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Table of contents

Volume 260

2017

◂ Previous issue   Next issue ▸

6th International Conference on Mechatronics - ICOM'17
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View all abstracts

Accepted papers received: 19 October 2017
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Preface

OPEN ACCESS   011001

6th International Conference on Mechatronics - ICOM'17

➕ View abstract   📄 View article   📕 PDF

OPEN ACCESS   011002

Peer review statement

➕ View abstract   📄 View article   📕 PDF

Papers

OPEN ACCESS   012001

Effects of Coil Diameter in Thickness Measurement Using Pulsed Eddy Current Non-destructive Testing

Khairun Nisa Azaman, Ali Sophian and Faris Nafiah

➕ View abstract   📄 View article   📕 PDF

OPEN ACCESS   012002

Realization and Addressing Analysis In Blockchain Bitcoin

Raja Sakti Arief Daulay, Surya Michrandi Nasution and Marisa W. Paryasto

+ View abstract   ▤ View article   ▥ PDF

OPEN ACCESS   012003

Implementation and Analysis of the use of the Blockchain Transactions on the Workings of the Bitcoin

Muhammad Reza Rizky Fauzi, Surya Michrandi Nasution and Marisa W. Paryasto

+ View abstract   ▤ View article   ▥ PDF

OPEN ACCESS   012004

Classification of the Correct Quranic Letters Pronunciation of Male and Female Reciters

Safiah Khairuddin, Salmiah Ahmad, Abdul Halim Embong, Nik Nur Wahidah Nik Hashim, Tareq M.K. Altamas, Syarifah Nuratikah Syd Badaruddin and Surul Shahbudin Hassan

+ View abstract   ▤ View article   ▥ PDF

OPEN ACCESS   012005

Flip-Chip Bonding Fabrication Technique

Tengku Muhammad Afif bin Tengku Azmi and Nadzril bin Sulaiman

+ View abstract   ▤ View article   ▥ PDF

OPEN ACCESS   012006

Mechatronics technology in predictive maintenance method

Nurul Afiqah A. Majid and Asan G.A. Muthalif

+ View abstract   ▤ View article   ▥ PDF

OPEN ACCESS   012007

Human location estimation using thermopile array sensor

S Parnin and M M Rahman

+ View abstract   ▤ View article   ▥ PDF

OPEN ACCESS   012008

Speech-based Class Attendance

Umar Faizel Amri, Nik Nur Wahidah Nik Hashim and Noor Hazrin Hany Mohamad Hanif

+ View abstract   ▤ View article   ▥ PDF

OPEN ACCESS   012009

Traffic intensity monitoring using multiple object detection with traffic surveillance cameras

H G Muhammad Hamdan and O O Khalifah

✚ View abstract　　　📄 View article　　　📕 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012010

Control of cooperative manipulators in holding deformable objects

A A Alkathiri and N Z Azlan

✚ View abstract　　　📄 View article　　　📕 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012011

Dragon Stream Cipher for Secure Blackbox Cockpit Voice Recorder

Fadira Akmal, Surya Michrandi Nasution and Fairuz Azmi

✚ View abstract　　　📄 View article　　　📕 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012012

Enhancement web proxy cache performance using Wrapper Feature Selection methods with NB and J48

Dua'a Mahmoud Al-Qudah, Rashidah Funke Olanrewaju and Amelia Wong Azman

✚ View abstract　　　📄 View article　　　📕 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012013

UAV State Estimation Modeling Techniques in AHRS

Shikin Razali and Amzari Zhahir

✚ View abstract　　　📄 View article　　　📕 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012014

Modelling and Simulation Analysis of Rolling Motion of Spherical Robot

N N Kamis, A H Embong and S Ahmad

✚ View abstract　　　📄 View article　　　📕 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012015

Development of Fuzzy Logic Controller for Quanser Bench-Top Helicopter

M. H. Jafri, H. Mansor and T.S. Gunawan

✚ View abstract　　　📄 View article　　　📕 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012016

Design and analysis of planar spiral resonator bandstop filter for microwave frequency

S. M. A. Motakabber and Muhammad Shaifudin Suharsono

✚ View abstract　　　📄 View article　　　📕 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012017

Real-time Human Activity Recognition

N. Albukhary and Y.M. Mustafah

+ View abstract　　　　▤ View article　　　　⬚ PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012018

Optimized Vibration Chamber for Landslide Sensory and Alarm System

Eliza Sabira Binti Ismail, Mohamed Hadi Habaebi, Jamal I. Daoud and Md Rafiqul Islam

+ View abstract　　　　▤ View article　　　　⬚ PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012019

Miniaturized Water Flow and Level Monitoring System for Flood Disaster Early Warning

Salami Ifedapo Abdullahi, Mohamed Hadi Habaebi, Teddy Surya Gunawan and MD Rafiqul Islam

+ View abstract　　　　▤ View article　　　　⬚ PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012020

The Effect of Electrical Stimulation in Improving Muscle Tone (Clinical)

M F Azman and A W Azman

+ View abstract　　　　▤ View article　　　　⬚ PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012021

An Experimental Design of Bypass Magneto-Rheological (MR) damper

MM Rashid, Mohammad Abdul Aziz and Md. Raisuddin Khan

+ View abstract　　　　▤ View article　　　　⬚ PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012022

