DEVELOPMENT OF CONTROL ALGORITHM FOR SPOT COOLING SYSTEM

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DEVELOPMENT OF CONTROL ALGORITHM FOR SPOT COOLING SYSTEM

by

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LIST OF ABBREVIATION

CAMshift	Continuously Adaptive Mean Shift Tracking Algorithm
CETDEM	Centre for Environment, Technology & Development Malaysia
Cmd	Command Prompt
GISS	Goddard Institute for Space Studies
GPS	Global Positioning System
GUI	Graphical User Interphase
HDMI	High-Definition Multimedia Interface
HIS	Hue, Saturation and Intensity
HSV	Hue, Saturation, and Value
ICMP	Internet Control Message Protocol
IR	Infrared
IR LED	Infrared Light Emitting Diode
L*a*b	Lab colour space
LED	Light Emitting Diode
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
NASA	National Aeronautics and Space Administration
NoIR	No Infrared
PIR	Pyroelectric Infrared
RFID	Radio-frequency identification
RGB	Red, Green and Blue
ROI	Region of Interest
RPI	Raspberry Pi
RSSI	Received Signal Strength Indicator
WiFi	Wireless Fidelity

YCbCr	Luma component, blue difference and red difference Chroma components

LIST OF SYMBOLS

$\boldsymbol{D}$	State transition matrix
$\boldsymbol{\Sigma}$	Covariance of the model
$\overline{\boldsymbol{\Sigma}}$	Predictions covariance of the model
$\boldsymbol{K}$	Kalman gain
$\boldsymbol{M}$	Measurement matrix
$\boldsymbol{Q}$	Covariance of the process noise
$\boldsymbol{R}$	Covariance of the measurement noise
$\boldsymbol{t}$	Time
$\boldsymbol{v}$	Innovation
$\boldsymbol{W}$	Process noise
$\boldsymbol{X}$	State of the model
$\overline{\boldsymbol{X}}$	Prediction state of the model
$\boldsymbol{Z^t}$	Current observation

PEMBANGUNAN ALGORITMA KAWALAN BAGI SISTEM PENYEJUKAN SETEMPAT

ABSTRAK

Pendingin hawa ialah perkakas elektrik yang paling biasa dalam setiap isi rumah. Cabaran untuk mengurangkan penggunaan tenaga elektrik pendingin hawa kian menjadi topik hangat di kalangan penyelidik. Matlamat projek ini adalah untuk membangunkan algoritma kawalan bagi sistem penyejukan setempat. Sistem ini akan mengesan dan menjejaki denak bukan manusia. Denak ini akan direka cipta untuk dipakai oleh pengguna supaya penghawa dingin menghalakan angin ke arah pengguna. Algoritma ini akan dilaksanakan dalam Raspberry Pi 3 dengan menggunakan Rekabentuk Berasaskan Model melalui Matlab. Sebuah kamera NoIR akan digunakan untuk menangkap imej inframerah dan cahaya yang boleh dilihat akan ditapis oleh filem cakera liut. Denak bukan manusia akan dibuat daripada IR LED dan ia akan dikesan dengan menggunakan teknik kontras warna dan analisis tompok. Pengerakan denak akan dijejaki dengan menggunakan Kalman filter. Sistem ini telah berjaya dilaksanakan. Hasilnya akan dikesan dengan menggunakan Interfasa Pengguna Grafik (GUI) di dalam komputer. Keputusan daripada eksperimen menunjukkan bahawa sistem ini dapat mengesan denak bukan manusia dengan ketepatan lebih daripada 98% semasa siang dan malam.

DEVELOPMENT OF CONTROL ALGORITHM FOR SPOT COOLING SYSTEM

ABSTRACT

Air conditioner has become the most common electrical appliance in every household. In recent years, the challenge to reduce the energy usage of air conditioner has become a hot topic among researchers. This project's aim is to develop a Control Algorithm for Spot Cooling system. The system helps to detect and track a non-human decoy. The decoy is designed to be wearable by the user so the air conditioner will blow the air towards the user. The Spot Cooling algorithm is implemented on a Raspberry Pi 3 using Model-Based Design with Matlab. A NoIR camera is used to capture infrared images and the visible light is filtered using a floppy disc film. The non-human decoy which is made up of infrared light emitting diode (IR LED) is detected from the captured image using colour thresholding and template matching techniques. The movement of the decoy is tracked using a Kalman filter. The system was successfully implemented. The detection result was verified using a graphical user interface (GUI) software running on a computer. The experimental results showed that the system can achieve more than 98% of correct detection rate for both day and night conditions.

CHAPTER 1

INTRODUCTION

1.1 Background

Based on the research finding by the scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased about 0.8 degree Celsius since 1880 [1]. It is obvious that the year 2016 is the warmest year among all as shown in Figure 1.1 [2].

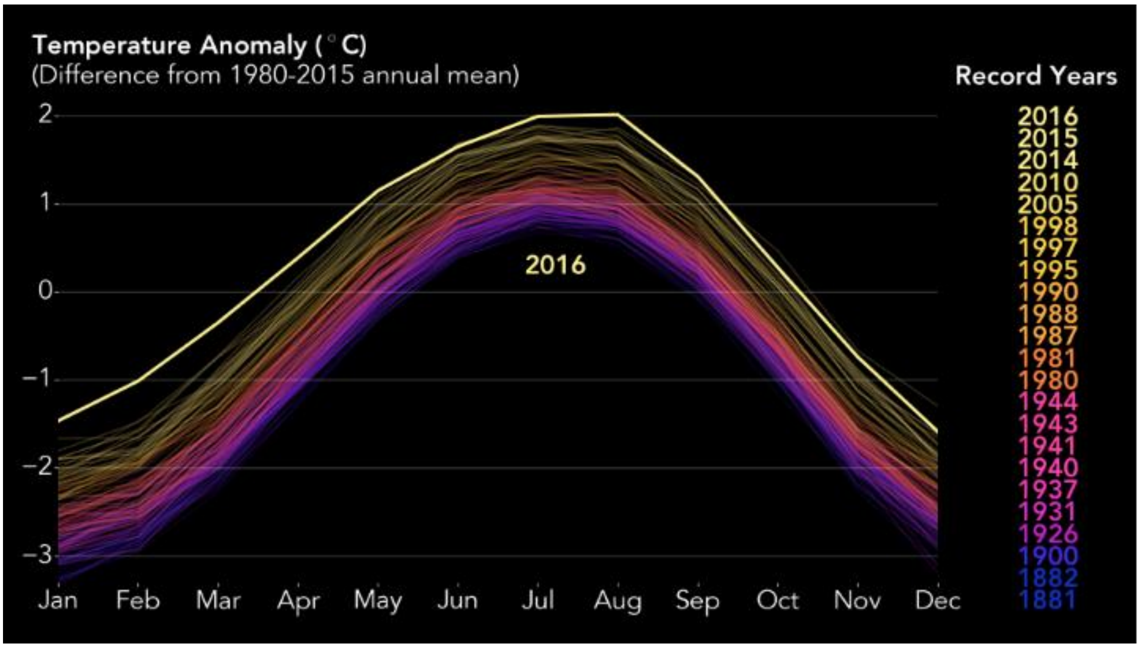

Figure 1.1 Yearly annual temperature cycle from 1880 to 2016 [2]

