongkut's Institute of Technology Ladkrabang,
1 Chalong Krung, 1 Alley, Lat Krabang, Bangkok 10520, Thailand
[5]Satrinonthaburi School, Nonthaburi,
120 Pibulsongkram Rd., Suan Yai Subdistrict, Mueang Nonthaburi, Nonthaburi 11000, Thailand

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Hygiene is necessary to maintain human health. Hygiene keeps the body clean and free from germs, preventing the spread of diseases, which has been especially important during the COVID-19 pandemic. For this reason, we designed automatic alcohol hand sanitizers (AAHSs): one with an IR sensor and one with an ultrasonic sensor. The sanitizers will help prevent germs from spreading via the hands of people because no part of each device need be touched during its use. The AAHS with the ultrasonic sensor has various advantages over that with the IR sensor: it is 32% cheaper to produce, easier to configure and maintain, has a higher average score for user satisfaction, is smaller and more portable, and can use rechargeable batteries. In addition, its low cost makes it more suitable for commercialization. It can also be installed both outdoors and indoors. In an outdoor test, it was demonstrated to operate flawlessly. This paper includes useful information on the components of the AAHSs with the two types of sensor and an evaluation of their performance using confusion matrices.

1. Introduction

The world is currently in a pandemic due to the spread of COVID-19, which was first observed in December 2019 in Wuhan, China. The virus is highly contagious, and the World

*Corresponding author: e-mail: wirote.jon@mail.pbru.ac.th
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Health Organization (WHO) has provided various guidelines to reduce its community transmission. One of the recommended actions is to frequently wash the hands with soap or hand sanitizer.(1) Frequent hand washing could reduce the risk of virus transmission by around 55%.(2) Hand hygiene is one of the most important actions to prevent the transmission of pathogenic microorganisms and can reduce the spread of infection, even among high-risk populations.(3) A hand sanitizer dispenser is used to control the amount of alcohol gel or liquid received by the hands. Hand sanitizer dispensers are wall or table-mounted and placed in locations easily accessible to users such as restrooms, corridors, gate entrances, and receptions. Hand sanitizer dispensers come in various forms. Some are automatic, where hands placed underneath a sensor enable the sanitizer to dispense alcohol gel or liquid. An automatic alcohol hand sanitizer (AAHS) helps prevent the spread of infectious viruses in crowded areas such as schools, universities, and shopping malls.(4,5)

Hand hygiene sanitizers(6,7) can be made contactless and automatic in different ways by using various sensors. In general, IR(4,8,9) and ultrasonic(10–12) sensors have been commonly used to produce low-cost sanitizer dispensers. Some sanitizers use sensors(5,13–15) to both detect the hands and monitor the level of alcohol, and devices can use IoT to monitor the levels of water and alcohol. A new light-dependent resistor (LDR) sensor(16) can be used to improve the performance of outdoor hand hygiene sanitizers on a sunny day. Such devices have already been produced and implemented in universities and urban areas. However, there is a significant cost associated with electronic and automated hand hygiene systems.

In this paper, AAHSs were designed with two different types of sensor: an AAHS with an IR sensor and an AAHS with an ultrasonic sensor. Their performance characteristics were compared using confusion matrices.(17–20) It is intended that these two designs will lead to the realization of low-cost devices.

2. Methods

The research methodology used in this study is described in this section. This study can be divided into four steps, as described in the following subsections:

(1) Design
(2) Implementation
(3) Results and satisfaction survey
(4) Summary

2.1 Design

The system architectures of the AAHS with the IR sensor and the AAHS with the ultrasonic sensor are shown in Fig. 1. The main components of the two AAHSs are listed in Table 1. The three main components of both devices are explained as follows.

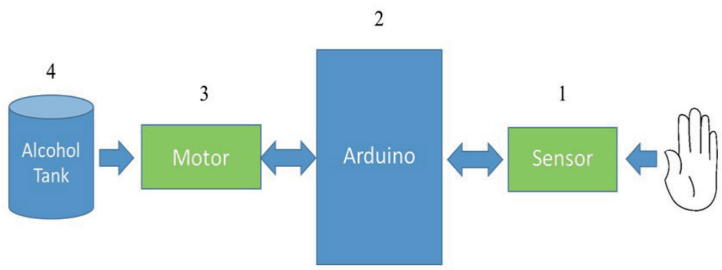


Fig. 1. (Color online) System architecture.