Prediction of Beck Depression Inventory (BDI-II) Score Using Acoustic Measurements in a Sample of Iium Engineering Students

Muhamad Fikri Zanil, Nik Nur Wahidah Nik Hashim and Huda Azam

+ View abstract　　　　▤ View article　　　　⬚ PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012023

Prediction of dry ice mass for firefighting robot actuation

M T Ajala, Md R Khan, A A Shafie, MJE Salami and M I Mohamad Nor

+ View abstract　　　　▤ View article　　　　⬚ PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　012024

Modified Ashworth Scale (MAS) Model based on Clinical Data Measurement towards Quantitative Evaluation of Upper Limb Spasticity

A Ahmad Puzi, S N Sidek, H Mat Rosly, N Daud and H Md Yusof

+ View abstract　　　　▤ View article　　　　⬚ PDF

OPEN ACCESS   012025

Network-Based Real-time Integrated Fire Detection and Alarm (FDA) System with Building Automation

F Anwar, R I Boby, M M Rashid, M M Alam and Z Shaikh

+ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012026

Trajectory tracking in quadrotor platform by using PD controller and LQR control approach

Maidul Islam, Mohamed Okasha and Moumen Mohammad Idres

+ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012027

Assistive-as-Needed Strategy for Upper-Limb Robotic Systems: *An Initial Survey*

I. M. Khairuddin, S. N. Sidek, H. Md Yusof, K. Baarath and A. P. P. A. Majeed

+ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012028

Nanosatellites constellation as an IoT communication platform for near equatorial countries

A Narayanasamy, Y A Ahmad and M Othman

+ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012029

Wireless Battery Management System of Electric Transport

Ataur Rahman, Mizanur Rahman and Mahbubur Rashid

+ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012030

Time response for sensor sensed to actuator response for mobile robotic system

N S Amir and A A Shafie

+ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012031

Improvement of Dimensional Accuracy of 3-D Printed Parts using an Additive/Subtractive Based Hybrid Prototyping Approach

A N M Amanullah Tomal, Tanveer Saleh and Md. Raisuddin Khan

+ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012032

The effect of electrohydrodynamic force on the lift coefficient of a NACA 0015 airfoil

Y Yusof, A Hossain, A H Abdullah, Rizal M E Nasir, A Hamid, N Muthmainnah and M N

✚ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012033

Network Function Virtualization (NFV) based architecture to address connectivity, interoperability and manageability challenges in Internet of Things (IoT)

Shariq Haseeb, Aisha Hassan A. Hashim, Othman O. Khalifa and Ahmad Faris Ismail

✚ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012034

Determining the Time of Flight and Speed of Sound on Different types of Edible Oil

N. A. Azman and S. B. Abd Hamid

✚ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012035

Closed-loop model identification of cooperative manipulators holding deformable objects

A A Alkathiri, R Akmeliawati and N Z Azlan

✚ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012036

Effect of Temperature on Ultrasonic Signal Propagation for Extra Virgin Olive Oil Adulteration

N.A. Alias, S.B. Abdul Hamid and A. Sophian

✚ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012037

Design of Dual Band Microstrip Patch Antenna using Metamaterial

Md Rafiqul Islam, A.A Alsaleh Adel, Aminah W. N. Mimi, M. Sarah Yasmin and Farihah A.M. Norun

✚ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012038

Optimum concentric circular array antenna with high gain and side lobe reduction at 5.8 GHz

Mohammed Zaid, Md Rafiqul Islam, Mohamed H Habaebi, AHM Zahirul Alam and Khaizuran Abdullah

✚ View abstract   📄 View article   📄 PDF

OPEN ACCESS   012039

Applying Mechatronics to Improve the Safety of Children in Vehicles - What Can Be Done?

Khairul Hazziq Zufar and Ahmad Jazlan

✚ View abstract   📄 View article   📄 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　　　　　　　　012040

Object Detection Technique for Small Unmanned Aerial Vehicle

M. Faiz Bin Ramli, Ari Legowo and Syariful Syafiq Shamsudin

+ View abstract　　　　📄 View article　　　　📄 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　　　　　　　　012041

Performance analysis of rain attenuation on earth-to-satellite microwave links design in Libya

Md Rafiqul Islam, Asma Ali Hussein Budalal, Mohamed H Habaebi, Khairayu Badron and Ahmad Fadzil Ismail

+ View abstract　　　　📄 View article　　　　📄 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　　　　　　　　012042

Speech to Text Translation for Malay Language

Rami Ali Al-khulaidi and Rini Akmeliawati

+ View abstract　　　　📄 View article　　　　📄 PDF

OPEN ACCESS　　　　　　　　　　　　　　　　　　　　　　　　　　012043

Rapid lard identification with portable electronic nose

Marsad Latief, Aida Khorsidtalab, Irwan Saputra, Rini Akmeliawati, Anis Nurashikin, Irwandi Jaswir and Gunawan Witjaksono

+ View abstract　　　　📄 View article　　　　📄 PDF

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Human location estimation using thermopile array sensor

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Abstract. Utilization of Thermopile sensor at an early stage of human detection is challenging as there are many things that produce thermal heat other than human such as electrical appliances and animals. Therefrom, an algorithm for early presence detection has been developed through the study of human body temperature behaviour with respect to the room temperature. The change in non-contact detected temperature of human varied according to body parts. In an indoor room, upper parts of human body change up to 3°C whereas lower part ranging from 0.58^{0} C to 1.71^{0} C. The average changes in temperature of human is used as a conditional set-point value in the program algorithm to detect human presence. The current position of human and its respective angle is gained when human is presence at certain pixels of Thermopile's sensor array. Human position is estimated successfully as the developed sensory system is tested to the actuator of a stand fan.

