Human Location Detection System Using Micro-Electromechanical Sensor for Intelligent Fan

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Abstract. This paper presented the development of sensory system for detection of both the presence and the location of human in a room spaces using MEMS Thermal sensor. The system is able to detect the surface temperature of occupants by a non-contact detection at the maximum of 6 meters far. It can be integrated to any swing type of electrical appliances such as standing fan or a similar devices. Differentiating human from other moving and or static object by heat variable is nearly impossible since human, animals and electrical appliances produce heat. The uncontrollable heat properties which can change and transfer will add to the detection issue. Integrating the low cost MEMS based thermal sensor can solve the first of human sensing problem by its ability to detect human in stationary. Further discrimination and analysis must therefore be made to the measured temperature data to distinguish human from other objects. In this project, the fan is properly designed and program in such a way that it can adapt to different events starting from the human sensing stage to its dynamic and mechanical moving parts. Up to this stage initial testing to the Omron D6T microelectromechanical thermal sensor is currently under several experimental stages. Experimental result of the sensor tested on stationary and motion state of human are behaviorally differentiable and successfully locate the human position by detecting the maximum temperature of each sensor reading.

1. Introduction
Human life is getting more comfortable and less burden with many intelligent inventions by scientist and engineers. Since then, the intervention of human to the appliances becoming less as the automated system is rising. The key to the automatic devices is the use of a good sensor, transducer, actuator and excellent control system. Ability in making the decision with respect to the event that is driven by the changing environment is what describes the intelligent of the devices. Creating an environment that is able to respond to the human that inhabits it is becoming the central of this research. Smart devices is the device that are not ignorant about their environment, surrounding, situation, task and location where it is located [8]. Smart or intelligent device therefore start from the selection of the sensors.

Aside from home automation, this project build the standing fan especially for old citizen and disable people. In a situation that they are unable to monitor the fan at all time, the fan is expected to understand their needs in an intelligent way by estimating the extreme angle swing. The power consumed for one fan is depends on its operating time and its actuator ratings. This means that to reduce power consumed, the fan must only operated when it is in need where human presence in the operating area. Therefore the need to sense people will become ever more pressing as the accurate information from the sensor is required. Energy wastage, inefficient angle of fan, non-autonomous is the effect that must be faced by the user of standing fan. This is because the operating principle of
normal standing fan is the discrete system that works based on powered on the device. Therefore there is no other way to save the energy consumed unless the user wisely used the fan when in needed and turn it off while finished. The underlying reason to those mentioned problem are because of non-automated system, no controller used. Only involving current supply to turn on and rotates the devices, also, there is no sensor for interacting with the environment condition. Standing fan which retain all of the mentioned properties make it fail to differentiate and analyze the environment it served.

All of those factors will cause the fan fail to differentiate between human and static things. Human motion cannot be expected and can be said dynamic. Things such as furniture and appliances can be group as static things. In a place such as indoor room, human and things can be differentiated by using suitable sensors even if human is in static. Together with the suitable sensor, approximate distance is possible to calculate. And more, fan also unable to estimate the range of human presence. Human presence can be further described by its position with respect to the sensing devices. The range of human to the sensing devices may be in terms of distance, angle, left or right side, height and etc.

The ultimate goal is for the sensor system able to differentiate the presence of human and non-human, either is in static or a dynamic. Therefore, the selection of the suitable sensors for human sensing such as the presence, and location was focused to the MEMS-IR and distance measuring sensors. A compatible and yet, rational human sensing method must be developed to ensure a stable standing fan performance. As such it is expected that to analyze the temperature data from the MEMS sensor, and the decision of approximate fan extreme swing angle. At the end of this project, we will compare the fan performance using two different sensor system i.e Ultrasonic (US) and Thermal Sensor. However, this paper will only cover the sensory system by using thermal sensor.

2. Comparable study
Related researches were selected to be analyzed further in terms of their objectives, technique, and application to determine the research gaps. Research gap increases the chances of one research to be continued and developed more. It differentiates one research to another even it is in the same field and can be derived from one of the elements in the tabulated data or it can also be derived from any of the elements of interest. There exist a clear gap among the research in terms of research methodology and application.

In this research, the important parameters are the distance of human from the sensor and human body temperature. The performance of the standing fan will be compared between the US and MEMS. At the presence, US is used widely in home automation and rehabilitation such as indoor lightning system, mobile rescue robot, and robotic lamp, service type robot, security system, animation, walking support system for blind people, shoes obstacle detection system, home security system and patient body movement for radiotherapy emission. Variety of techniques used for human presence and detection such as Kalman Filter, Neural Network, learning machine and any other preprocessing methods have been used by the past researchers.

This research is the continuation of [1], though it has the same application, further the technique of localization detection and fan actuating system is different. Pyroelectric or motion sensor have been implemented in [1] which only can detect the temperature variation which cause a signal loses when human stays longer or in ‘static’ at the same spot. Therefore the standing fan suffer one major drawback which in turn cause the inefficient on and off during fan operation as it fail to sense the present of occupants in a room. Therefore, MEMS IR thermal sensor is used to replace pyroelectric motion sensor which solve the mentioned drawback.