To overcome the hot weather, the demand of air conditioner is increasing rapidly where most households have at least one air conditioner. Based on the statistics compiled by The Japan Refrigeration and Air Conditioning Industry Association, there is an overall increase of 4.2% in the number of air conditioners which reached 15.15 million units in

Asia, excluding Japan and China [3]. The demand of the air conditioner keeps increasing from the year 2010 to 2015 as shown in Figure 1.2.

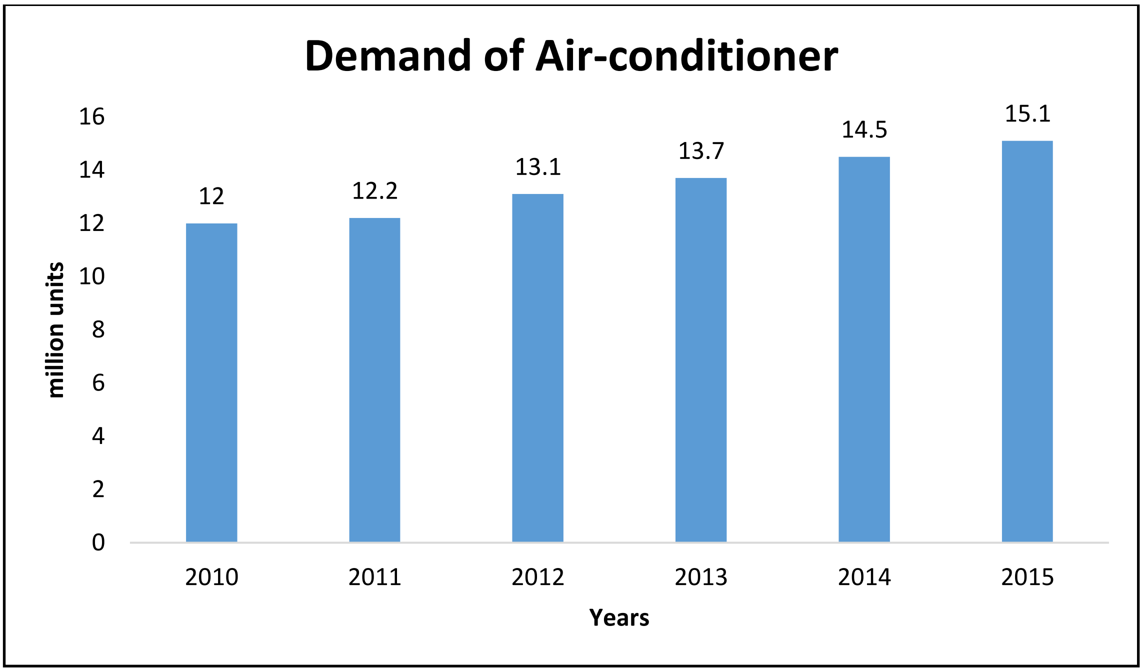

Figure 1.2 Demand of air conditioner in Asia

Based on the research by Centre for Environment, Technology & Development Malaysia (CETDEM), 44.23% of the energy is used for cooling purpose as shown in Figure 1.3 [4]. The energy usage for the air conditioner is too high and thus there are a lot of researches working on ways to reduce the energy consumption of air conditioner in recent years.

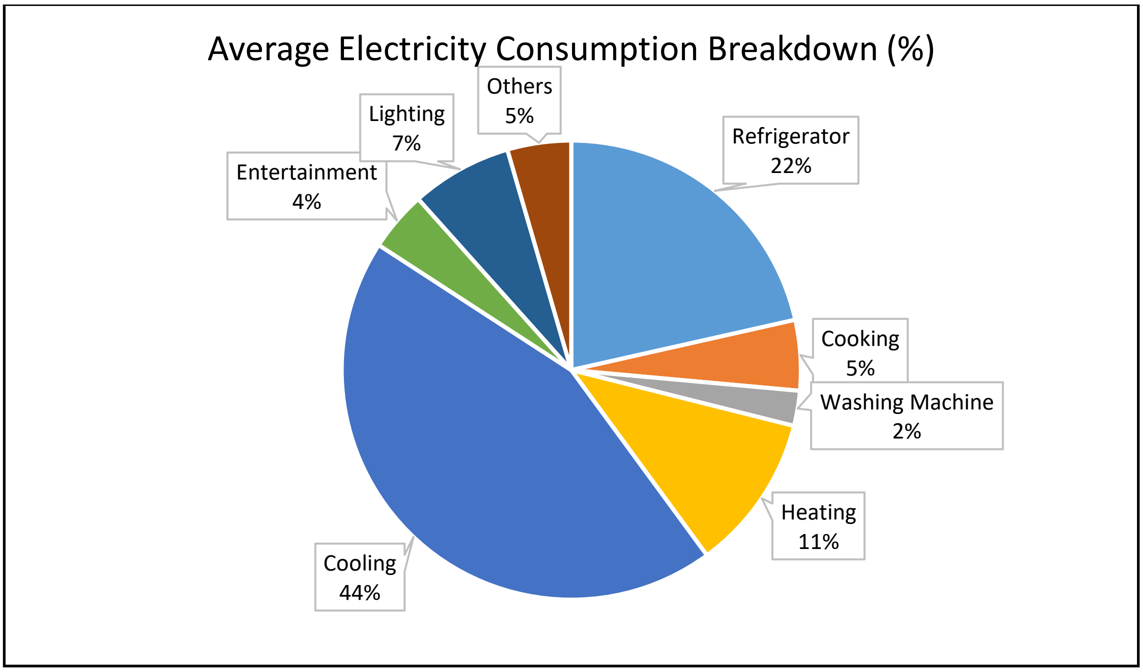

Figure 1.3 Household energy consumption graph

A lot of new technology such as inverter technology in air conditioner is invented to reduce the energy consumption. The inverter technology is used to control the speed of the motor by varying the frequency of the power supply. By varying the frequency of power supply, the speed of the compressor motor can be controlled to suit with the room temperature. When reaching the desired temperature, the inverter air conditioner can lower the speed of the compressor motor to reduce the energy consumption. In contrast, non-inverter air conditioner is unable to control its compressor motor, so the motor will stop when reaching the desired temperature and restart again when the temperature rises [5]. This technology can save more energy as compared to non-inverter air conditioner as the stop/start cycle in non-inverter air conditioner requires higher energy consumption.