1. Introduction
Localization estimations of a subject prior to the location of the sensor can be interpreted using distance, angle, and coordinates. Depending on the parameters measured by sensor, the output is translated into distance, angle, coordinates, and etc. Our early work in [1], only tested a single Thermopile sensor to distinguish the sensor behaviour with respect to number of human in the sensor's field of view (FOV). Result support that the location of occupants can be determine by the highest and distinguishable temperature value of the pixels. However, we could not solely depend on one, but want to strengthen the finding by adding another stage of human sensing detection precedence the localization stages which is presence detection stage. Thus, the main direction of this work is to develop algorithm for human location detection and to rotate an actuator to the detected location.

2. Thermopile sensor
Thermal sensor or temperature sensor is a device that detects heat, a distinguishable property that human has. In general, operation types of Thermal sensor can be either contact or non-contact based. Examples of contact types of temperature measurement sensor are Thermocouple, RTD and Thermistor. Meanwhile, for non-contact sensors for thermal radiation measurement are Pyroelectric, Thermopile, and Bolometer. To this date, research for applying non-contact Thermal sensor for human sensing is not as common as the other sensors such as Pyroelectric and Ultrasonic. The possible application of this human detection heat-based sensory system are home automation, security, and other indoor types of application.

Many of the Thermal sensor used MEMS technology, a process to create a tiny microscopic size of mechanical devices (i.e. MEMS Thermopile). Thermopile array types of Thermal sensor is one of the

famous passive sensor among the researcher for human detection. It comprises of a stack of junction (i.e. serially connected Thermocouple) [2] of two diverse materials that when the voltage is applied at the junction, voltage difference and temperature difference will be produced. Passive characteristics does not allow it to radiate energy to the surrounding. Therefore, Thermopile sensor will not be affected by the reflectivity of the materials or object [3]. As Thermopile is a non-contact Temperature sensor, energy radiated by the object is collected by the absorber attached to the Thermocouple junction make it possible for the temperature to be measured from a distance location.

Method proposed in [3] for human detection in application for pedestrian counting at doorway used TPA81 Thermal sensor manufactured by Devantech Ltd. A person is said to be detected when the temperature exceeds the normalized or threshold temperature. Furthermore, different result of the correct detection rate for different walking speed are recorded. It was found that correct detection rate decreases as the speed is increasing from 98% to 90% for $0.5 \frac{m}{s}$ to $2 \frac{m}{s}$ walking speed. For the high pedestrian traffic entrance experiments, 95.7% correct detection was documented. It has a total of 18 times false detection in the duration of 30 minutes.

Kuki et al. in [4] proposed a multiple human location estimation system using Thermopile array sensors. Sensors installed at the ceiling detect the temperature of an empty room space. They employ a background removal and fuzzy inference on the temperature distributions. The system does not give a good result in human presence detection but it is excellent in human counting. It has 52.4±12.4% total correct rate for a dynamic or moving human test. A higher correct rate is obtained for a stationary position as thermal distribution of stationary person is clear than a moving person.

There is also a research attempt to detect human temperature wirelessly using 40X60 Thermal array sensor for smart camera application [5]. When the sensor reading is recorded, it can produce a thermal image similar from the output of thermal camera. That is the reason it can produce an image if the sensor FOV is wide. As such in his research, many set of Thermal sensors are needed for having a bigger picture frame. The thermal images are then filtered and isolated using MATLAB to the areas of high heat. Their result shows the physical shape of human body can be clearly seen at distance of 0.5 meter from the sensor.

In [6] using Daubechies Wavelets (i.e. a nonlinear and non-parametric method) to eliminate the high frequency noise from the thermopile array sensor readings. The process of eliminate the noise that coming from the unstable data using Daubechies Wavelets give a better result without altering useful information such as signal rupture produces by human presence. The time series graph human presence denotes that once human is exiting, temperature drops to ambient temperature.

In [7], they design a sensing units that state the status of room occupancy and counts the number of human using two OMRON Thermopile sensors. They found that at a long range of between 6 m to 9 m, temperature reading recorded an average rise of 3^0 C upon the presence of an object known to be 10^0 C warmer than the ambient temperature. Furthermore, overlapping two sensor FOV allows the identification of the human location with respect to the sensor position. Both sensors will give an intersection point for the detected human since both FOV are overlapping.

