論　　文　　要　　旨

DETECTION OF HUMAN BY THERMOPILE INFRARED SENSORS

サーモパイル型赤外線センサによる人検出に関する研究

金沢大学大学院　自然科学研究科

システム創成科学専攻

氏名:　張　西鵬

Abstract

There are some equipments can be used to detect human, such as pyroelectric infrared sensor, ultrasonic sensor, camera and so on. However, their systems have some problems with the boundedness detection, low resolution, privacy and high cost. So we propose to use thermopile infrared sensors without focus lens and with high-gain amplifier to detect human position and movement. It even can detect human without moving.

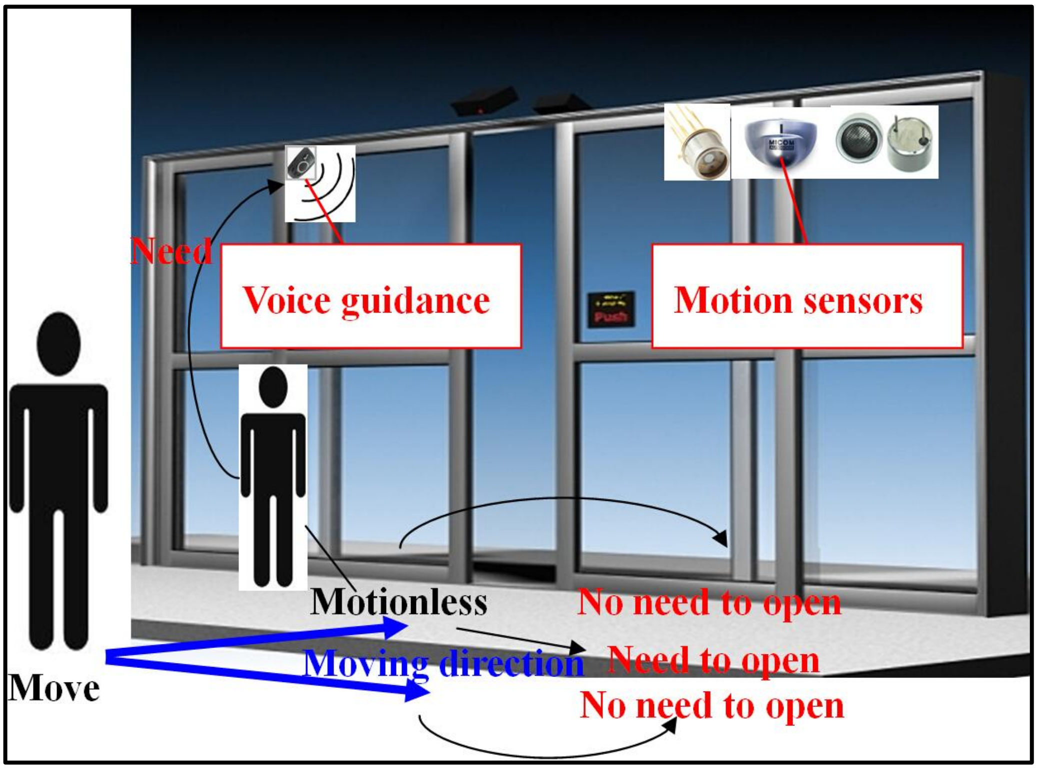
We separately studied about detection of human by thermopile infrared sensors in three cases.

Case 1 is that detection of human 2D position by thermopile sensor which are put on the table mounted at different angles. Case 2 is that detection of human position and motion by thermopile sensor which are fixed on the ceiling and kept in vertical direction. Case 3 is that in order to enlarge the detectable area, we considered detection of human position and motion by two tilted thermopile infrared sensors mounted on the ceiling. After measuring, we can build an approximate equation between output voltage, distance and angle from each sensor to human. These equation set can be solved by steepest descend method for the outputs of two sensors, and 2D human position can be obtained in real-time.