Other MEMS types of sensor similar to IR thermal sensor is MEMS accelerometer which can be applied in rehabilitation for visually challenge [6], home automation [2], human assistance [3, 4], and machine navigation [5]. Meanwhile the application for human sensing using US are also found in detection of human motion [9, 11], presence and localization [9, 10], rehabilitation [14], tracking and identification for smart home [12]. Those are some of the related research that have common implementation of US and MEMS.
3. Heat based human sensing method
The most common human sensing method is image processing using the camera. Though there are other method by sensors such as radar, motion, pressure, and etc. The detection accuracy of human at the early stage would determine the other stages of sensing detection. The stages of human sensing can be grouped in the Spatio Temporal Properties (STPs) which consists the sensing of human presence, location, counting, tracking, and identity [13]. Standing fan is a type of a swing electrical appliances. Therefore, Identity sensing is not necessary. Meanwhile, counting and tracking may also be added afterwards. Figure 1 shows the stages of the human sensing covered in the research scope.

![Diagram showing stages of human sensing](image)

**Figure 1.** Human-sensing from presence detection to the identifying identity. Only two sensing scope will be needed in this project which are presence and location

To this date, research for applying MEMS based sensor for human sensing is not as much as the other sensor such as camera and radar. Some of the possible application of this human detection heat-based sensory system is home automation, security, and other indoor types of application. The methods of human sensing in this research rather use heat as input variable. For an indoor workspaces, the possible movable occupants would be human and pets. While, other things such as appliances remain stationary. However, those three (human, pets, and electrical appliances) share one common property which is heat. The challenge in this research is to eliminate the temperature data from those that is categorized as non-interest subject (i.e pets and appliances).

Table 1 shows the temperature range of human and pets at the skin surface. Human temperature is slightly higher than animals. Temperature range of cat and dog is overlap at the value of 38.3 to 39.1 °C. Even if they did have the range of heat value, other factors such as type and thickness of the clothes would affect the readings of the thermal sensor. The challenges in this research is heat is changing or transferring. Body heat reflect value change depends on the clothes. Clothes such different thickness, color, and fabric will reflect different temperature. Body heat also changes in an
Table 1. Range of temperature for human and pets

| Object     | Temp range (°C) |
|------------|-----------------|
| Human- Armpit | 36.1 to 37.2  |
| dog        | 38.3 to 39.2   |
| Cats       | 37.7 to 39.1   |

indoor and can be loosed to indoor surrounding. As over the time a person temperature in an indoor will be approximately same as the surrounding. Body heat fluctuates about 0.5°C everyday depends on time and activities. Also, body heat is varying at different part of the body. Therefore, a proper height of the sensor location should be arranged to at least target the sensor to the upper part of the human body.

4. MEMS-IR thermal sensor

The D6T series sensors are made up of a cap with silicon lens, MEMS thermopile sensor chips, and dedicated analog circuit and a logic circuit for converting to a digital temperature value on a single board through one connector. This project uses Omron D6T-8L-06 series. It works by I2C communication protocol. It is as small as (14x18) mm size and a very sensitive infrared temperature sensor. Instead of measuring temperature on a single point, it can detect it in an array of pixels. The view angle of sensor are 62.8° and 6° for X and Y direction respectively. We could estimate the (Field of View) FOV for the different distance of detection as in table 2. It is the theoretical value for the width and height of each pixel. The width and height of FOV is increasing linearly as the increase of the detection distance, X (m).

Table 2. Theoretical FOV ranging.

| Detection Distance, X(m) | Width of FOV, Wpn(m) | Width of FOV per Pixel, W(m) | Height of FOV, H(m) | Detection power |
|--------------------------|----------------------|------------------------------|---------------------|-----------------|
| Setting by default       | Wpn = 2X * Sin (62.8/2) | wpn = Wpn / n , where n=8 | H= 2X*Sin (6/2)    | Decreases over distance X |
| 1                        | 1.04202              | 0.13025                      | 0.10467             |                 |
| 2                        | 2.08404              | 0.26051                      | 0.20934             |                 |
| 3                        | 3.12606              | 0.39076                      | 0.31402             |                 |
| 4                        | 4.16808              | 0.52101                      | 0.41869             |                 |
| 5                        | 5.21010              | 0.65126                      | 0.52336             |                 |

\[ n = \text{number of pixel}, X = \text{detection distance}, Wpn = \text{total width of FOV}, wpn = \text{width of FOV per pixel}, H = \text{height of FOV} \]

Thermal sensor used can detect the non-contact temperature up to 5 meters and nevertheless the detected temperature falls with distance. Given the same amount of power supply, the intensity should be decrease as the object move further from the FOV of thermal sensor. Even though the FOV area is getting bigger as it is further than the sensor, the data collected can be unstable and noisy. Detection temperature gets higher in response to the closeness of object because the sensor detects an average temperature over the targeted area. Temperature of the object detected would depends on the pixel background and objective temperature. Depending on the area distance, the temperature value [7] can be described as in equation 1.
\[ T_X = \frac{T_B + T_O}{A} \]  

(1)

Where,

\[ T_X \] = Detected temperature  
\[ T_B \] = Background temperature  
\[ T_O \] = Objective temperature  
\[ A \] = Pixel area

Detected temperature is therefore the summation of background and objective temperature over the pixel area. Figure 2 shows the set up for the experiment and the enlarged view of the thermal sensor. The FOV of thermal sensor is illustrated by the eight pixel (i.e. Pixel 0 to Pixel 7). The total width and height of the FOV is denoted by W and H respectively.

