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Design of a Smart Surveillance Robot Using HUSKYLENS AI Vision Sensor

Sin Ting Lim*, Shawn Pereira, Li Wah Thong and Tetuko Kurniawan

***Abstract* – This study aims to enhance security by implementing a smart surveillance robot using existing facial recognition technology. The developed robot is equipped with the HUSKYLENS AI vision sensor camera and an ESP32 CAM module to provide a real-time video feed to a connected computer via Wi-Fi. The results demonstrate the successful integration of facial recognition technology into the surveillance robot's functionality. The robot exhibits an acceptable ability to identify and track intruders, underscoring its potential for enhancing security applications. The robot features a height of 12 cm, a width spanning 11.5 cm, a length measuring 19 cm, and a weight totalling 1.3 kg. Operating on a basic configuration of two main wheels, the robot forms a two-wheeled system with three degrees of freedom (DOF). The developed robot demonstrates an ability to identify and track intruders with a tested accuracy of 77.5%, precision of 80%, specificity of 79%, and sensitivity of 76.1%. The compact and low-profile design enables it to operate discreetly in diverse environments, making it particularly well-suited for scenarios where inconspicuous surveillance is needed.**

Keywords—Surveillance, Robots, HuskyLens, Facial Recognition, Machine Learning.

I. INTRODUCTION

A smart surveillance robot is an advanced security solution that integrates robotic technology with intelligent surveillance capabilities. Unlike traditional stationary surveillance systems, smart surveillance robots are mobile, autonomous devices designed to enhance security measures through real-time monitoring.

Smart surveillance robots can be found in several applications, including continuous monitoring in large or complex environments where human patrols might be impractical [1-2]. They are also deployed in emergency response scenarios, providing real-time data in situations like fires, natural disasters, or hazardous environments. Additionally, smart surveillance robots have proven beneficial in military applications [3-5], where their capacity for autonomous operation and real-time data transmission enhances surveillance capabilities.

Table 1 summarises the existing smart surveillance robots. Smart surveillance robots can be broadly categorized into two types: those employed for general security purposes and those specifically designed to monitor and navigate hazardous areas. A key

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distinguishing factor between these types lies in the additional sensor capabilities integrated into robots intended for hazardous areas [6]. A common feature across these robots is the use of microcontrollers such as Arduino or ESP32 CAM module, sharing advantages such as user-controlled operation over the internet via Wi-Fi and providing real-time video feedback.

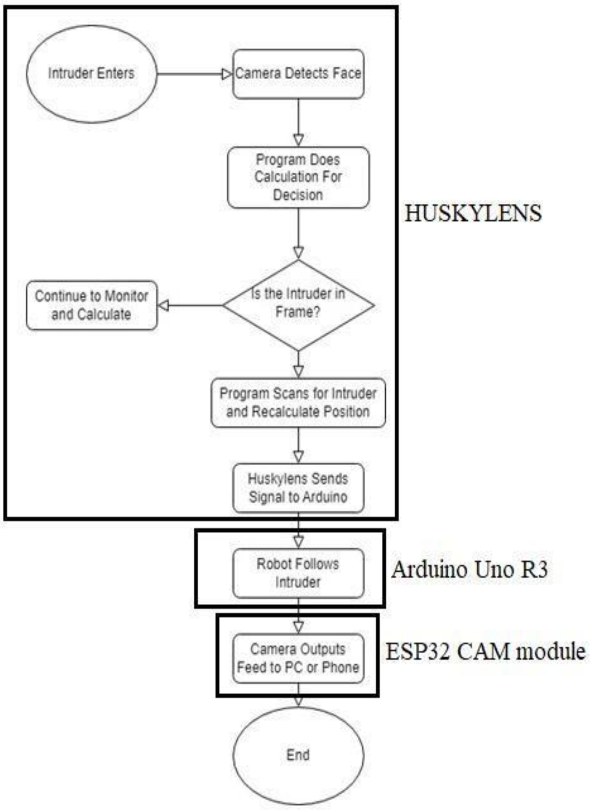
TABLE 1: Summary of existing smart surveillance robots.