3. Algorithm development

3.1 Changes in non-contact human body temperature using single Thermopile sensor

Experiment is conducted to analyse the changes of human body temperature with respect to the room temperature using a single Thermopile sensor D6T-8L-06. The sensor is tilt to 90° angle therefore the adjustment can cover the whole length of human body. The measured distance of 2 m from the sensor gives the total width and a width of every pixel to be about 0.2 m each respectively. At this total wideness, it is enough to fit in the height of a man up to 1.7 m. Meanwhile, Thermopile sensor is attached at the height of 70 cm to the fixed position aluminium rod. The pixels of Thermopile sensor are positioned to target different human body parts such as head, neck, shoulder, midriff, waist, thigh, leg, and lower leg.

As controlled parameters, experiment is conducted in an indoor room as outdoor environment have high sunlight penetration exposure that can affect temperature readings. A 5 mX3 m room is used throughout the experiment. Before experiment subjects are rested in an air-conditioned room for a period of time (i.e. 10 to 15 minutes), then is brought to the experimental room with no air conditioning appliance. The purpose is to study the minimum net changes since the body already regulate to a balance thermal comfort after sitting long in the air condition room. Therefore, the changes in temperature can be used as the setting point or condition in the algorithm to detect the human presence.

An image of the sensor FOV is captured right before the subject entered the experimental area. Different configurations of human body (i.e. front, side and back) in front of the sensor is shown in figure 1. The significant of this configuration to illustrates the freedom of the human behaviour in front of the sensor as human may face the presence detection device from front, side or blocking the fan from back.
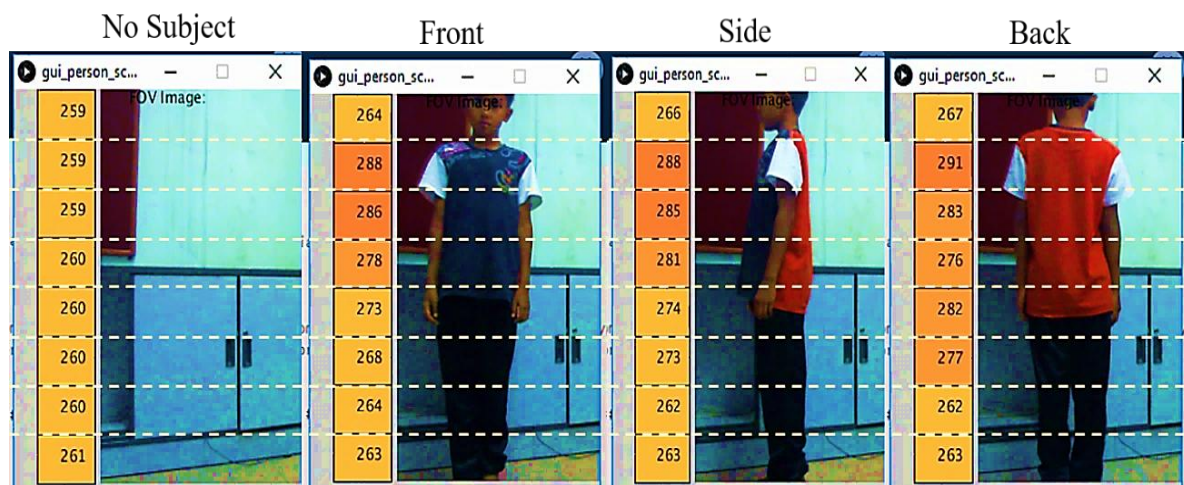
Figure 1. Sample of GUI windows for the experiments for Front, Side, and Back position. The program is developed using Processing user interface. Temperature value is in multiple of 10 and unit is in ^{0}C.

Changes in the temperature is used as the setting point or condition in the algorithm to detect the human presence. This research denoted each body part temperature as T_p. Where the subscript p denotes for the parts of human body (i.e. head, shoulder, chest, midriff, waist, thigh, leg and lower leg). Equation (1) and equation (2) are used to estimate the changes of section of human body temperature, ΔT_p to the room temperature, T_R.

$$\Delta T_p = T_p - T_{R,AVG} \tag{1}$$

$$T_{R,AVG} = \frac{\sum_0^N T_X}{N} \tag{2}$$

$T_{R,AVG}$ is notation for average temperature for sensor pixels in the room. While, notation T_X is used to describe the temperature data of each pixel and the formulae for derivation of T_X is explain in our previous work in [1]. Table 1 tabulated the result of the experiment for ten subjects.

Table 1. Average Changes in temperature of body parts for front, side, and back configuration for 10 subjects with respect to average temperature, ΔT_p

Body Parts (p)	Front (^{0}C)	Side (^{0}C)	Back (^{0}C)
Head	1.6042	1.6960	1.4875
Shoulder	2.8990	2.5163	2.6263
Chest	2.5563	2.7563	2.9563
Midriff	2.4763	2.0613	2.1363
Waist	2.2363	1.7412	2.3163
Tight	1.6563	1.5563	1.7088
Leg	1.0153	1.1486	1.2156
Lower leg	0.6833	0.5875	0.6833

Since human wear a variety of types and thickness of clothes, the non-contact temperature will not give the output as high as the normal skin temperature (i.e. 36-37^0 C). Rather the expected output will be less due to the thermal insulation of the clothes.   The average changes in temperature resulted that human takes a change of more than 2^0 C for upper parts of the human body except for the head. While, the lower part of a body changes at average of more than 1℃ except for the lower leg. This result is used as the conditional set points in the program to detect human presence in the next section.