Table 1
Components of AAHS with IR sensor and AAHS with ultrasonic sensor.

Components	AAHS with IR sensor	AAHS with ultrasonic sensor
1. Sensor	IR	Ultrasonic
2. Arduino	Arduino	Arduino
3. Motor	Pump motor	Servo motor
4. Alcohol tank	Yes	Yes

2.1.1 AAHS with IR sensor

IR sensor: The user's hands are placed under the nozzle, before the sensor. The sensor transmits data to the Arduino board.

Arduino board: The Arduino board receives a signal to turn on the pump motor.

Pump motor: The Arduino board activates the pump, which dispenses a specific amount of alcohol liquid (or alcohol gel) from the nozzle.

2.1.2 AAHS with ultrasonic sensor

Ultrasonic sensor: The user's hands are placed under the nozzle, before the sensor. The sensor transmits data to the Arduino board.

Arduino board: The Arduino board receives a signal to turn on the servo motor.

Servo motor: The Arduino board activates the servo motor, which rotates the shaft by 40° to dispense a specific amount of alcohol gel from the nozzle.

2.2 Implementation

The hardware of the two devices was wired as shown in Figs. 2 and 3. However, the components needed coding to allow them to communicate with a connected device. Figures 4 and 5 show flow charts of Arduino coding for these devices. Both devices needed coding for their operation, as shown in Figs. 6 and 7. The inside layout design of both devices is shown in Table 2. The devices work as follows (see Table 2).

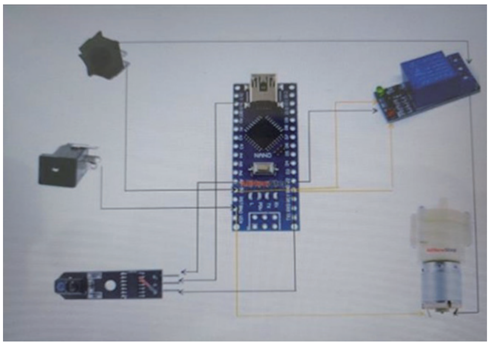


Fig. 2. (Color online) System wiring diagram for AAHS with IR sensor.

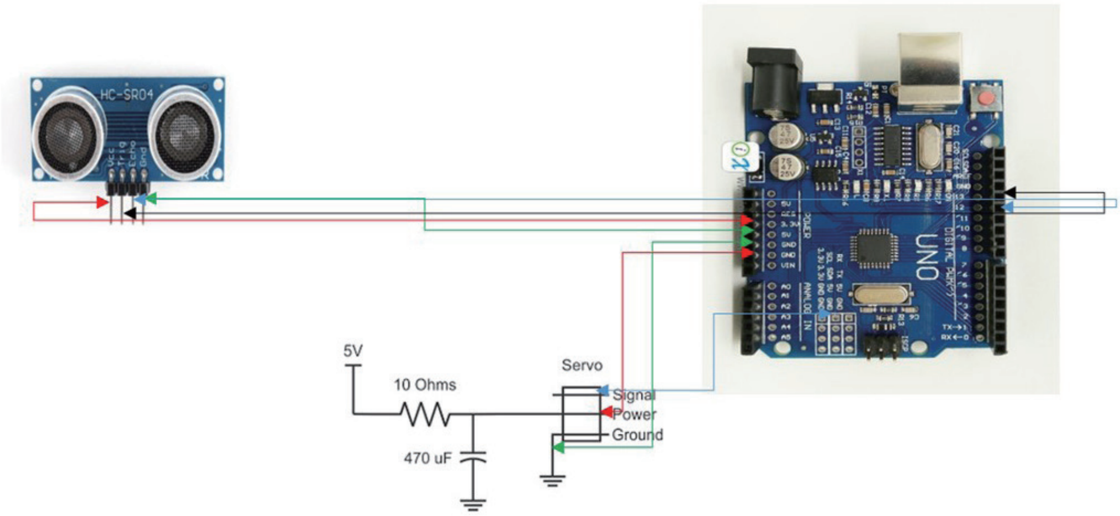


Fig. 3. (Color online) System wiring diagram for AAHS with ultrasonic sensor.