Indeed, inverter technology for air conditioner can reduce energy consumption but there is still some problems as conventional air conditioner often cools down the entire room or space regardless of the presence of humans. It is a waste of energy to cool down an unoccupied area. Through controlling the direction of airflow from the air conditioner, we can possibly achieve the same cooling effect, with a reduced energy consumption. This is a concept known as spot cooling, which helps in reducing energy consumption without sacrificing the consumers' comfort.

1.2 Problem Statement

To achieve spot cooling technology for air conditioner, human presence sensor is the most common technology used in many air conditioners to divert the airflow. The most basic human presence sensor consists of a thermal sensor to detect the heat emitted from human body [6]. This type of sensor faces problems when there is presence of other heat sources such as a cup of hot coffee. The sensor is unable to differentiate between human and other heat sources and thus causes confusion and misdetection [7].

Some of the human presence technologies use Pyroelectric Infrared (PIR) sensors. PIR detector is able to detect motion and it is widely used due to low cost, low power consumption and non-contact characteristics [8]. The weakness of this sensor is that it is unable to prioritize the cooling zone when there are several persons in a room. Besides, if the user is static the PIR sensor is unable to detect the user.

1.3 Research Objectives

The main aim of this research is to develop a control algorithm for spot cooling purpose where it can be implemented into an air conditioner. The specific objectives of this project are as follows:

- To develop a non-human decoy and its detection algorithm. The decoy system must be unique and cannot be interfered by other objects or humans in the room.

- To develop a non-human decoy tracking and prediction algorithm with fast respond and lock-in time.
- To implement and test the functionality of the control algorithm for spot cooling.

1.4 Scope of the Research

This project focused on developing a control algorithm for detecting, tracking and predicting the non-human decoy using infrared (IR) imaging and interface it with Matlab. The system focuses only on indoor application where it can be implemented into air conditioner system in the future. The whole system is workable either at day or night as IR image is easy to capture and interpret for both day and night.

For the control algorithm, it is only specific to the non-human decoy designed in this research using the IR LED. The control algorithm will detect, track and predict the non-human decoy movement and accurately pointed out the position of the non-human decoy in the GUI. The prototype system will be tested independently and not interface to the air conditioner at this moment.

1.5 Thesis Organization

There are 5 main chapters in the thesis which consists of the introduction, literature review, methodology, result and discussion, and conclusion of this research. For chapter 1, it includes the introduction of this project's background, problem statements, research objective and the scope of research.

Chapter 2 discusses the literature review of the past works related to this project. The discussion and explanation of the past studies on object detection and object tracking are presented where different algorithms and equations to detect and track the object are also included in this chapter.

Chapter 3 presents the methodology of this research which clearly explains the methods applied and the steps in Matlab used to develop the control algorithm for spot cooling. The hardware, parameters and equations involved in the developing are presented in this chapter.

The findings of this project are displayed in Chapter 4. This chapter shows the results obtained from Matlab. The detection rate of the proposed Spot Cooling system at day and night are compared and discussed. The findings of this project are illustrated in tables and figures.

Finally, the conclusion of this project is presented in Chapter 5. This chapter covers the summary of the outcomes and the future works that can be carried out to improve the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, the work and research done by previous researchers to reduce the energy consumption of air conditioner are discussed. Besides, image processing method will be introduced for object tracking, object detection and prediction.

In section 2.2, the new technology that develops for air conditioner by other researchers is explained. Section 2.3 describes the existing indoor positioning technology. Section 2.4 explains the features selection for object detection and tracking. Section 2.5 discusses the object detection method that can be used in this project. Object tracking and prediction methods are discussed in section 2.6. Section 2.7 presents a summary of this chapter.

2.2 New Technology about Air Conditioner

A recent technology developed by a group of researchers from Hitachi Ltd is area detection technology for air conditioner [9]. This technology uses a camera to detect the layout condition and then control the direction of air flow and the air capacity. Conventional home air conditioners are unable to detect the shape or size of the room or whether the door is closed or open. Therefore, it is unable to adjust the air flow based on the layout and eventually a heat pooling area will occur and it is unable to regulate the desired temperature in the whole room.

The technology uses a camera to capture the walls and corners of a room and detect the layout, enabling the whole room to be regulated at the desired temperature. As the layout of the room had been detected, the air conditioner can be controlled to concentrate the airflow into the corner or the adjacent room [9].

This technology is able to save energy and at the same time maintain the room at desired temperature. However, there is a weakness in this technology as it only detects the layout of the room without checking the presence of user. Cooling the whole room without presence of user will be a waste of energy.

2.3 Indoor Positioning Technology

To detect the presence of user in an area, indoor positioning technology is needed. Global Positioning System (GPS) is a very effective way to locate a location at outdoor environment but its accuracy is extremely low in indoor environment. This is due to the lack of line-of-sight transmission channel between the satellite and the receiver [10].

A research on improving the Radio-frequency identification (RFID) for indoor positioning system by using particle swarm optimization-based artificial neural network is conducted by a researcher from Shanghai University of Engineering Science. RFID indoor positioning system is quite common but the accuracy needs to be improved and they suggested to eliminate the influence of environment factors by using Gauss filtering algorithm.

The positioning process can be divided into 2 part which is offline phase and online phase. In offline phase, they will collect the information between tags and reader to build up a database. Next, the data collected will be filtered using Gaussian filter to obtain the perfect Received Signal Strength Indicator (RSSI) information. Lastly, the vector RSSI will then be fit into a positioning model and the output (x,y) will be sent to online database [11].

This method greatly improves the accuracy of indoor positioning system but it is not applicable in this project as RFID indoor positioning system will need to have a few RFID readers. The cost of the system will be too high to be implemented in domestic air conditioner.