Related Work	Advantages	Disadvantages
Salh and Nayef (2014) [7]	Facial recognition, gas detection and it is autonomous	No tracking features, bulky and unstable
D'Auria et al. (2018) [8]	Small and inconspicuous, user-control via Bluetooth/Wi-Fi	Biped design of the robot may cause slower movement, the power source is not stated, could be mistaken for a children's toy due to the outlook of the model
Anandravisekar et al. (2018) [9]	Small/hard to detect, user remote controlled, wide signal range of remote control, obstacle detection, equipped with a metal detector, high maneuverability	No facial recognition, no autonomous, no tracking feature
Nayyar et al. (2018) [1]	User control via 2.4 GHz controller, temperature and humidity detection, solar-powered, built-in robotic arms	No autonomous, bulky
Bharathi et al. (2018) [5]	User control via Bluetooth/Wi-Fi, Object detection and classification	No facial recognition, no autonomous, no tracking features, no tracking feature
Zhang et al. (2019) [10]	Real-time video streaming, includes IoT, utilizes Velodyne 16-lines Lidar, has motion control, autonomous navigation	No facial recognition, faces problems over larger distances, works only on pre-planned maps, bulky
Akilan et al. (2020) [11]	Motion and detection, user remote controlled through the internet, wide signal range of remote control, obstacle detection	No facial recognition, no autonomous, no tracking feature
Rangapur et al. (2020) [12]	User control via Bluetooth, small and inconspicuous	No facial recognition, not autonomous, remote control may lose signal over a longer range, no tracking feature
Kumari and Sanjay (2020) [13]	User control via Wi-Fi, object detection and classification, small and compact, real-time video and audio feed	No facial recognition, no autonomous, no tracking features
Thirumaraiselvi et al. (2022) [14]	PIR sensor detects the presence of living objects in the robotic environment, including IoT functionality, facial recognition, voice-commanded	Bulky and looks messy, can be easily spotted, not autonomous, does not actively follow a subject, needs time to train AI
Tippannavar et al. (2022) [15]	Face recognition has obstacle detection, including IoT	Bulky, non-inconspicuous, does not actively follow intruder, wires may easily disconnect
Janani et al. (2022) [4]	Includes IoT, face recognition, and provides live video feed over long-distance	Built for military use only, non-autonomous, controlled by remote control, physically unstable
Lakare et al. (2022) [16]	User remote controlled through internet, wide signal range of remote control	No facial recognition, no autonomous, no tracking features, bulky, wire connections do not look too secured
Lee and Shih (2022) [17]	Facial recognition, subject tracking, autonomous, equipped with lidar for more accurate mapping, obstacle avoidance	Physically unstable, needs time to train AI, bulky
Chandrukumar et al. (2022) [18]	User control via Wi-Fi, Bluetooth/Wi-Fi connectivity	No facial recognition, no autonomous, no tracking feature
Siswoyo and Indrawan (2023) [19]	Line detection, built-in user GUI, utilizes real-time feedback, object identification	No facial recognition, bulky, not for surveillance use, bulky

Specifically, the Smart Indoor Surveillance Robot (SISR) developed by Tippannavar et al. [15] appears bulky and it also lacks inconspicuousness, with a design that does not actively follow intruders, potentially leading to easily disconnected wires and limiting its feasibility. Similarly, the surveillance robot developed by Janani et al. [4] has limitations for its bulkiness, messy appearance, ease of detection, lack of autonomy, and failure to actively track subjects. Moreover, it demands a substantial amount of time for AI training in facial recognition. In summary, a shared limitation in some of the existing surveillance robots is the absence of facial recognition or a high-performance face recognition algorithm, non-autonomous operation, lack of tracking features, and the tendency to be relatively large or bulky. To overcome the limitation, this study aims to develop a small and inconspicuous robot that includes existing high-performance facial recognition to enhance the overall functionality of a surveillance robot.