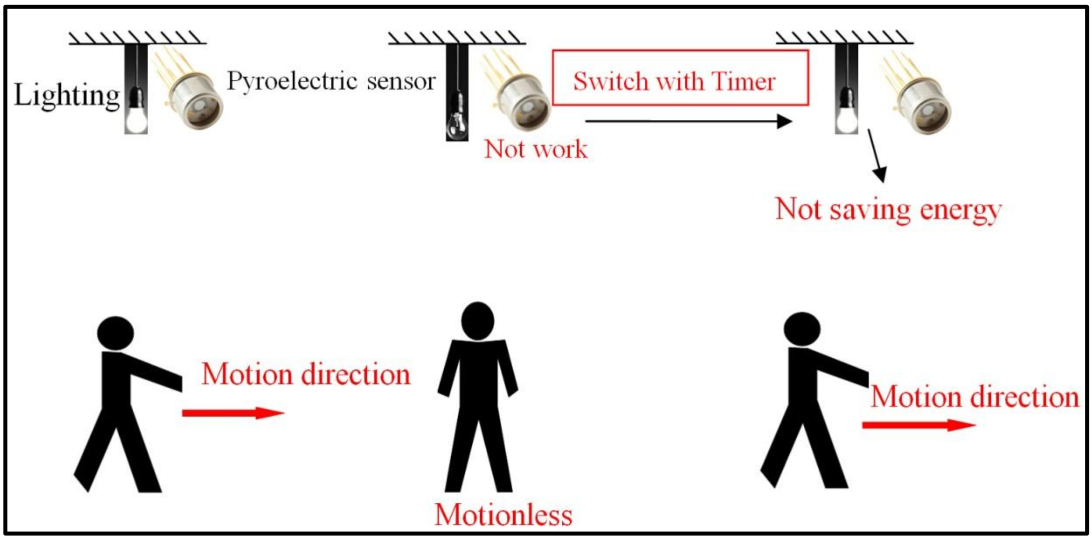
1 Introduction

In recent years, the detection of human-beings is very important in many different areas, such as human-robot interaction, work-cell safety, people counting, monitoring and tracking etc. Among these areas, many types of equipment, such as automatic doors, automatic switches, voice guidance devices, are automatically controlled by detecting human-beings. The types of sensors used are as diverse as the application equipment. For example, the motion sensors and voice guidance equipment are implemented on automatic doors.

However, these detectors have their respective problems in the detection process. For example, they work all the time, even when they are not necessary (**Fig. 1**), such as when an automatic door opens for a person who is just standing near it and has no intention to go through it. Sensor systems that detect people's positions and movements, such as coming near, going away, stopping, and passing, are needed. Common cameras and thermography cameras employed in buildings can produce real-time images and identify human situations well, but cost and privacy can be problems; people do not like to be photographed unless there is a good reason. Ultrasonic sensors are often used in location systems but they tend to be disturbed by sources of noise in the natural environment, and it is difficult to detect not only the presence but also the movement of people. Pyroelectric detectors are widely used in motion detection applications for home security and automation systems, but their outputs are differential, or proportional to the rate of change of incidental radiation. This leads to slightly lower detection: pyroelectric detectors can only detect people when they move.



(a)



(b)