Recently, indoor positioning system using light-emitting diodes (LED) becomes the focus of a lot of researchers. This is due to the advantages of high positioning accuracy, licence-free operation, no electromagnetic interference and low-cost operation. The indoor positioning methods using visible light communication can mainly divide into 3 types which are triangulation, proximity and image positioning.

i. **Triangulation**: The target's position is determined by distance measurement from at least three reference locations using the received signal strength. Time of arrival and time difference of arrival techniques are used.
ii. **Proximity**: the target's position is determined by the reference position of beacon or signal post located near the object on a map. The accuracy depends very much on the resolution of the grid [12].
iii. **Image positioning**: the target's position is determined using a camera based on the coordinate of the LEDs in the real world and also in the captured image [13].

The image positioning method is based on Equation (2.1) - (2.2). The block diagram is shown in Figure 2.1. The camera which locates at O acts as a receiver and the LEDs are evenly distributed on the ceiling. The camera which consists of a lens and a two-dimensional sensor extracts the coordinates of the three LEDs from the captured video or photos through image processing. Feature extraction is used to extract the important information from LED, detect the LED and lastly get its coordinates.

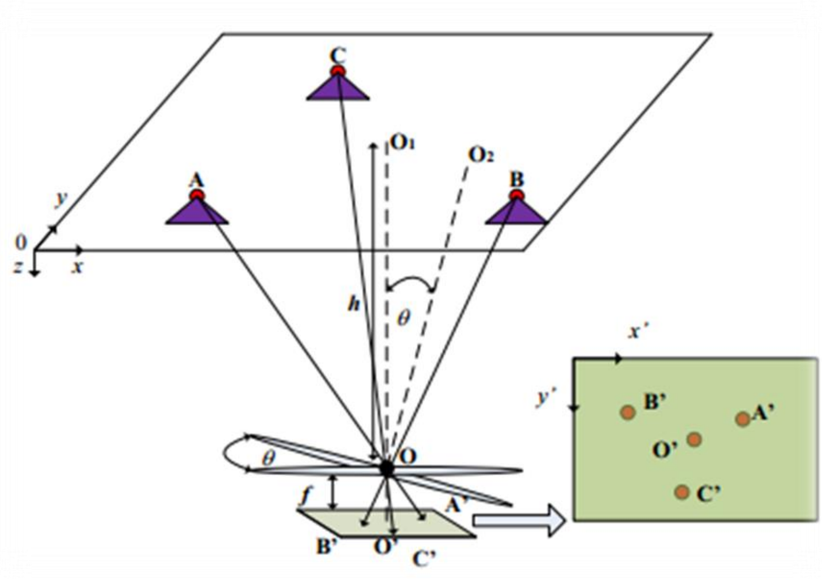

Figure 2.1 A system block diagram of image processing based indoor positioning system [13]

The distance of O_1A (d_{O1A}), O_1B (d_{O1B}) and O_1C (d_{O1c}) can be obtained from:

$$\frac{h}{f} = \frac{d_{O1A}}{d_{O'A'}} = \frac{d_{O1B}}{d_{O'B'}} = \frac{d_{O1C}}{d_{O'C'}} \tag{2.1}$$

With d_{O1A}, d_{O1B} and d_{O1C}, the x and y coordinates of O can be obtained using a set of three quadratic equations as follows:

$$\begin{cases} d_{O1A}^2 = (x_A - x)^2 + (y_A - y)^2 \\ d_{O1B}^2 = (x_B - x)^2 + (y_B - y)^2 \\ d_{O1C}^2 = (x_C - x)^2 + (y_C - y)^2 \end{cases} \tag{2.2}$$

In this research, image processing method for indoor positioning is used because it is cheaper and easy to be implemented on air conditioner.

2.4 Feature Selection for Object Detection and Tracking

For image processing method of indoor positioning, the target's location is determined using a camera capturing the scene of the room and some algorithms are implemented to detect the target. Feature selection is a critical step in image processing so that the desired object can be detected and tracked. The feature selected must be unique and easily distinguished from the picture or video. In general, many tracking algorithms use a combination of different features. The details of common features are discussed in the following subsections.

2.4.1 Colour

Colour is one of the most famous features that can be used if the object's colour is difference from the background. In image processing, the RGB (red, green, blue) colour space is usually used to represent the colour. The red, green and blue components are called the primary colours. Other colour spaces that commonly used in computer graphics are HIS (Hue, Saturation and Intensity), HSV (Hue, Saturation and Value), YCbCr (luma component, blue difference and red difference chroma components) and L*a*b (Lab colour space) [14]. There is no last word on which colour space is better in image processing, so it depends fully on the user.

2.4.2 Edges

Object boundaries usually generate strong changes in image intensities. One of the benefits about the edges features is they are less sensitive to illumination changes compared to colour. Edges features are commonly used to detect the boundary of an object.

2.4.3 Optical Flow

Optical flow is a dense field of displacement vectors which defines the translation of each pixel in the region. It is computed using the differences of brightness of corresponding pixels in consecutive frames [15]. For motion-based segmentation and tracking applications, optical flow is the best choice.

2.4.4 Texture

Texture is a measure of the intensity variation of a surface which quantifies properties such as smoothness and regularity. Texture requires processing steps to generate the descriptors and it is less sensitive to illumination changes compared to colour features.

2.5 Object Detection Method

Object detection is the process to find out the area of interest such as decoy, human, bicycles and other objects in an image or video [16]. The most common approach for object detection is to use the information contained in a single frame. However, to reduce the number of false detection, some object detection methods use the temporary information computed from the sequence of frames. The temporal information is usually in the form of frame difference which highlights the changing regions in the consecutive frames [17]. A few popular object detection methods will be discussed below.

2.5.1 Point Detectors

A point detector is an algorithm that takes one image as input and then output the interest points which have an expressive texture and related by a transformation [18]. The interesting point should have the characteristics as below:

- Clear (preferably mathematically well-founded) definition
- Well-defined position in image space
- Local image structure around the interesting point is rich in terms of local information contents
- Stable under local and global perturbation in the image domain

2.5.2 Background Subtraction

Background subtraction is the best method to detect the moving object provided the background is static. This method is done by finding the deviations from the static background model for each incoming frame. Any significant change in an image region from the background model signifies a moving object. The pixels constituting the regions undergoing change are marked for further processing. Usually, some algorithms are needed to process the detected region and identify the interested object.

2.5.3 Segmentation

The aim of image segmentation is to partition the image into distinct regions that are meant to correlate strongly with objects or features of interest in the image [19]. Image segmentation helps to save the time to process the image or video. The two main challenges for image segmentation are finding the criteria for good segmentation and the method for achieving efficient partitioning.