3.2 Multiple sensor algorithm

The algorithm to combine two Thermopile sensors can be written as in the form of equations. Equation (3) and equation (4) lists the temperature that can be collected by each of two sensors at instant time, t. $TPAT$ is the temperature at the surface of the sensors itself. Both Thermopile sensors will give one TPAT and 1×8 array of FOV pixels.

$$T\ Distributions\ sensor1 = \{TPAT(t), T0(t), T1(t), T2(t), \ldots, T7(t)\} \tag{3}$$

$$T\ Distributions\ sensor2 = \{TPAT(t), T0(t), T1(t), T2(t), \ldots, T7(t)\} \tag{4}$$

Combination of both sensors into 1×16 array excluding the sensor's surface temperature (i.e. $TPAT$ (℃)) give new temperature distribution of T_X as in equation (5).

$$While\ T_X = \{ T0(t), T1(t), T2(t), \ldots, T15(t)\} \text{ ℃} \tag{5}$$

Recall that T_X is the temperature outputted from the Thermopile sensor which depends on the objective and background temperature. Because of the human skin temperature can be distinguishable and always be higher than any other temperature we could compare the temperature from Equation 5 to find the maximum pixel in the array, T_{max} using equation (6).

$$T_{max} = \max_{0\ \leq i \leq 15} T_X \text{ ℃} \tag{6}$$
$$T_{max} = \max_{0 \leq i \leq 15}\{ T0(t), T1(t), T2(t), \ldots, T15(t)\} \text{ ℃} \tag{7}$$

Equation 6 can also be written as in equation (7). To distinguish the types of object in front of sensor FOV (i.e. human and non-human), T_{max} is further compared with the setting point value from its average temperature data from the previous experiment.
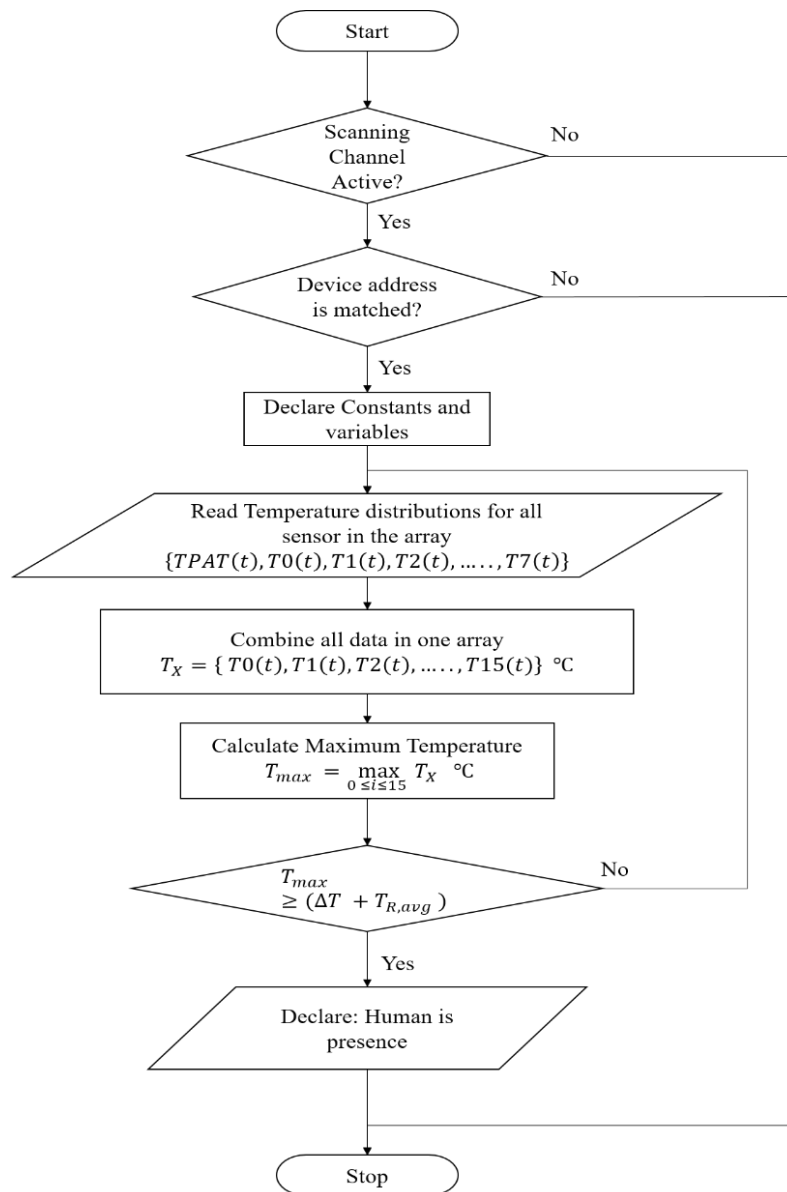
Figure 2. Flowchart for human presence detection algorithm using Thermopile sensor. Maximum number of Thermopile sensor can be used in the algorithm is 4.

$$Human\ presence = \begin{cases} 1, & T_{max} \geq (\Delta T + T_{R,avg}) \\ 0, & T_{max} < (\Delta T + T_{R,avg}) \end{cases} \qquad (8)$$

From equation (8), human is detected and returned value of 1 when the condition is true and returned zero if otherwise. The presence of human in the room as estimated in the equation is only depend on the temperature regardless of the state of motion. In this research, change of temperature due to the presence of human, ΔT generally is chosen as 2^0 C as the height of sensor aim to sense at the upper part of the body. Figure 2 shows the algorithm flowchart for human presence detection. Once the human is detected, the direction in terms of angle is estimated as in section 5.