Fig. 1 Devices to detect human-beings

2 Thermopile infrared sensor and circuit

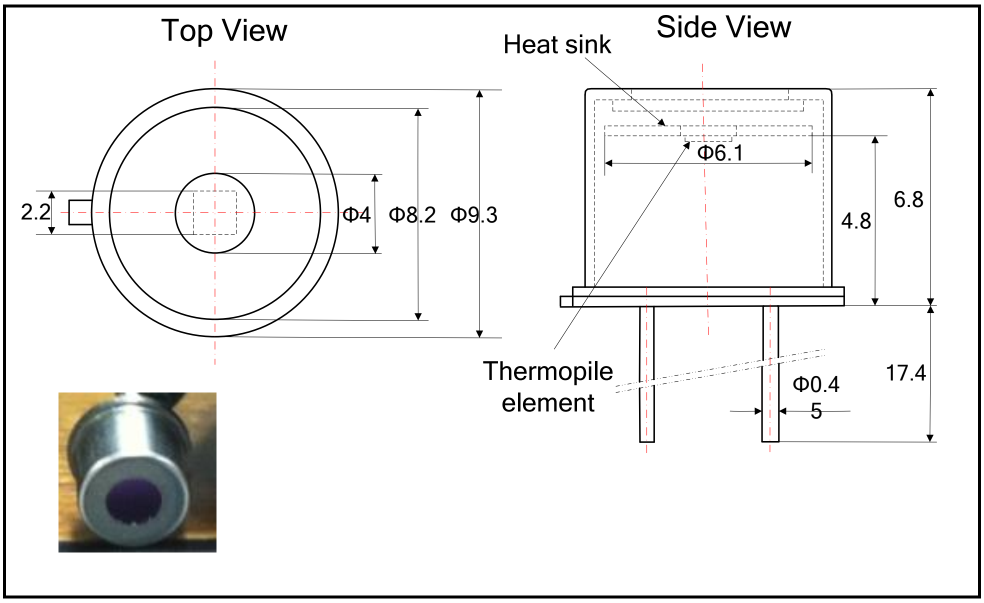


Fig. 2 External dimensions of thermopile sensor

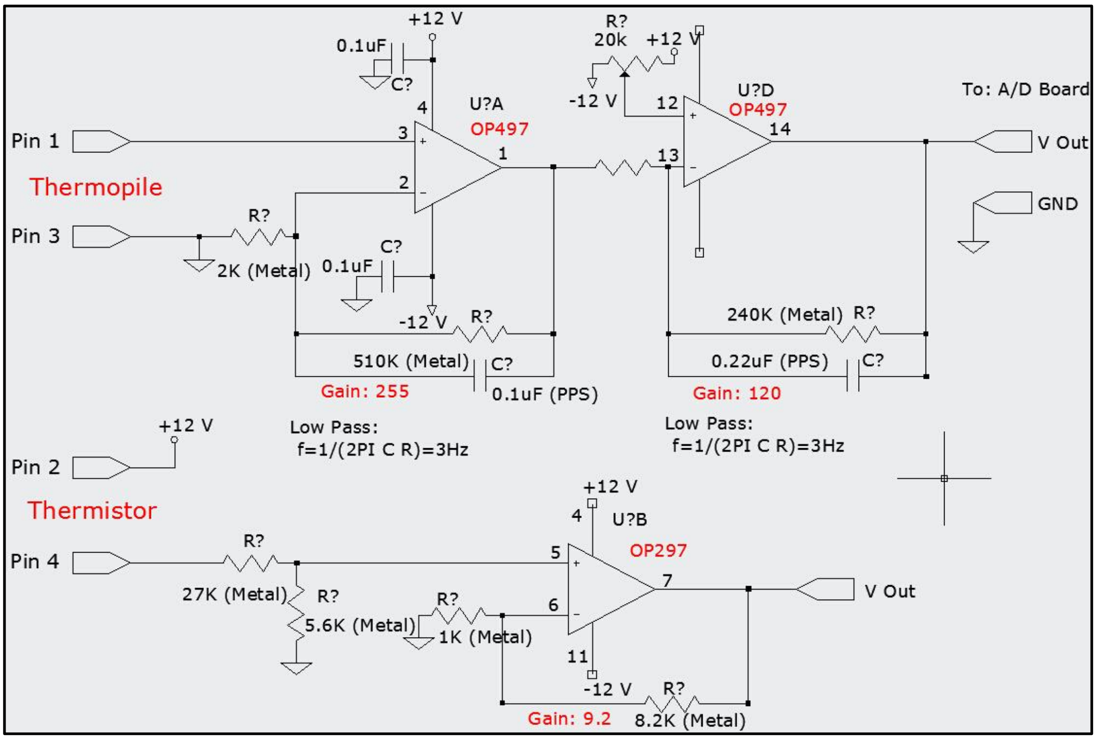


Fig. 3 Circuit of thermopile sensor

3 Case 1: Detection of human by thermopile sensors from wall

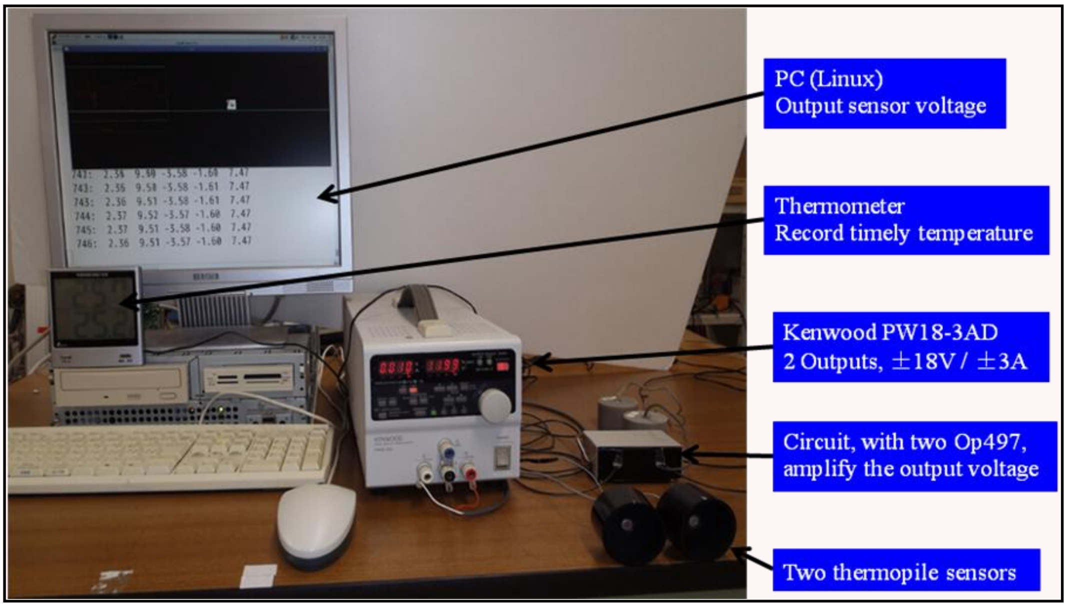


Fig. 4 Experimental setup

Through measurements and approximation of sensor characteristics, finally we got the relationships between output voltage, distance and angle from each sensor to human.

$$V(r,\theta,T) = (a_5 T + a_6)[1 - a_3\theta^2 + a_4\theta^4]/(r + a_1)^2$$

then built equation set by two sensors, and calculated human position(x,y) by utilizing steepest decent method, finally we got real-time results shown as Fig.6.