2.5.4 Supervised Learning

Object detection can be performed by learning different object views automatically from a set of examples by a supervised learning mechanism. Sets of training data with labels are given to the supervised learning mechanism to generate a function that maps inputs to desired outputs. This method requires a large collection of training data for each object class. Additionally, the object class must be manually labeled [17]. The error of detection can be minimized by providing more training data or increasing the number of interactions.

2.6 Object Tracking

Object tracking is the process to locate a moving object over time using a camera. Object tracking is often time-consuming due to the amount of data that is contained in the video. Thus, object detection method is used to simplify the video and reduce the time to track the object. The task of detecting the object and establishing correspondence between the object instances across frames can either be performed separately or jointly. In the first case, object detection algorithm is used to detect the object and then the tracker tracks the object in each frame. This method will be more accurate but time-consuming and is not suitable for real-time tracking. In latter case, the region of interest is jointly estimated by interactively updating the object location and the region represented using previous frames [17]. This method will be used for this project. Below sub-sections will discuss a few object detection and tracking methods.

2.6.1 Continuously Adaptive Mean Shift Tracking Algorithm (CAMshift)

The CAMshift algorithm is based on the mean shift algorithm which is a robust non-parametric iterative technique for finding the mode of probability distributions. CAMshift algorithm is based on the adaptation of Mean Shift that, given a probability density image, finds the mean of the distribution by interacting in the direction of maximum increase in probability density. The main difference between CAMshift and the Mean Shift algorithm is that CAMshift uses continuously adaptive probability distributions while Mean Shift algorithm is based on static distributions, which are not updated unless the target experiences a big change [20]. The overall block diagram CAMshift tracking algorithm is shown in Figure 2.2.

Some drawbacks of the CAMshift tracking algorithm is that it is unable to continuously track the object if the object is blocked by some obstacles. As there could be a lot of obstacles in the indoor situation, thus this method is not suitable to be implemented in this project. A more suitable method for this project is discussed in the next section.

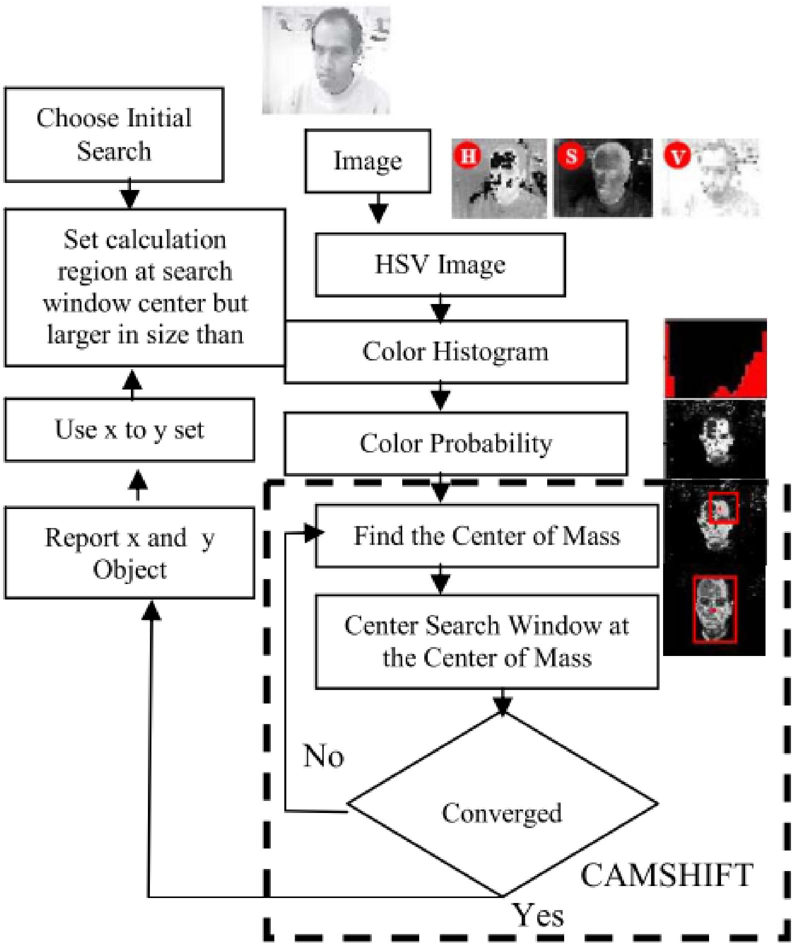

Figure 2.2 CAMshift tracking algorithm [21]

2.6.2 Kalman Filters

A Kalman filter is used to estimate the state of a linear system where the state is assumed to be Gaussian distributed. Kalman filter is an accurate prediction as it included noise and other inaccuracies [17]. Kalman filter consists of two steps: prediction and correction. The prediction step uses the state model to predict the new state of the variables:

$$\overline{\boldsymbol{X}}^{\boldsymbol{t}} = \boldsymbol{D}\boldsymbol{X}^{\boldsymbol{t-1}} + \boldsymbol{W} \tag{2.3}$$

$$\overline{\boldsymbol{\Sigma}}^{\boldsymbol{t}} = \boldsymbol{D}\boldsymbol{\Sigma}^{\boldsymbol{t-1}}\boldsymbol{D}^{\boldsymbol{t}} + \boldsymbol{Q}^{\boldsymbol{t}} \tag{2.4}$$

where $\overline{\boldsymbol{X}}^{\boldsymbol{t}}$ and $\overline{\boldsymbol{\Sigma}}^{\boldsymbol{t}}$ are the states and the covariance predictions at time $\boldsymbol{t}$. $\boldsymbol{D}$ is the state transition matrix which defines the relation between the state variables at time $\boldsymbol{t}$ and $\boldsymbol{t}$-1. $\boldsymbol{Q}$ is the covariance of the process noise $\boldsymbol{W}$.