![Figure 2. Standing fan with MEMS IR thermal sensor and enlarged view of the sensor FOV](image)

5. Behavior of the measured data

In the non-contact temperature module, only the surface temperature measurement data can be acquired. Any objects of the same temperature will read the same. If so, it is impossible to differentiate between human, animals and electrical appliances as those three are the common occupants in the indoor room. One solution to differentiate it is by analyzing the data measured by the thermal sensor in terms of pattern and behavior using any available software. Formula or set of conditional ranging may be developed and improved the accuracy of the human detection.

Experiment for collecting the data was done using Arduino, an open source software microcontroller based and a Processing as a visual development tool. USB camera is used and aligned with the MEMS thermal sensor to record the experimental data and time frame images, though it is only be used for the purpose of describing the FOV of the sensor during experiment. A graphical user interface program using the Processing development language is developed for displaying the current image and current temperature from the thermal sensor. This preliminary experiment is done in two modes, mainly ‘Stationary’ and ‘Dynamic motion’.
5.1. Human in stationary

Here, we define ‘stationary’ as in the application as such as a person sitting in front of the fan FOV and did not move the main joint such it cause the body to move from one point to another. A hand and head movement may be acceptable but not the main body. Two sets of experiment was conducted concluded that MEMS thermal sensor is able to read twice of temperature data in one second. Table 3 summarized the number of temperature array read from MEMS thermal sensor.

| Experiment | Time Tested (Seconds) | Number of Data Array read | Data Temperature reading per second |
|------------|------------------------|---------------------------|-------------------------------------|
| 1          | 370                    | 792                       | 2.14                                |
| 2          | 439                    | 1067                      | 2.43                                |

A four seconds temperature and FOV images with a distance of 1.5 meters away from sensor are recorded as in figure 3.a. The occupants sit at the chair allowing the sensor to target and sense the upper part of the body. Main body of the subject remain stationary while only the small movement of head, neck, shoulder, arm, wrist and hands are made. Experiment was conducted in an indoor room of approximately 26°C (i.e. $T_B=26^\circ$C). While the temperature on the sensor surface is recorded between 26.4 to 26.5°C.

**Figure 3** (a). The 4 seconds image of the occupant position in stationary (b). The 4 seconds temperature data at Pixel 0 to Pixel 7 for occupant in stationary
The corresponding temperature reading for figure 3(a) is shown in figure 3(b). All the temperature in figure 3(b) is the detected temperature, $T_X$. As long as the main body did not make the obvious move, the behavior of each pixel remain in the same pattern for all 8 readings. As marked in the red circles, the region in which the main body located is at pixel 5 as it always give the highest temperature value. Pixel 5 temperature value ranging from 29.1 to 30.0°C to give the changes in just 0.9°C. While the other Pixel’s data fluctuates between 5°C. The pattern remains similar until the end of both experiments stated in table 3.

5.2. Human in motion
Motion in this research context is the continuous movement that result in the changing of the current position. Human could be in dynamic state if he is walking, running, and moving the main body to another pixel of FOV. A person walk 1.5m away across the sensor with normal speed are recorded as in figure 4. Result shows that the peak or maximum temperature changes over pixel, from P0-P7 or from P7-P0 while the temperature of other pixels fluctuates within only 5°C.

The shifting of the maximum temperature value (i.e red circles) followed the direction of the occupant’s motion. Therefore, this result will not only give the current location but can be used to check the occupant’s path. This will only works when the occupant is walking by maintaining the speed to be constant. In a condition that the occupant is running across the sensor FOV faster than the sensor reading per second as mentioned in table 3, the sensor will not be able to record the similar pattern of maximum pixel’s shift shown in figure 4. Different occupant’s behavior will result in different pattern of the measured data.

**Figure 4.** (a). The images of the moving occupant. (b). The corresponding temperature in duration of 2.5 seconds.
6. Conclusion and future works

By looking further ahead to the future, there would be many promising application to the sensory system for human location detection. As the preliminary experiment resulted in the comparable behavior for both static and dynamic, further analyze should be done to find the suitable swing angle of the fan by using either mathematical computational or preprocessing. It is clearly indicated from the result that the location of occupants can be determine by the highest and rare temperature value. Swinging angle of the fan head is supposed to swing at the suitable range of with respect to the human location.

An additional MEMS thermal sensor will be added in parallel and connected to the (Serial Data Line) SDL and (Serial Clock Line) SCL pins of the microcontroller via PCA9545 I2C-bus switch. Additional sensors will widen the sensor FOV’s width depending on the sensor-to-sensor placement. Finally, the design of the gear system of the fan blade motor and fan swing angle motor should be come afterwards.

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