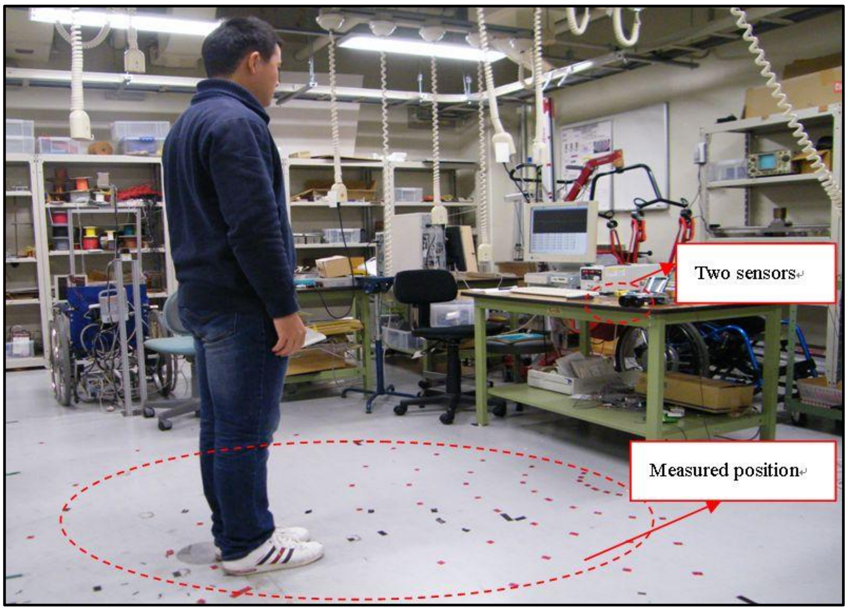


Fig. 5 A photo of experimental scene

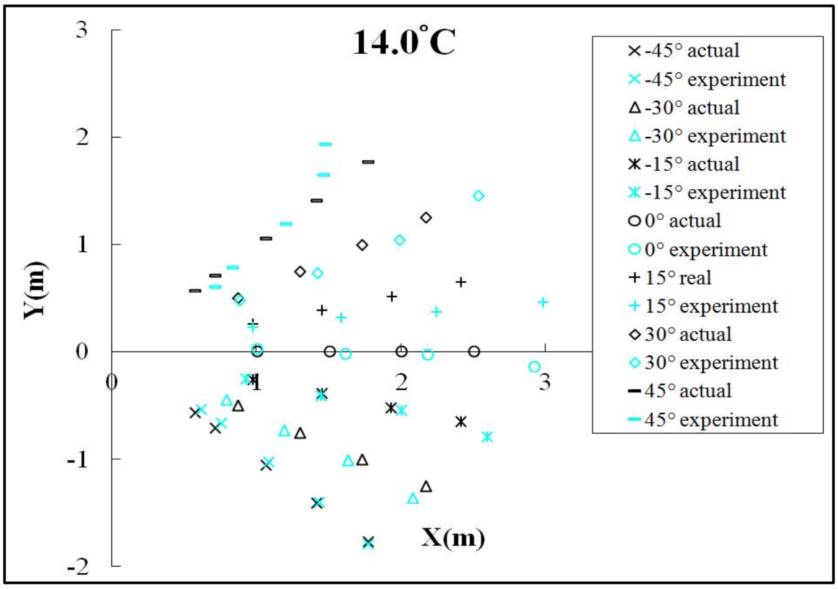


Fig. 6 Result about detection of human by two thermopile sensors

4 Case 2: Detection of human by vertical sensors from ceiling

Through measurements and approximation of sensor characteristics, finally we got the relationships between height, distance, orientation and sensor output from each sensor to human.

$V = V_T(T) \cdot V_h(h) \cdot V_r(r) \cdot V_\alpha(\alpha)$

among them,

$V_{T,h} = V_T(T) \cdot V_h(h) = a_0/(h + a_1)^2$

$V_r(r) = a_2 r^5 + a_3 r^4 + a_4 r^3 + a_5 r^2 + a_6 r + a_7$

$V_\alpha(\alpha) = 1 - a_{10}\alpha^2$

then built equation set by two sensors, and calculated human position(x,y) by utilizing steepest decent method, and body orientation is calculated like Fig. 7. And the procedure of human motion shows as Fig. 8. Finally we got real-time results shown as Fig. 10 and Fig. 11.