Similarly, the correction step uses the current observation $Z^{\boldsymbol{t}}$ to update the object's state:

$$\boldsymbol{K}^{\boldsymbol{t}} = \overline{\boldsymbol{\Sigma}}^{\boldsymbol{t}}\boldsymbol{M}^{\boldsymbol{t}}[\boldsymbol{M}\overline{\boldsymbol{\Sigma}}^{\boldsymbol{t}}\boldsymbol{M}^{\boldsymbol{t}} + \boldsymbol{R}^{\boldsymbol{t}}]^{-\boldsymbol{1}} \tag{2.5}$$

$$\boldsymbol{X}^{\boldsymbol{t}} = \overline{\boldsymbol{X}}^{\boldsymbol{t}} + \boldsymbol{K}^{\boldsymbol{t}}\underbrace{[\boldsymbol{Z}^{\boldsymbol{t}} - \boldsymbol{M}\overline{\boldsymbol{X}}^{\boldsymbol{t}}]}_{\boldsymbol{v}} \tag{2.6}$$

$$\boldsymbol{\Sigma}^{\boldsymbol{t}} = \overline{\boldsymbol{\Sigma}}^{\boldsymbol{t}} - \boldsymbol{K}^{\boldsymbol{t}}\boldsymbol{M}\overline{\boldsymbol{\Sigma}}^{\boldsymbol{t}} \tag{2.7}$$

where $\boldsymbol{v}$ is called the innovation, $\boldsymbol{M}$ is the measurement matrix, $\boldsymbol{K}$ is the Kalman gain, which is the Riccati Equation (2.5) used for propagation of the state models. $\boldsymbol{R}$ is the covariance of the measurement noise. Note that the updated state $\boldsymbol{X}^{\boldsymbol{t}}$ is still distributed by a Gaussian [22].

In this project, Kalman filter will be used to continuously track the location of the object even the decoy is being obstructed.

2.7 Summary

This chapter consists of two parts. The first part describes the new technology about the air conditioner and current technology developed for indoor positioning. In part two, it describes the basic of image processing. The common features, object detection and object tracking methods are introduced and explained. The methodology to develop the proposed system in this project will be further discussed in Chapter 3.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter discusses the methodology of this project. In section 3.2, the design of spot cooling system is explained. The main components used in the embedded system are a Raspberry Pi (RPI) 3 Model B programmable microcontroller board, an infrared (NoIR) Camera and a floppy disk film. IR LED is the main component of the decoy system. The usage of the components is explained with respect to their respective operating principles. In section 3.3, the details of the spot cooling algorithm are explained. The algorithm is divided into a few parts based on the flow chart shown in Figure 3.9. In section 3.4, the validation step for the system is presented. Finally, section 3.5 presents the summary of this chapter. The overall flow process of this project is shown in Figure 3.1.

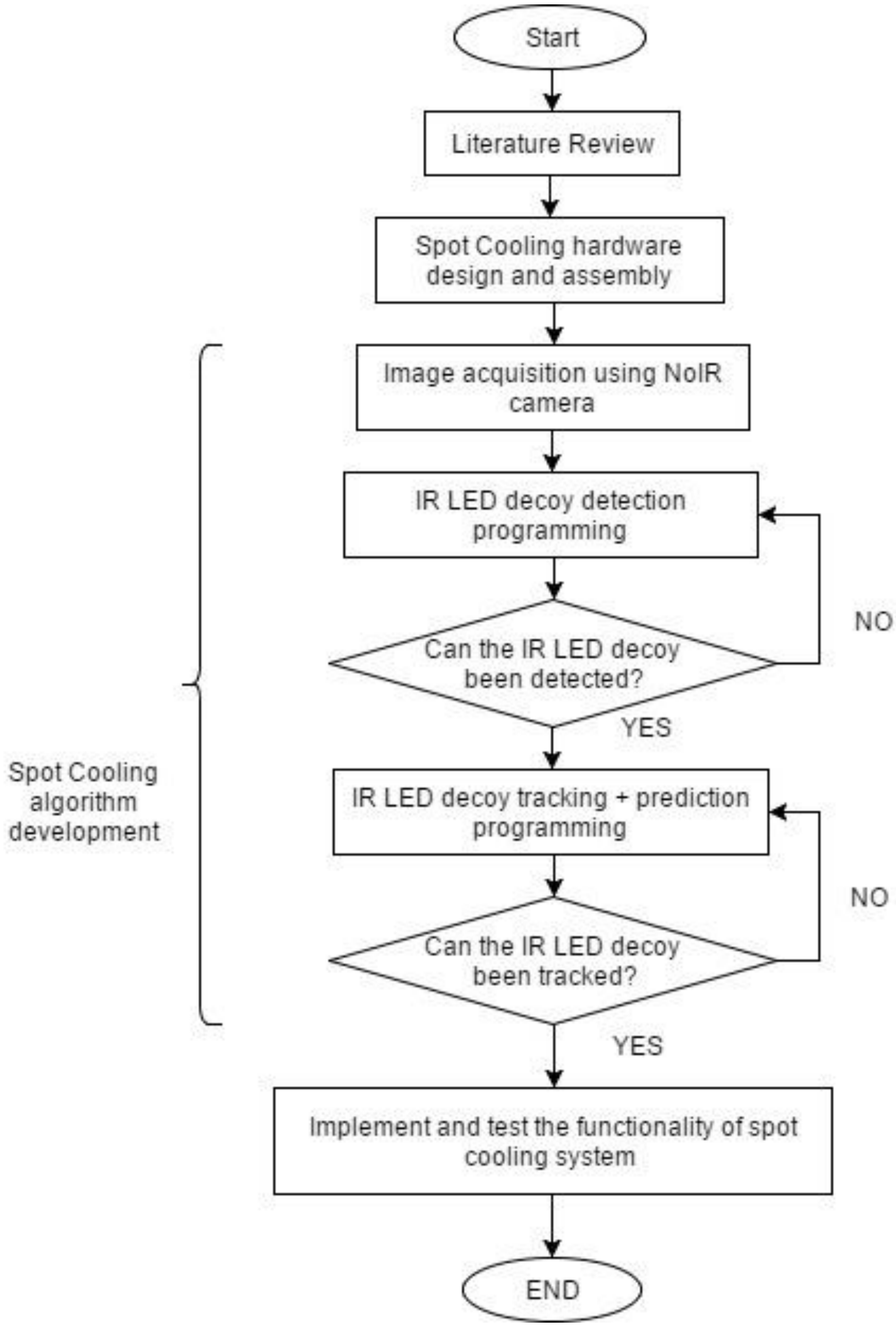

Figure 3.1 Overall project flow chart

3.2 Design of Spot Cooling System

The spot cooling system can be divided into two parts. The first part will be the main system where it will be implemented on the air conditioner. The main system is illustrated in Figure 3.2. The second part is the decoy system. The decoy system is made up of IR LEDs with a blinking circuit.