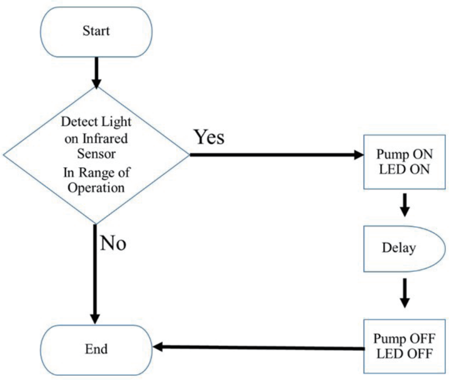


Fig. 4. Flow chart for AAHS with IR sensor.

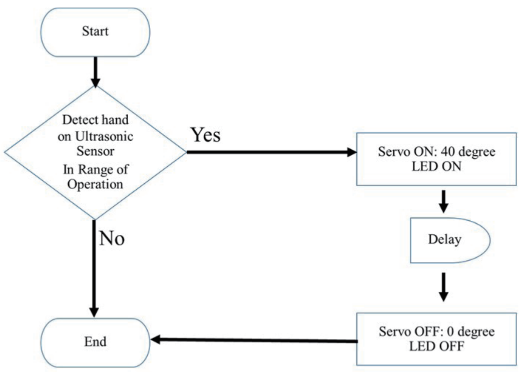


Fig. 5. Flow chart for AAHS with ultrasonic sensor.

```
int ledPin = 2;
int sensor = A7;
int val = 0;
int state; void setup ( )
{
pinMode(ledPin, OUTPUT
Serial.begin(9600);//Serial.println("Arduino ALL TEST");
}
void loop ( )
{
val = analogRead(sensor); //Read from sensor.
Serial.println(val); // Display value from sensor.
if (val > 500)
{
if (state == 1)
{
digitalWrite(ledPin, HIGH); // LED lighted
delay(100);
digitalWrite(ledPin, LOW); // LED unlighted
state = 0;
}
}
else
{
digitalWrite(ledPin, LOW); // LED Unlighted
state = 1;
}
delay (100);
}
```

Fig. 6. (Color online) Coding in AAHS with IR sensor.

```
#define ECHO_PIN     11
#define MAX_DISTANCE 20
NewPing sonar(TRIGGER_PIN, ECHO_PIN, MAX_DISTANCE);
Servo myservo;
int state = 0;
void setup() {
  Serial.begin(115200);
  myservo.attach(4);
  myservo.write(40);
}
void loop() {
  delay(50);
  int SR = sonar.ping_cm();
  Serial.println(SR);
  if (state == 0) {
    if (SR <= 1) {
      myservo.write(40);
    }
    else {
      delay(700);
      myservo.write(0);
      delay(700);
      state = 1;
    }
  }
  else if (state == 1) {
  myservo.write(40);
    delay(5000);
    state = 0;
  }
}
```

Fig. 7. (Color online) Coding in AAHS with ultrasonic sensor.

2.2.1 AAHS with IR sensor

The IR sensor of the AAHS dispenser detects the IR energy emitted from hand heat. When hands are placed in the operating range of the sensor, the IR energy quickly fluctuates to trigger the pump to activate and dispense the amount of sanitizer set in the coding.

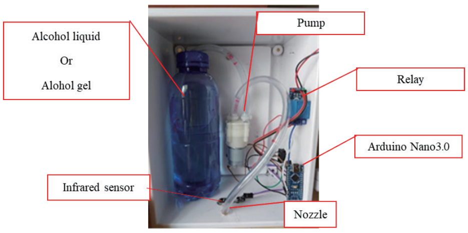
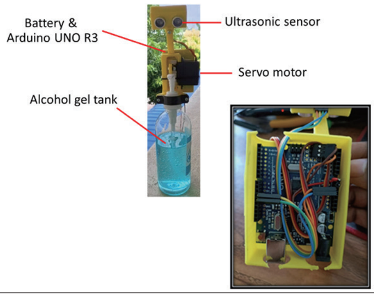
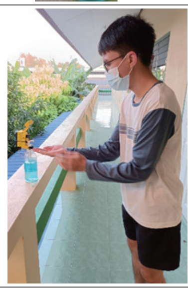
2.2.2 AAHS with ultrasonic sensor

The ultrasonic sensor of the AAHS detects the presence of a hand and triggers the servo motor, causing it to rotate the shaft by 40° to dispense a specific amount of alcohol gel from the nozzle set in the coding.