4. System block diagram and schematics

Block diagram of Thermopile sensory system is shown in figure 3. Sensor array is considered as 'Device' and is connected to the 'Master' (i.e. Controller) through the 'Slave' (i.e. multiplexer). When the controller sends the address of $0X70$ to multiplexer, all the four channel is enable. As the channels are enable, controller read the temperature distributions, T by commanding read and write to the device address of $0X0A$.
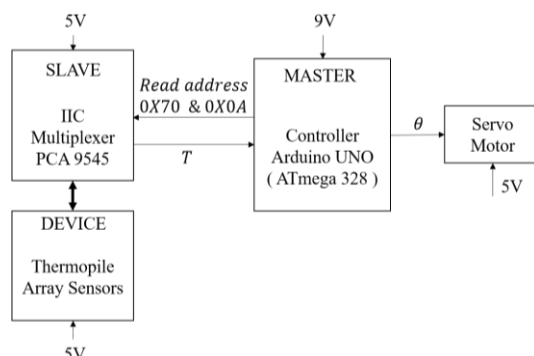
Figure 3.   Block Diagram of Thermopile array sensor.

After the human location (angle) is estimated, controller use the value to rotate the actuator toward the current human location.

Thermopile array sensor used Inter-Integrated Circuit (IIC) communication protocol. Therefore, data can be transmitted and received only using two serial lines, which are, Serial Data (SDA) and Serial Clock Line (SCL). Arduino Microcontroller only have one SDA and SCL pin. Therefore, multiplexer switch is needed to connect multiple Thermopile together. PCA9545 is a 4-channel switch multiplexer. PCA 9545 comes in a very small size of surface mounting chips.

5. Sensor array arrangement
5.1 Sensor Array Positioning

Since one D6T-8L-06 can have a wide width angle of 62.8^0, another sensor is added to widen the sensor FOV. The position of one sensor to another matter as much as to reduce the uncovered spot (i.e. blind spot). The following restricts the arrangement of the Thermopile sensors: -

  i.   Two sensors FOV must not be overlapped
  ii. Two sensors must close enough to reduce blind spot between each FOV.

A sensors holder is designed to satisfy the design constraint. Therefore, this combination of two sensors has the maximum of 125.6^0 wide width-angle of sensors FOV and a total of 16 independent pixels. Figure 4 shows the illustration of subject movement in 125.6^0 wide width-angle.
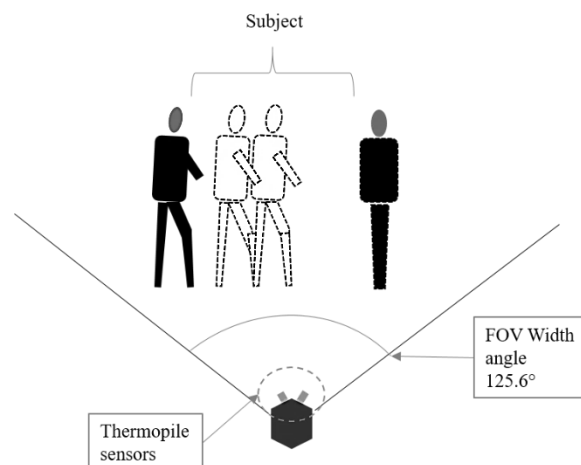

Figure 4. Illustration of the FOV of two Thermopile D6T-8L-06 sensors.

5.2 Actuator angle direction estimation Method

The next step after sensing the human presence is to direct the servo motor to the location that the human is presence. Taking the advantage that the eight pixels have independent temperature value and

has a horizontal FOV of 62.8^0 for single sensor, we develop an active FOV of 125.6^0. Shown in the figure 5(a), is the position of the eight pixels of sensor 1 and 2. To minimize the blind spot and maximize the total sensor's FOV, sensor 1 is flipped to 180^0. This configuration has interchange the pixel position of the sensor 1 causing both P0 of the sensors to meet in the middle section.

As the horizontal angle of the sensors are 62.8^0 each, and each pixel have wide angle, $\emptyset$ of 7.85^0. Therefore θ_1 and θ_2 are both 27.2^0.
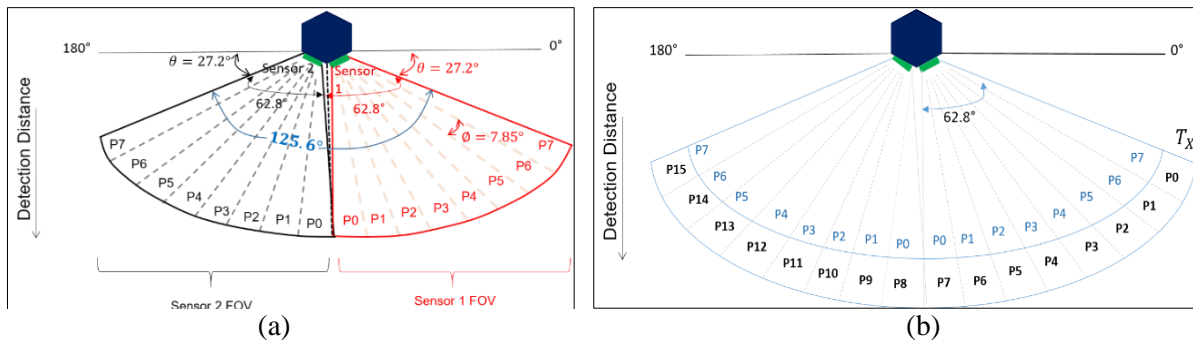
Figure 5. a) Total FOV angles. b) T_X arrangement.