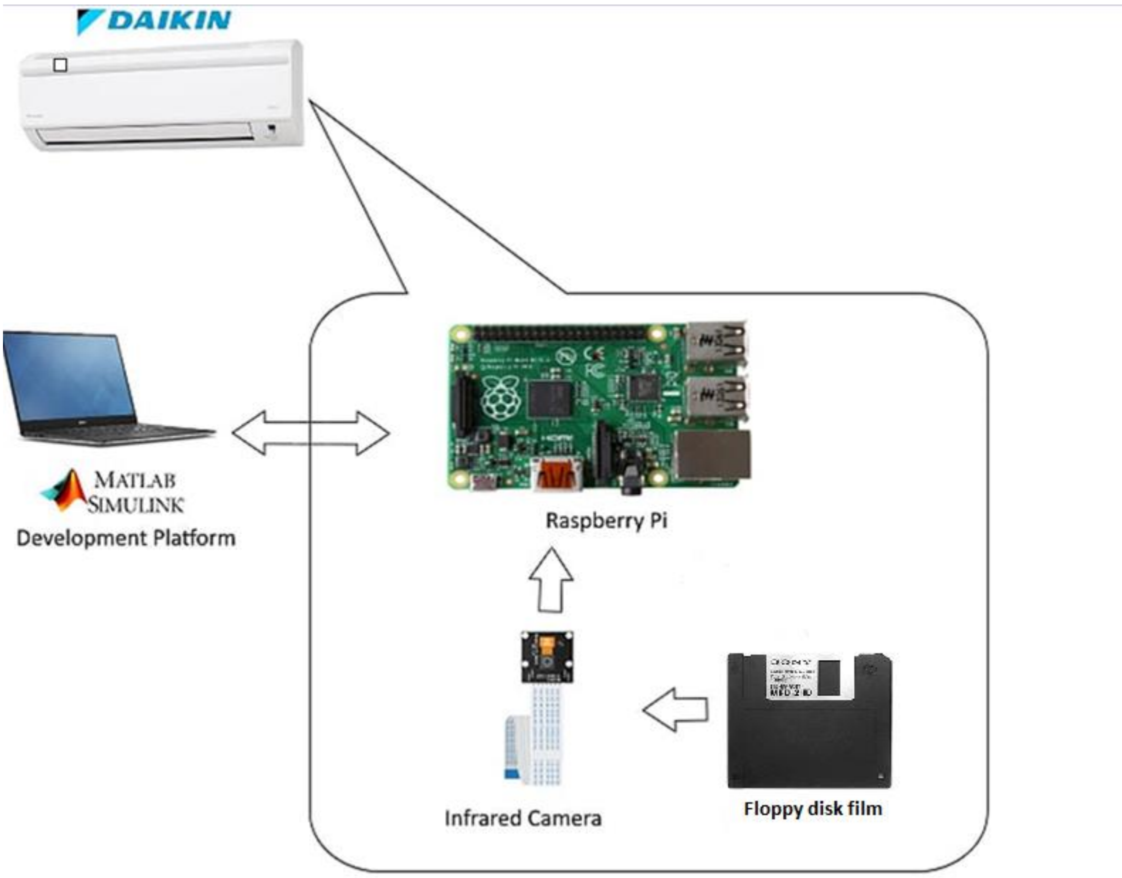

Figure 3.2 Overall Block Diagram of the Spot Cooling Main System

3.2.1 Hardware Design

The overall block diagram of the spot cooling main system is presented in Figure 3.3 where the interfaces relationship between the components is shown. A power supply which is a power bank is used to provide electricity to the RPI. Floppy disc film is attached to the lens of NoIR camera to filter out the visible light. All images or videos captured by the NoIR camera will only contain infrared light images and this will ease the image processing. Infrared image is chosen because it is able to capture the decoy during day and night time. RPI functions as the brain to process the real-time video capture to detect the decoy.

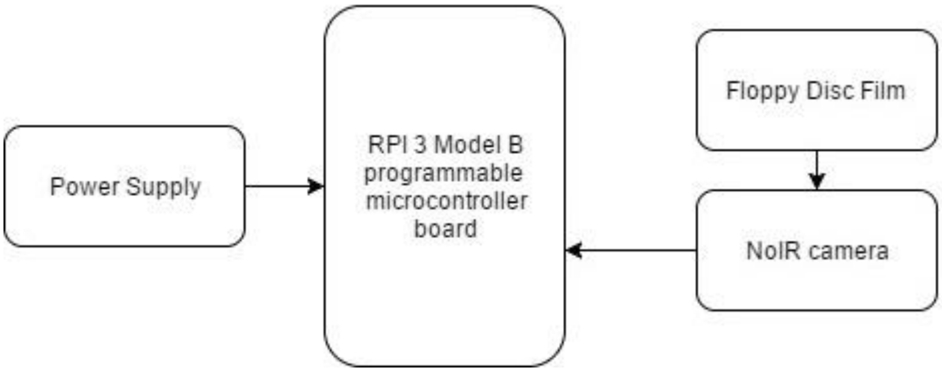

Figure 3.3 Block diagram for spot cooling main system

The main system of the proposed spot cooling system is shown in Figure 3.4. A NoIR camera is secured to the front surface of the module with some downward tilt angle so that it can capture the whole scene of the room. The real situation of the room will be acquired by the NoIR camera and then the image will proceed to the image processing stage. The ribbon cable of NoIR camera is inserted into the camera serial interface (CSI) connector located between Ethernet and High-Definition Multimedia Interface (HDMI) port as shown in Figure 3.5 [23]. The CSI camera connector is opened by pulling the tabs upwards. Then, the ribbon cable is inserted into the connector, CSI camera connector is then pushed towards the HDMI out port and downwards [23]. A floppy disc film is attached to the lens of the camera to filter out visible light. Therefore, only infrared light will be captured in the image and this will ease the subsequent image processing stage.