3. Results

This section presents the results for the range of operation, the settability of the time delay of the sanitizer, the performance of outdoor utilization, the total cost, and the satisfaction of 40 users for both devices.

Table 2
(Color online) Inside layout design, completed sets, and implementation for both devices.

<table>
<tr><th>Topic</th><th>AAHS with IR sensor</th><th>AAHS with ultrasonic sensor</th></tr>
<tr><td>1. Inside layout design</td><td>
</td><td>
</td></tr>
<tr><td>2. Completed set</td><td></td><td>
</td></tr>
<tr><td>3. Implementation</td><td></td><td></td></tr>
</table>

3.1 Range of operation of two devices

The performance of both devices was evaluated using confusion matrices. Confusion matrices are typically used in machine learning to evaluate or visualize the behavior of models in supervised classification contexts. A confusion matrix is a square matrix in which the rows represent the actual classes of the instances and the columns represent their predicted classes. This matrix contains all the raw information about the predictions made by a classification model on a given data set. In a binary classification task, the confusion matrix is a 2 × 2 matrix. To evaluate the generalization accuracy of a model, it is common to use a testing data set, which was not used during the learning process of the model. In the results, there are two decision classes, P (positive) and N (negative), and the entries in the table are called true positives, false positives, true negatives, or false negatives (see Table 3). We evaluated the accuracy and precision of both devices as follows.

$$Accuracy = \frac{(TPs + TNs)}{(TPs + TNs + FPs + FNs)} \tag{1}$$

Table 3
Confusion matrix.

		Actual value	
		P	N
Predicted value	P	True positives (TPs)	False positives (FPs)
	N	False negatives (FNs)	True negatives (TNs)

Table 4
Predicted and actual values of AAHS with IR sensor.

No.	Distance between hand and sensor (cm)									
	0.5		1		1.5		2		2.5	
	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual
1	W	W	W	W	W	W	W	W	NW	NW
2	W	W	W	W	W	W	W	W	NW	NW
3	W	W	W	W	W	W	W	W	NW	NW
4	W	W	W	W	W	W	W	W	NW	NW
5	W	W	W	W	W	W	W	W	NW	NW
6	W	W	W	W	W	W	W	W	NW	NW
7	W	W	W	W	W	W	W	W	NW	NW
8	W	W	W	W	W	W	W	W	NW	NW
9	W	W	W	W	W	W	W	W	NW	NW
10	W	W	W	W	W	W	W	W	NW	NW
11	W	W	W	W	W	W	W	W	NW	NW
12	W	W	W	W	W	W	W	W	NW	NW
13	W	W	W	W	W	W	W	W	NW	NW
14	W	W	W	W	W	W	W	W	NW	NW
15	W	W	W	W	W	W	W	W	NW	NW

Note: W: working; NW: not working.

$$Precision = \frac{(TPs)}{(TPs + FPs)} \tag{2}$$

The predicted values for the AAHS with the IR sensor and the actual values obtained by measurement are shown in Table 4. From Table 4, we obtain the confusion matrix in Table 5. The accuracy of the AAHS with the IR sensor is 1 and its precision is also 1.

Figure 8 illustrates the range of operation for the AAHS with the ultrasonic sensor. The predicted values for the AAHS with the ultrasonic sensor and the actual values obtained by measurement are shown in Table 6. From Table 6, we obtain the confusion matrix in Table 7. The accuracy of the AAHS with the ultrasonic sensor is 0.85 and the precision is 0.83.

The settability of the time delay means the ability to set the time delay between the sensor detecting the hand and the dispensing of the alcohol gel. For the AAHS with the IR sensor, the time delay can be set because the pump motor can be used to dispense an amount of alcohol. For the AAHS with the ultrasonic sensor, the time delay cannot be set to control the dispensing of an amount of alcohol gel. Because the servo motor is used to press the dispenser pump, the amount of alcohol gel dispensed is in dependent of the time when the dispenser pump is pressed.

Table 5
Confusion matrix of AAHS with IR sensor.