The detection power will decrease over the increase in detection distance. As explained in the algorithm, a set of new pixel number is introduced to store the combination of both sensors pixels containing 16 elements in the array of T_X (equation (5) and illustrated in figure 5(b).

Upon detecting the presence of human in any pixels of T_X, the fan-head servo will move to the centre of the pixel. Let say, human is detected at P0, then servo will rotate at an angle of $\theta + (\emptyset/2)$. The most right of sensor 1 is set to be the 0^0 angle.

The presence of human in the next pixel will increase the angle by $\emptyset$. The last swinging angle is therefore $\theta + \frac{31\emptyset}{2}$ which is equivalent to $(125.6° + 27.2° - \frac{7.85°}{2})$ or $(180° - 27.2° + \frac{7.85°}{2})$. Figure 6 depict the assignation of angle of the servo is directed to go if the certain pixel is occupied with human presence.
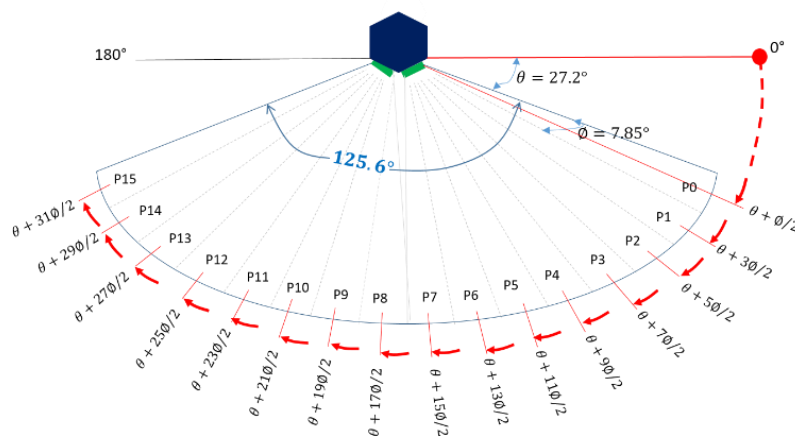

Figure 6. Angle assignation of each pixel location.

6. Result

Similar to [1], we tested the developed algorithm to a Standing Fan which swing according to the presence of human in the room.

6.1 Single Human Detection (Following Mode)

The fan under test was kept in a 5X3 m room that has one window, one door lead to outside, and two doors lead to another room. All doors have at least a 10 mm allowable distance between the floor to allow the door to be open, therefore the temperature from the other two rooms may affect the test room through the space under it. The window was not exposed to the direct sunlight as the hallway very wide, but still heat transfer from the window could not be neglected. The air-condition from the two room was turn on, and the door is open and closed at any time. The first mode of the test is to see the fan response corresponding to the subject facing to the fan. This means that the Thermopile sensory system will only detect the Front body temperature. Initially, subjects are asked to step on all the grid point marked on the floor and stay stationary. Figure 7 illustrate the motion of the swing fan upon the presence of a subject. It is observed that the fan head follows the subject by estimating the correct angle successfully.