II. METHODOLOGY

Figure 1 outlines the operational sequence of the proposed smart surveillance robot. Initially, pictures of the intruder are fed into the HUSKYLENS AI Vision Sensor to undergo the machine learning process. As the intruder enters the premises, the HUSKYLENS camera detects their face. The program then conducts calculations and sends signals to the Arduino. If the intruder's face is within the frame, the robot remains stationary. When the intruder moves, updated calculations prompt signals to the Arduino, guiding the robot to ensure the intruder's face stays in view. Through this iterative process, the robot begins to track the intruder. Simultaneously, a live feed is transmitted to a web server via a secondary ESP32 CAM module. This allows continuous monitoring of the intruder's



location by personnel in a different part of the building.

FIGURE 1. Proposed framework.

The 3D model and the circuit connection of the proposed robot are shown in Figure 2 and Figure 3 respectively.

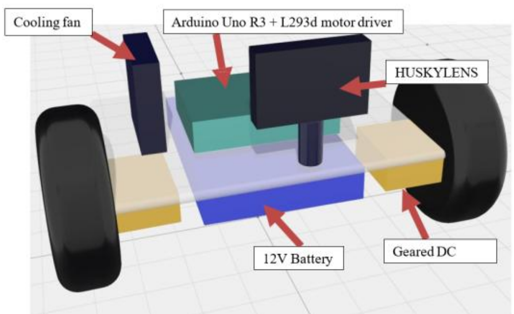
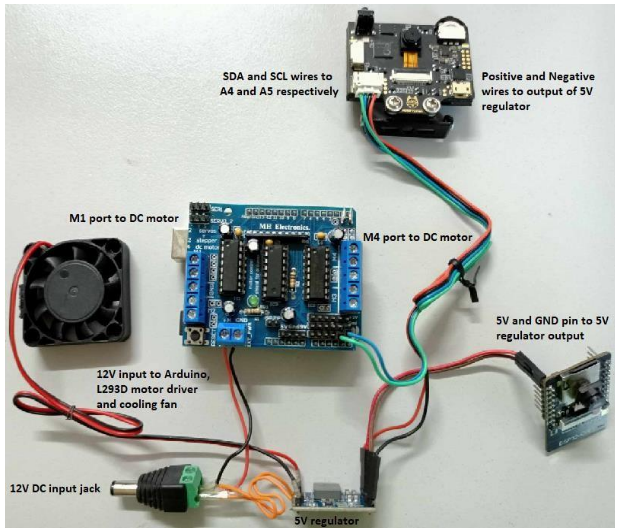


FIGURE 2. 3D model of the proposed robot.

As seen in Figure 2, the L293d motor driver is mounted directly on top of the Arduino Uno by aligning the pins on the motor driver with the ports on the Arduino as the version of the motor driver is manufactured to be compatible with the Arduino R3 board. The HUSKYLENS comes equipped with an I2C (Inter-Integrated Circuit) port. An I2C connection is a widely used serial communication protocol that facilitates communication between integrated circuits or electronic components on a circuit board. It is a multi-master, multi-slave protocol, allowing multiple devices to communicate with each other over a common bus. The I2C communication involves two



main lines: the Serial Data Line (SDA) and the Serial Clock Line (SCL).

FIGURE 3. Circuit connection of the proposed robot.

As seen in Figure 3, the HUSKYLENS communicates with the Arduino through I2C, with the SDA and SCL wires connected to the A4 and A5 pins on the Arduino, respectively. These pins are also accessible on the motor driver shield. The two motors are then connected to the M1 and M4 ports on the L293d motor driver to facilitate the robot's movement. A 12V battery is attached to the underside of the chassis to independently power the Arduino, HUSKYLENS, L293d motor driver and ESP32 CAM module. Additionally, a fan is installed on the chassis to cool down the 12V regulator chip on the Arduino Uno. An external 5V voltage regulator is linked between the 12V battery and the ESP32 CAM module and HUSKYLENS, stepping down the voltage from 12V to 5V to reduce the risk of burning either component. An extra caster wheel is also integrated into the robot to enhance its stability.