		Actual values	
		Working	Not working
Predicted values	Working	60 (TP)	0 (FP)
	Not working	0 (FN)	15 (TN)

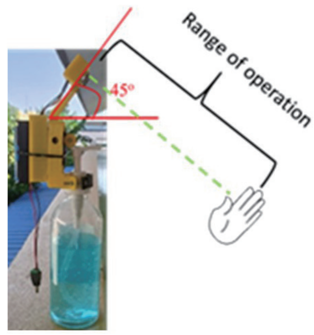


Fig. 8. (Color online) Testing range of operation for AAHS with ultrasonic sensor.

Table 6
Predicted and actual values for AAHS with ultrasonic sensor.

No.	Distance between hand and sensor (cm)													
	1		2		5		10		15		20		25	
	Pre-dicted	Ac-tual	Pre-dicted	Ac-tual	Pre-dicted	Ac-tual	Pre-dicted	Ac-tual	Pre-dicted	Ac-tual	Pre-dicted	Ac-tual	Pre-dicted	Ac-tual
1	NW	NW	W	W	W	W	W	W	W	W	NW	NW	NW	W
2	NW	NW	W	W	W	W	W	W	W	W	NW	NW	NW	NW
3	NW	NW	W	W	W	W	W	W	W	W	NW	NW	NW	NW
4	NW	NW	W	W	W	W	W	W	W	W	NW	NW	NW	W
5	NW	NW	W	W	W	W	W	W	W	W	NW	W	NW	NW
6	NW	NW	W	W	W	W	W	W	W	W	NW	W	NW	W
7	NW	NW	W	W	W	W	W	W	W	W	NW	W	NW	NW
8	NW	NW	W	W	W	W	W	W	W	W	NW	W	NW	NW
9	NW	NW	W	W	W	W	W	W	W	W	NW	W	NW	W
10	NW	NW	W	W	W	W	W	W	W	W	NW	W	NW	NW

Note: W: working; NW: not working.

Table 7
Confusion matrix of AAHS with ultrasonic sensor.

		Actual values	
		Working	Not working
Predicted values	Working	50 (TP)	10 (FP)
	Not working	0 (FN)	10 (TN)

Therefore, the AAHS with the IR sensor can control the amount of alcohol, while the AAHS with the ultrasonic sensor cannot.

As shown in Table 8, ten tests were performed with the delay time in the program set to values of 100, 600, 1100, and 2100. The obtained results demonstrate that the alcohol gel dispensing time can be set by setting the delay variable in the program for the driver of the AAHS with the IR sensor. On the other hand, the setting time delay for the AAHS with the ultrasonic sensor does not affect the amount of alcohol gel dispersed. Therefore, we did not test this function.

Table 8
Time required to dispense amount of alcohol gel compared with set time delay for AAHS with IR sensor.

No.	Operation				
	Set delay time (s)				
	100	600	1100	1600	2100
1	1.35	3.67	6.84	8.27	10.41
2	1.11	4.23	6.65	8.09	10.38
3	1.05	3.79	7.16	8.78	11.25
4	1.90	3.94	6.34	8.12	11.23
5	1.96	4.12	6.45	9.16	11.34
6	1.07	4.11	6.03	8.95	10.76
7	1.09	4.51	7.30	9.12	12.08
8	1.96	3.87	7.21	9.29	11.44
9	1.28	4.05	6.08	8.80	11.68
10	1.27	4.37	6.12	8.66	12.38
Average time to dispense	1.404	4.066	6.618	8.724	11.295

Table 9
Performance of both devices implemented outdoors.

No.	AAHS with IR sensor		AAHS with ultrasonic sensor	
	Predicted	Actual	Predicted	Actual
1	W	W	W	W
2	W	NW	W	W
3	W	NW	W	W
4	W	NW	W	W
5	W	NW	W	W
6	W	NW	W	W
7	W	NW	W	W
8	W	W	W	W
9	W	NW	W	W
10	W	NW	W	W

Note: W: working; NW: not working.

3.2 Performance of devices implemented outdoors

Next, we evaluated the performance of each AAHS outside. The predicted values for the two AAHSs and the actual values obtained by measurement are shown in Table 9.

From Table 9, we obtain the confusion matrices in Tables 10 and 11. The accuracy and precision of the AAHS with the IR sensor are both 0.2. Both the accuracy and precision of the AAHS with the ultrasonic sensor are 1.