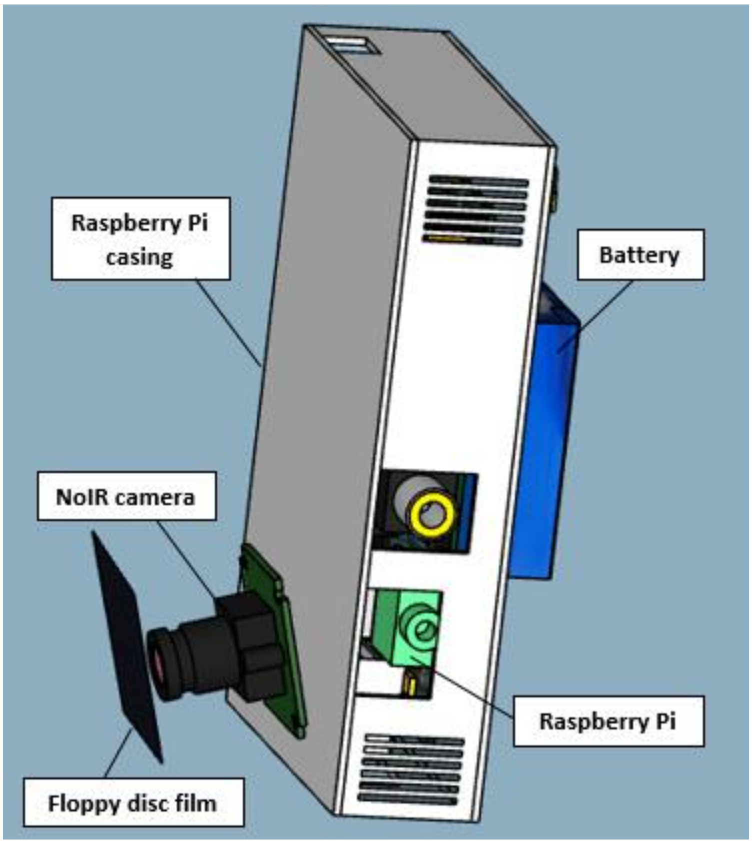

Figure 3.4 Assembly of the Spot Cooling System – Main system

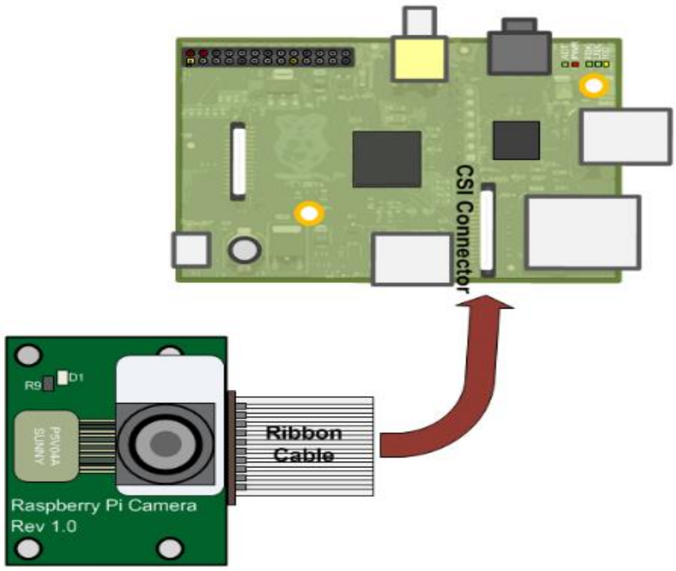

Figure 3.5 Connection of NoIR camera to RPI 3 [24]

Due to RPI 3's reliability, processing speed and versatility, it is selected to be used as the main controller of the module. The RPI will be programmed to carry out image acquisition and image processing. Besides, another big improvement from RPI 2 to RPI 3 is that RPI 3 contains onboard Wireless Fidelity (WiFi) and Bluetooth [25]. The RPI 3 is programmed to connect to a specific hotspot as soon as it boots up. This enables the RPI 3 to communicate with computer wirelessly. The main function for the wireless communication is to validate the detection result of the proposed spot cooling algorithm through a GUI. After the image is processed, the result will be sent to a computer and display with a green circle on the detected object. WiFi is selected as the method of data transmission because its transmission range is enough for an indoor application and its data rate is faster compared to Bluetooth and Radio Frequency (RF) transmission.

For spot cooling decoy system, the overall block diagram is presented in Figure 3.6 where the interface relationship between the components is shown. A power supply which is a 3.7V LiPo battery is used to provide electricity to the IR LEDs. IR LED is chosen as the main component of the decoy system as it is cheap, detectable by the NoIR camera and it will not disturb users. A blinking circuit will be implemented to the IR LEDs to lengthen the battery life.

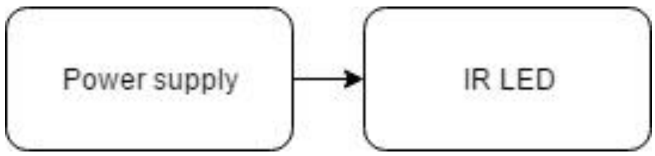

Figure 3.6 Block diagram for spot cooling decoy system

The assembly of the decoy system is shown in Figure 3.7. The IR LED array is specially arranged in an 'X' shape so that the system is able to identify the decoy from other disturbances. Each IR LED is arranged in parallel to reduce its voltage drop. A 3.7V

LiPo battery is selected as the power source due to its small and thin size, and it is rechargeable.

A blinking circuit will be implemented into the decoy system to reduce its energy consumption and lengthen the battery life. The design of the circuit is as shown in Figure 3.8. An op-amp is used to create an oscillating signal to switch on and off the Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) at 6kHz with 50% duty cycle. With 50% duty cycle, the energy usage will be reduced by half. The frequency is fixed at 9kHz so that the infrared light emitted by IR LED can still be captured by the NoIR camera working at a frame rate of 20Hz.

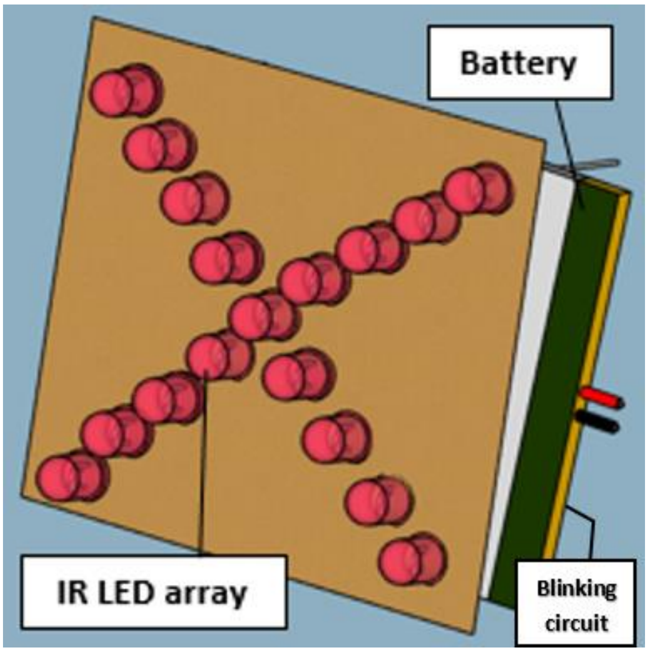

Figure 3.7 Assembly of the Spot Cooling System – decoy system