A. Face Recognition

The HUSKYLENS AI vision [20] was selected as the face recognition technology in this project as it offers an economical and efficient way to integrate facial recognition capabilities into the surveillance system. The sensor's proficiency in object tracking, gesture detection, and pattern recognition, is all driven by its underlying Kendryte K210 chip. Several alternatives were considered, such as utilizing Python programming in conjunction with a Raspberry Pi for AI training from scratch. However, this option was deemed impractical due to the extended training time required and the high cost associated with the Raspberry Pi. Another alternative explored was the use of Nvidia Jetson, but its compatibility with Arduino posed challenges, making integration less seamless.

B. Components Used

In this project, an ESP32 CAM module was utilized to provide a live feed accessible via a phone or PC through an internet connection. The ESP32 CAM module was chosen due to its integrated camera and Wi-Fi modules. The Arduino Uno, as a compact and versatile microcontroller board, serves as the brain of the proposed surveillance robot. It has 14 digital pins, 6 analog inputs, and a 16 MHz clock speed enabling integration with components such as the HUSKYLENS, motor drivers, and motors. The L293D motor driver shield for Arduino is responsible for controlling the movement of the proposed smart surveillance robot's wheels. The L293D motor driver shield can drive two separate motors simultaneously through the integration of two H-bridge circuits, allowing independent control of the direction and speed of each motor. The H-bridge configuration also enables the motors to move forward, backwards, or come to a complete stop.

C. Face Samples

Face samples are needed to evaluate the accuracy of the proposed robots. Face samples of the first type are collected to represent recognized faces, which correspond to non-intruders. For this purpose, a total of 20 volunteers took part in the evaluation, including 8 Chinese, 7 Indian, and 5 Malay. The volunteers were informed that their identities would remain confidential and would not be revealed. Upon providing consent, the volunteers were requested to submit self-portraits and to be physically present near the robot during the experiments. The identities of the volunteers were anonymized and replaced with unique IDs, as depicted in Figure 4.

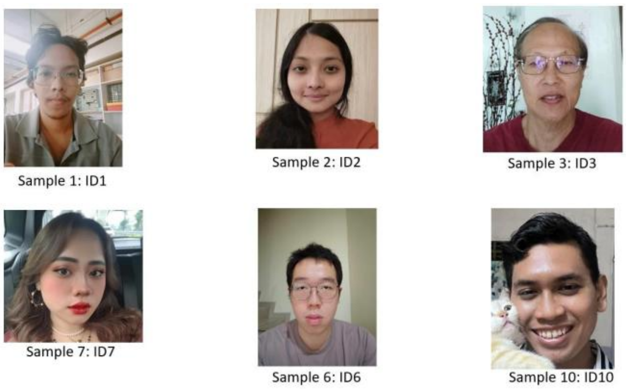


FIGURE 4. Self-portraits of the volunteers to serve as non-intruders.

Face samples of the second type represent unrecognized faces, which correspond to intruders. As such, 20 distinct facial samples from an online public database [21] were randomly selected to serve as the database for the second type of face sample. Examples of the samples are shown in Figure 5.

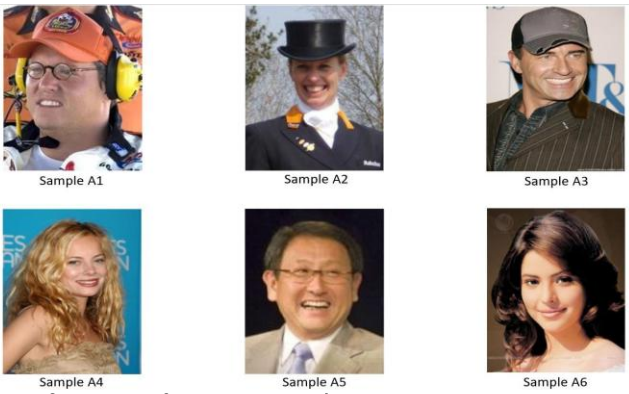


FIGURE 5. Sample images from public data to serve as intruders.

III. RESULTS AND DISCUSSIONS

The outlook and performance accuracy of the robot developed in this project were demonstrated in this section.