Ten tests were performed to implement the two devices outdoors under the same conditions (light, temperature). The accuracy of the AAHS with the IR sensor was 0.20 and its precision was also 0.20. The accuracy and precision of the AAHS with the ultrasonic sensor were both 1, indicating that the AAHS with the ultrasonic sensor works better than the AAHS with the IR sensor in outdoor implementation. In addition, the ultrasonic sensor has a slightly higher resolution than the IR sensor, especially for measuring small distances within their operation ranges.[21]

Table 10
Confusion matrix of AAHS with IR sensor.

		Actual values	
		Working	Not working
Predicted values	Working	2 (TP)	8 (FP)
	Not working	0 (FN)	0 (TN)

Table 11
Confusion matrix of AAHS with ultrasonic sensor.

		Actual values	
		Working	Not working
Predicted values	Working	10 (TP)	0 (FP)
	Not working	0 (FN)	0 (TN)

Table 12
User satisfaction results for AAHSs with IR and ultrasonic sensors.

No.	Criterion	AAHS with IR sensor	AAHS with ultrasonic sensor
		Average score (Min 1, Max 5)	
1	The device is easy and comfortable to use compared with other devices.	3.86	4.23
2	The device can reduce infection compared with touch-based devices.	3.96	4.54
3	The device dispenses a precise amount of alcohol each time it is used.	3.93	4.67
4	Attractiveness of appearance compared with other devices	3.24	3.92
5	Responsiveness of the device compared with other similar devices	3.93	4.32
6	Overall satisfaction with the device compared with other similar devices	3.95	4.53

3.3 Cost of producing devices

The AAHSs with the IR and ultrasonic sensors cost 790 and 540 baht to produce, respectively, i.e., the AAHS with the ultrasonic sensor is 32% cheaper to produce than the AAHS with the IR sensor.

3.4 Results of satisfaction survey for the two devices

Forty people from the university participated in a survey to evaluate user satisfaction with the two devices. The results in Table 12 indicate that the maximum score of these two devices is for the ability to reduce infection and the lowest score is for the appearance. The results also show that the AAHS with the ultrasonic sensor outperformed the AAHS with the IR sensor in every category in the satisfaction survey.

4. Conclusions

In this study, we developed two low-cost AAHSs, one with an IR sensor and one with an ultrasonic sensor. These devices were designed to prevent the spread of COVID-19. We evaluated the performance of the two devices from five aspects.

First, we evaluated the range of operation of the two devices. The AAHS with the ultrasonic sensor has a longer range of operation than the AAHS with the IR sensor and can work at a shorter range. In the future, these two devices could be adjusted by choosing appropriate components and circuits to set up the range of operation required.

Second, we evaluated the settability of the time delay for dispensing an amount of alcohol gel. A time delay can be set for the AAHS with the IR sensor because this device uses a motor pump to dispense the alcohol gel. On the other hand, the AAHS with the ultrasonic sensor uses a servo motor to press the alcohol pump. The designs of both systems can accommodate user needs.

Third, the analysis of the results for outdoor utilization using confusion matrices suggests that the AAHS with the ultrasonic sensor works perfectly, in contrast to the AAHS with the IR sensor. The location where the devices are installed will be the key to selecting the circuit designed.

Fourth, the AAHS with the ultrasonic sensor is cheaper to produce than the other AAHS. This criterion was the most important at the time of the study because of the urgent need to prevent the spread of COVID-19. The devices were designed to be easy to install and contain components that can be easily purchased from local suppliers, enabling their rapid implementation in local communities.

Fifth, the results of the user satisfaction survey indicate that the AAHS with the ultrasonic sensor was evaluated more highly by users.

The results obtained in this study provide valuable data for improving the effectiveness and reducing the cost of AAHSs. In future works, appropriate sensors for AAHSs can be designed in accordance with their location of implementation.

Acknowledgments

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About the Authors

Wirote Jongchanachavawat received his B.Sc. in solid-state electronics from King Mongkut's Institute of Technology Ladkrabang in 1994, his MBA from National Institute of Development Administration in 1999, his M.Eng. from King Mongkut's Institute of Technology Ladkrabang in 2000, his D.Eng. from King Mongkut's Institute of Technology Ladkrabang in 2009, and his B.Eng. from South-East Asia University in 2014. He has worked for more than 20 years in information systems and management at various companies. He has been an assistant professor at the Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University, Thailand, since 2022. His main research interests are in analog circuit design, management information systems, operation management, technology management, big data, IoT, and automation.