As the subject is move to another point, fan head also rotate to the new position. When the subject is at stationary, fan head also stays at its current position. Furthermore, sensors also could detect subject successfully up to 4 m. The test for the distance of 3 m is shown in figure 7 (a). Despite the successful response, there are cases of slower response of the system feedback. This happen only at the middle pixel location (i.e. pixel 7 and pixel 8).
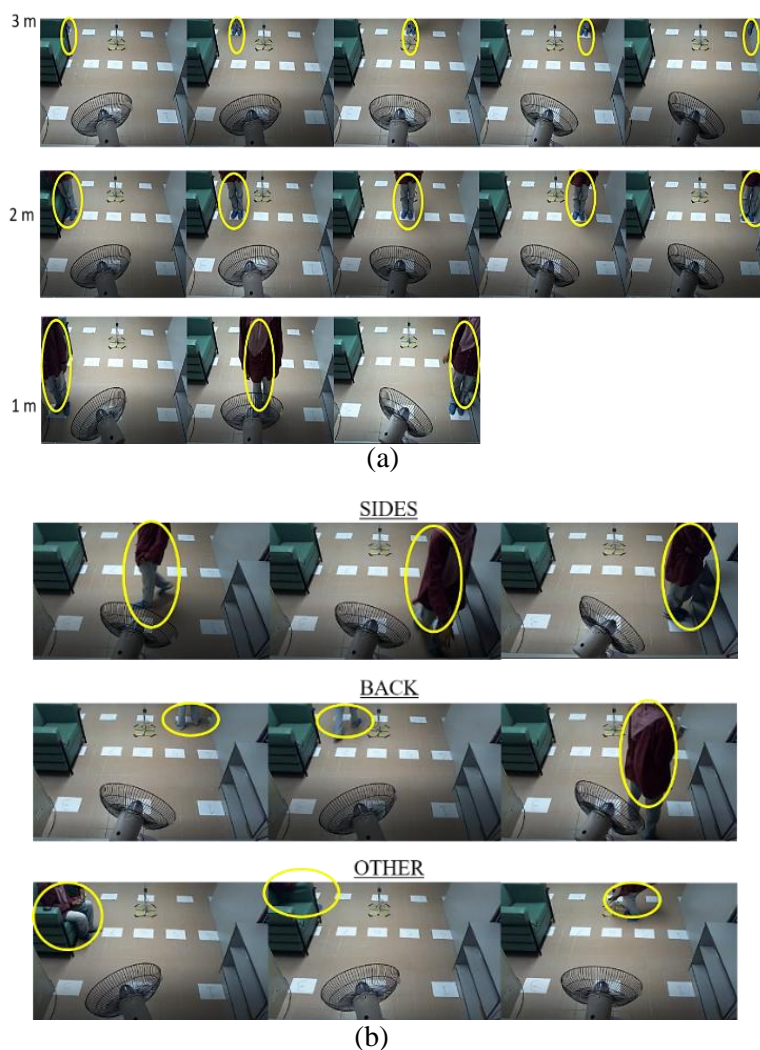

Figure 7. (a) Fan response to a subject facing FRONT of the sensor. (b) Fan response for single subject in free-style motion

In Figure 7 (b), the swing fan is tested during the subject move at free path. This test the sensor ability to detect human from either Front, Side, or Back of the body temperatures. Again, the fan is able to estimate the correct angle of the location of subject efficiently.

6.2 Multiple Human Detection (Ranging Mode)

In the real utilization of a regular Stand fan, the default swinging angle can serve multiple humans. Therefore, to make the fan to become more interactive corresponding to multiple human, ranging mode is developed. In this mode, the fan can estimate the swinging range between two extreme temperature at the pixel location occupied by humans. The larger the distance between the humans, the bigger the angle range. For example, if subject A and subject B move from far to closer, the swing angle also become smaller. Figure 8 illustrate the fan response to multiple human.
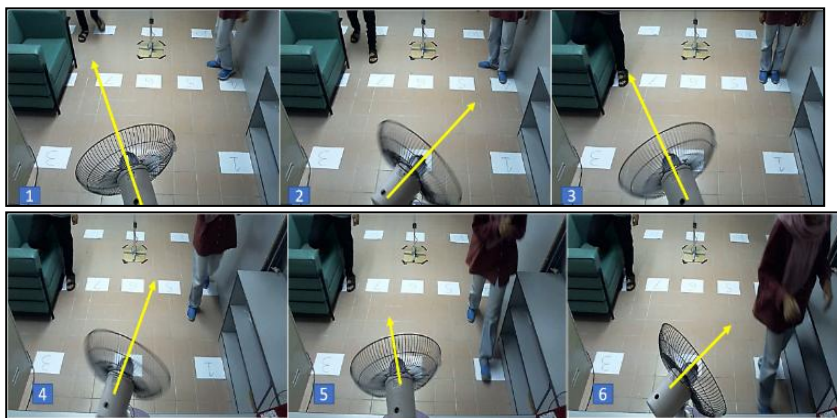

Figure 8. Fan response for multiple subject.

Thermopile sensory system developed have the advantages in detecting a single and multiple human presence and its respective location. However, the controller need to be program separately. It is possible to combined both mode into one program but it will require much deeper programming knowledge and time.

7. Conclusion

The number of Thermopile sensors used and their arrangements or positioning with respect to one another would return a different FOV. Vertical sensor arrangement was used to study the non-contact temperature change of human. While, in general application, horizontally array is used. The experiments result shows significant changes in the non-contact body temperature. Using the algorithm developed, ΔT_p is generally chosen as 2^0 as the height of the swing appliance (i.e. stand fan) is limited to detect the upper part of human body. Condition as in equation 8 is applicable to verify the human presence. However, it is needed for the algorithm to be tested on more subjects and at different other indoor room. Other heat producing device or things such as computer CPU, iron, pets, or even a cup of hot water should be added within FOV to test the reliable of algorithm in near future.

Thermal sensory system developed may even be applied in the security system or even a military purpose for aiming the direction of a target. For instance, in the surveillance system, sensory system can be attached with camera to record and widen the recorded area by following the motion.

To summarize, our approach is only applicable to detect up to 2 persons between FOV. Different programs are used for each situation (i.e. following mode is for a single person is presence and ranging mode is for more than one person is detected). Swing type of electrical appliances such as stand fan that used to test the Thermopile sensory system developed is chosen due to its wide household application. Therefore, producing new types of smarter stand fan that equipped with human detection system is far more important rather than to produce a regular type of fan. In future, it is hope that this system can be upgraded to detect multiple number of human in a single program mode.

8. References

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