A. Outlook of the Prototype

The developed robot takes on the appearance depicted in Figure 6 and Figure 7. It has a height of 12 cm, a width spanning 11.5 cm, a length measuring 19 cm, and a weight totalling 1.3 kg. The proposed robot operates on the basic configuration of two main wheels, forming a two-wheeled system with three degrees of freedom (DOF). As seen in Figure 4, the ESP32 CAM module and HUSKYLENS modules are strategically positioned to face the front, facilitating comprehensive monitoring of the surroundings. To enhance stability, a design decision was made to place most of the heavier components such as the battery and the motor on the underside of the chassis, effectively lowering the robot's centre mass and centre of gravity. The inclusion of a caster wheel, coupled with two drive wheels, contributes to the overall stability of the robot.

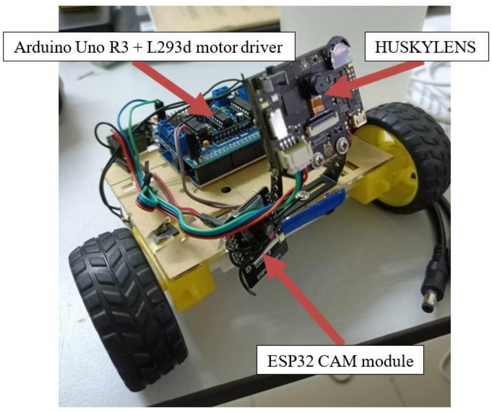


FIGURE 6. Front view of the proposed surveillance robot.

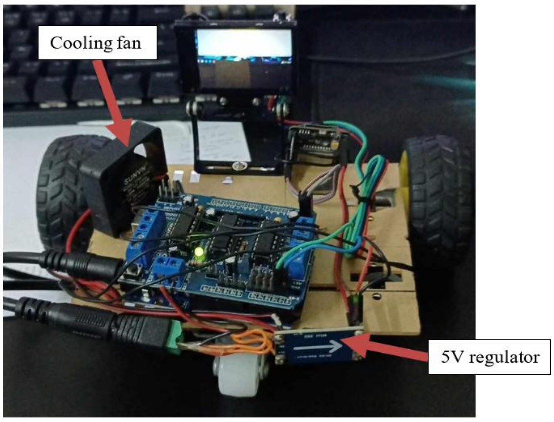


FIGURE 7. Rear view of the proposed surveillance robot.

B. Performance Accuracy

To measure the accuracy of the proposed robot in tracking unrecognized faces (intruders) and recognized faces (non-intruders), the robot was positioned in front of the volunteers serving as the non-intruders. Initially, the self-portraits from the volunteers were first introduced to the HUSKYLENS as recognized faces using the "learn face" function, storing them in its built-in memory storage. The volunteers were then asked to stand 1 meter away from the robot.

FIGURE 8. The robot detected a recognized face.

Figure 8 shows the recognized face corresponds to the ID number of one of the volunteers. The expectation was that the robot would remain stationary for any recognized face, indicating no identified intruders. If the robot indeed did not move, it would be considered a True Positive (TP). Conversely, any movement, such as slight or full rotation of any wheel, in response to a recognized face would be classified as a False Positive (FP).

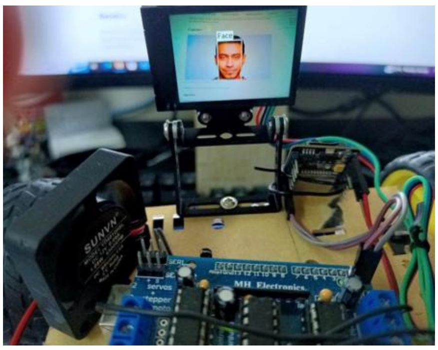


FIGURE 9. The robot detected an unrecognized face from a public database.