Bureerak Sungkongmueng received his B.Eng. and M.Eng. degrees in electrical engineering from Mahanakorn University of Technology in 2004 and 2013, respectively, He has been working as a lecturer at the Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University, Thailand, since 2015. His main research interests are in electrical machines and renewable energy. (bureerak.sun@mail.pbru.ac.th)

Chaleedol Inyasri received her B.Eng. and M.Eng. degrees from Naresuan University, Thailand, in 2009 and 2014, respectively. Currently, she is a lecturer at the Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University, Thailand. Her research interests are in alternative energies such as solar cell energy, innovation technology, and automation.
(chaleedol.jai@mail.pbru.ac.th)

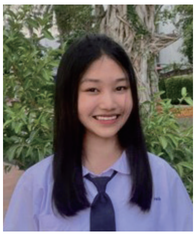
Ittipat Roopkom received his B.Eng. and M.Eng. degrees from Mahanakorn University of Technology, Thailand, in 2002 and 2005, respectively. In 2009, he received his D.Eng. degree in electrical engineering from King Mongkut's Institute of Technology Ladkrabang, Thailand. In 2022, he became an assistant professor at the Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University, Thailand. His research focuses on analog circuit design and wideband amplifiers. (ittipat.roo@mail.pbru.ac.th)

Noppon Mingmuang received his Doctor of Education in industrial and vocational education in 2001 from Clemson University, USA. He has been a lecturer at the Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University, Thailand, since 1994. His main research interests are in industrial management, quality control, quality assurance, and new innovative technology. (noppon.min@mail.pbru.ac.th)

Pichamol Putthed graduated from junior high school at Phetchaburi Rajabhat University Demonstration School in 2019. She is currently studying at Phetchaburi Rajabhat University Demonstration School on the Mathematics–Science Program. Her main research interests include mathematics, new technology for pharmacies, AI, and innovative technology for automatic systems. (pichamol.put@mail.pbru.ac.th)

Atiwat Srithammakan graduated from junior high school at Phetchaburi Rajabhat University Demonstration School in 2019. He is currently studying at Phetchaburi Rajabhat University Demonstration School on the Mathematics–Science Program. His main research interests are in animal food production, farm operations management, AI, and innovative technology for automatic systems. (atiwat.sri@mail.pbru.ac.th)

Boonpi Chinowan graduated from junior high school at Phetchaburi Rajabhat University Demonstration School in 2020. She is currently studying at Phetchaburi Rajabhat University Demonstration School on the Mathematics–Science Program. Her main research interests are in medicine, AI, and innovative technology for automatic systems in medicine.
(boonpi.chi@mail.pbru.ac.th)



Patcharapon Pathomphomma graduated from junior high school at Kanchanaphisek Wittayalai School, Surat Thani. She is currently studying at Phetchaburi Rajabhat University Demonstration School on the Mathematics–Science Program. Her main research interests are in medicine, AI, and innovative technology for automatic systems in medicine.
(Patcharaponbaipliw@gmail.com)

Peemongkol Kumngern graduated from junior high school at Protpittayapayat in 2021. Currently, he is studying at Triam Udom Suksa Pattanakarn Suvarnabhumi School on the Science and Mathematics English Program (EP). His main research interests are in medicine and medical innovation, AI, and innovative technology for automatic systems in medicine. (framefkumngern@gmail.com)

Suphat Bunyarittikit received his B.S. degree in architecture from King Mongkut's Institute of Technology Ladkrabang in 1993 and his M.S. in tropical architecture from King Mongkut's Institute of Technology Ladkrabang in 1999. Currently, he is a professor in the architecture school at King Mongkut's Institute of Technology Ladkrabang. His research interests are in vernacular architecture, business models and plans, innovative technology, and pure energy for architecture. (jeng_urb@hotmail.com)

Patchamon Jongchanachavawat graduated from junior high school at Satrinonthaburi School in 2021 after studying on the Science Math Technology Environment Program (SMTEP). Currently, she is studying at Satrinonthaburi School on the Enrichment Program of Science Mathematics Technology and Environment (ESMTE). Her main research interests are in medicine, new technology, innovative technology, AI, and automation in medicine. (patchamon.23072550@gmail.com)