The randomly selected face samples retrieved from an online database were displayed on the computer to act as intruders. The images were shown on the screen one by one, and the robot was placed 1 m away from the screen as seen in Figure 9. It is important to note that the previously learned faces from the previous experiment were retained in the HUSKYLENS storage. In this scenario, the robot was expected to track and follow the 20 unrecognized faces from the online database, considering them as potential intruders. If the robot moved in response to these unrecognized faces, it would be recorded as a True Negative (TN). Conversely, if the robot did not move when presented with an unfamiliar face, it would be classified as a False Negative (FN). The possible outcomes of the experiment are described in Table 2. It is crucial to note that these experiments focus on assessing the robot's behaviour concerning recognized and unrecognized faces, not the facial recognition capability of the HUSKYLENS.

TABLE 2: Outcome classification.

Outcome	Description of outcome
True Positive (TP)	Given a set of recognized faces, the number of samples whereby the robot did not move
False Positive (FP)	Given a set of recognized faces, the number of samples whereby the robot did move
True Negative (TN)	Given a set of unrecognized faces, the number of samples whereby the robot did move
False Negative (FN)	Given a set of unrecognized faces, the number of samples whereby the robot did not move

TABLE 3: Results for the outcomes.

TP	FP	TN	FN
16	4	15	5

The results demonstrated by the proposed robot are presented in Table 3. Based on the results, the accuracy, measuring the overall correctness of the system, is calculated at 77.5%. Precision, indicating the system's ability to correctly identify positive outcomes, stands at 80%. Specificity, gauging the system's accuracy in identifying negative outcomes, is reported as 79%. Sensitivity, representing the system's ability to correctly identify positive outcomes among the actual positives, is determined to be 76.1%.

In addition to the quantitative metrics, practical observations revealed some challenges encountered by the smart surveillance robot. The robot faced difficulties accurately identifying specific individuals, such as Sample 1 and 2 corresponding to ID1 and ID2, respectively, both of whom are siblings as seen in Figure 4. Despite the robot not exhibiting movement during the experiment, occasional misidentifications occurred between Sample 1 (ID1) and Sample 2 (ID2), particularly under dimly lit conditions. Further scrutiny suggests that this limitation is attributed to the facial recognition capabilities of the HUSKYLENS AI module.

In addition to that, an observation during the experiment highlighted a challenge faced by the robot in accurately identifying subjects of Asian ethnicity, particularly those of Chinese descent. Throughout the experiment, the robot exhibited a tendency to misclassify a sample face from the database, intended to be flagged as an intruder, as a non-intruder. Specifically, it repeatedly misidentified the unrecognized face as belonging to a recognized face, namely Sample 4 (ID4) which belonged to a sample of Chinese descent. This recurring error contributed significantly to the false negatives observed in the experiments.

An additional observation emerged during the experiment, revealing that the HUSKYLENS occasionally encountered momentary misidentifications of faces. While the HUSKYLENS promptly corrected these brief lapses, an interesting phenomenon occurred during this misidentification period. The robot-initiated movement, responding to the initial misidentification, and continued to move for a short duration even after the HUSKYLENS had rectified and accurately identified the face. This behaviour suggests a temporary influence by the HUSKYLENS on the robot's actions during the momentary misidentification phase. It is suspected that there are some leakages of current occurring in the circuit.

Another noteworthy challenge in HUSKYLENS is its difficulty in accurately recognizing a face when it is angled beyond certain degrees. Figure 10 below illustrates the limitations.

(a) (b) (c)

FIGURE 10. HUSKYLENS unable to recognize faces pointed (a) sideway (b) upwards (c) downwards.

Another challenge encountered during the study arose in darker lighting conditions, where both the HUSKYLENS and ESP32 CAM modules faced difficulties in focusing on objects in their field of view. To address this issue, a built-in LED light was placed on the ESP32 CAM module as seen in Figure 11.

FIGURE 11. The proposed robot with LED turned on.

An extra function was incorporated into the graphical user interface (GUI) to enable the controlled activation and deactivation of the LED as seen in Figure 12. This strategic use of LED illumination effectively resolved the visibility concerns in low-light environments for the proposed smart surveillance robot.

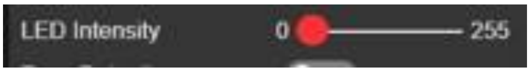


FIGURE 12. Slider to set LED intensity on the webserver GUI.

Furthermore, The L293d motor driver shield faces challenges in dealing with more advanced motor control functionalities, such as pulse-width modulation (PWM) for speed control. This basic design limitation becomes evident when the robot undergoes rapid directional changes, causing the tracked face to leave the camera's field of view. To address this issue, a partial solution was implemented by reducing the motor speed. However, this adjustment comes with its trade-offs, impacting the robot's overall responsiveness and agility. Despite these challenges, the L293d motor driver shield, with its fundamental design, may not fully support advanced motor control functionalities, potentially limiting its suitability for applications demanding more sophisticated motor control features.

Another challenge encountered was the overheating of the 5V regulator on the Arduino Uno R3, resulting from the input voltage being 12V. Given that the Arduino's specified voltage range is from 5V to 12V, employing a 12V input led to increased heat generation in the 5V regulator, elevating the risk of potential burnout. To address this issue, copper heatsinks were strategically added to both the top of the 5V regulator chip and the underside of the Arduino Uno board as shown in Figure 13. Additionally, a fan was incorporated to ensure consistent airflow over the copper heatsinks, effectively mitigating the overheating concern.

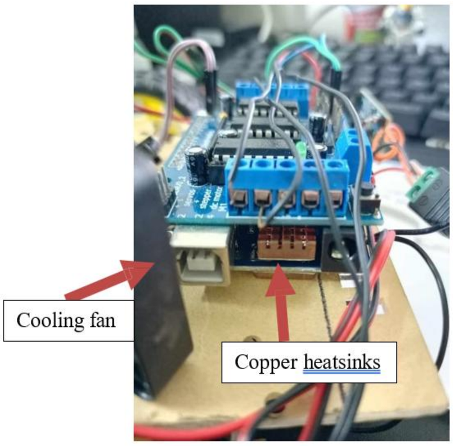


FIGURE 13. Copper heatsink installed on the 5V regulator.

IV. CONCLUSION

In this study, a smart surveillance robot based on HUSKYLENS AI vision sensor as facial recognition technology was developed and tested. The developed robot is autonomous, small, inconspicuous, low-cost and it can provide a real-time video feed to a connected computer via Wi-Fi. With tested accuracy, precision, specificity, and sensitivity metrics reaching acceptable levels, the robot showcases promising potential for bolstering security measures.

To enhance the precision of the robot's response to HUSKYLENS outputs, further testing of the electrical connections and power supply integrity is needed. Implementing additional measures, such as incorporating filters or conducting a thorough circuit analysis, could mitigate the impact of transient events on the robot's behaviour. As noted earlier, a challenge arose when the robot's rapid directional changes led to the tracked face leaving the camera's field of view. To address this, a partial solution was applied by reducing the motor speed. However, this modification introduces trade-offs, affecting the robot's overall responsiveness and agility. To fully resolve this issue, alternative approaches such as utilizing a different motor driver or revising the interface program between the Arduino and HUSKYLENS could be explored. While the robot's functionality should extend beyond merely moving its wheels, future exploration and implementation of motor control and design enhancements are necessary to actively follow the intruders so that the robot's full potential in security applications is fully harnessed.

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AUTHOR CONTRIBUTIONS

Sin Ting Lim: Conceptualization, Supervision, Methodology, Investigation, Writing - Review & Editing, Data Curation;

Shawn Pereira: Investigation, Formal Analysis, Software, Writing-Original Draft, Writing - Review & Editing, Software, Formal Analysis;

Li Wah Thong: Validation, Writing - Review & Editing, Formal Analysis, Data Curation.

Tetuko Kurniawan: Writing - Review & Editing

CONFLICT OF INTERESTS

No conflict of interests were disclosed.

ETHICS STATEMENTS

The study adheres to the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all volunteers prior to their participation, including consent to publish findings based on their face samples. The face samples used in this study cannot be shared publicly due to ethical considerations and privacy concerns to protect the identities of the participants. The data collection process was conducted under strict confidentiality protocols, and participants were assured that their information would not be disclosed beyond the scope of this research.

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