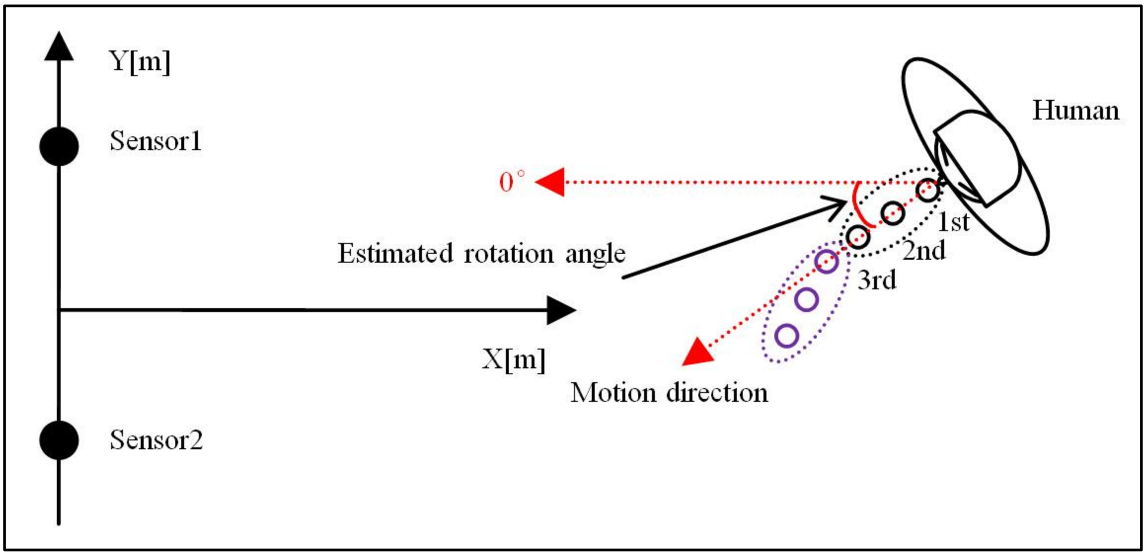


Fig. 7 Detection of human body orientation

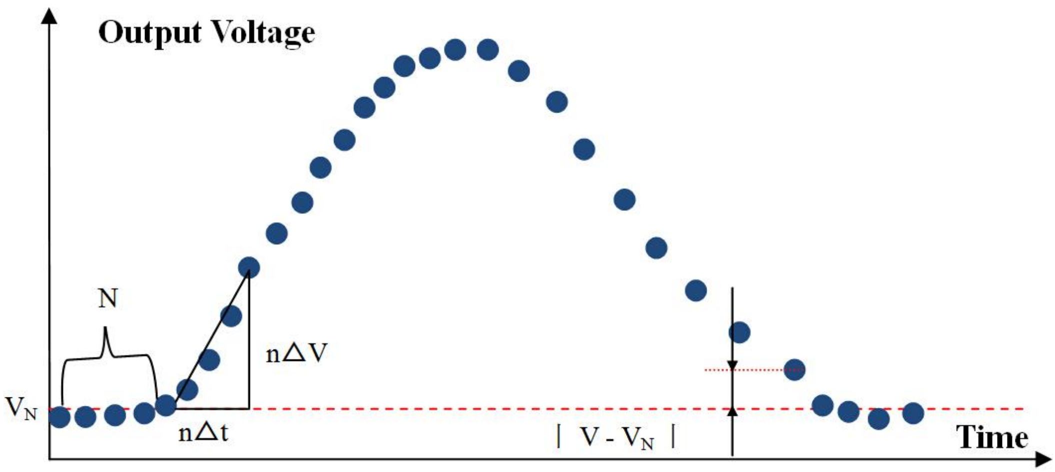


Fig. 8 Procedure of human motion

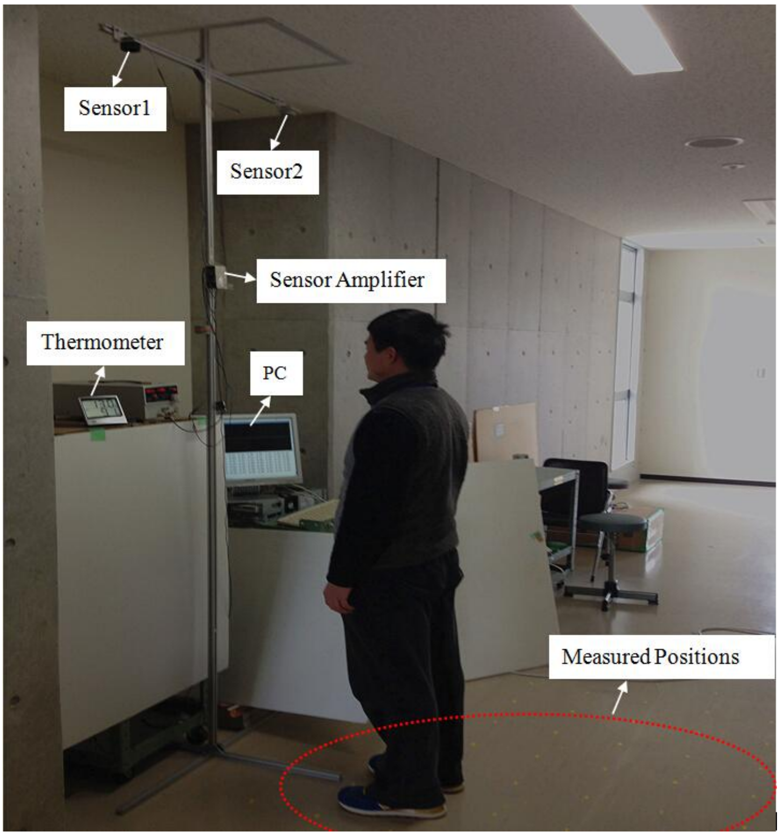


Fig. 9 A photo of experimental scene

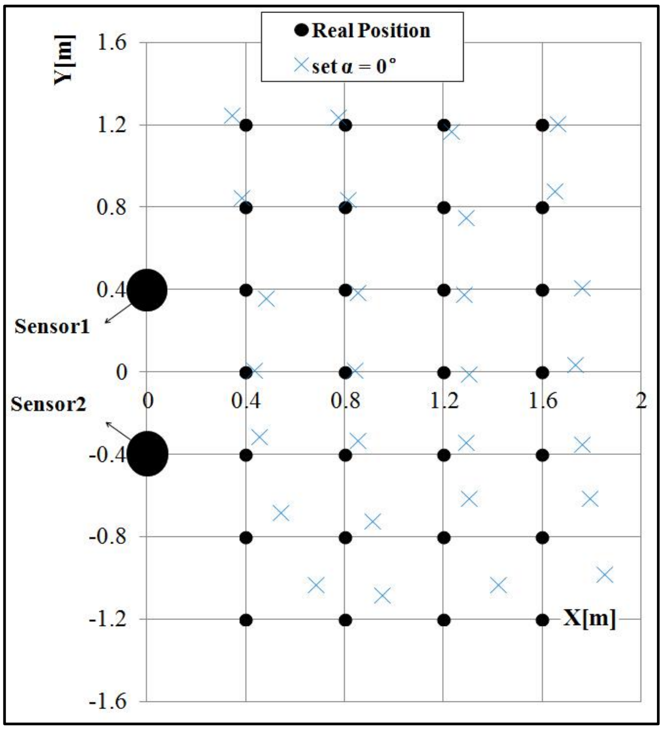


Fig. 10 Result about detection of human position by vertical sensors

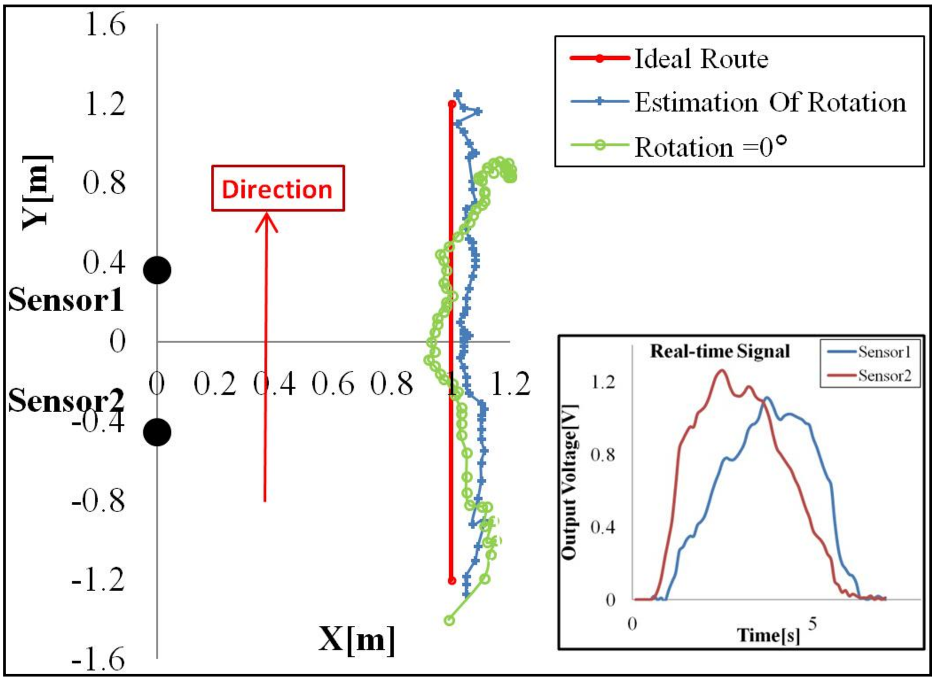


Fig. 11 Result about detection of human motions by vertical sensors

5 Case 3: Detection of human by tilted sensors from ceiling

Through measurements and approximation of sensor characteristics, finally we got the relationships between height, distance, orientation and sensor output from each sensor to human.

$$V = V_T(T) \cdot V_h(h) \cdot V_r(r) \cdot V_\alpha(\alpha)$$

When sensor is vertical, that is, sensor angle is 0°, the $V_r(r)$ should consist of two parts, $V'_r(r)$ and $V_\theta(\theta)$. Here, $V'_r(r)$ denotes the real relationship between distance (r) and sensor output voltage (V). Thus,

$$V_r(r) = V'_r(r) \cdot V_\theta(\theta)$$

$$V_{T,h} = V_T(T) \cdot V_h(h) = a_0/(h + a_1)^2$$

$$V_\alpha(\alpha) = 1 - a_{10}\alpha^2$$

$$V'_r(r) = a_1 r^4 + a_2 r^3 + a_3 r^2 + a_4 r + a_5$$

among them, The Rodrigues formula is used to solve the total sensitivity.

$$V_s = \int_0^\beta V_\theta(\theta)\, d\emptyset$$

then built equation set by two sensors, and calculated human position(x,y) by utilizing steepest decent method, finally we got real-time results shown as Fig.13 and Fig. 14.

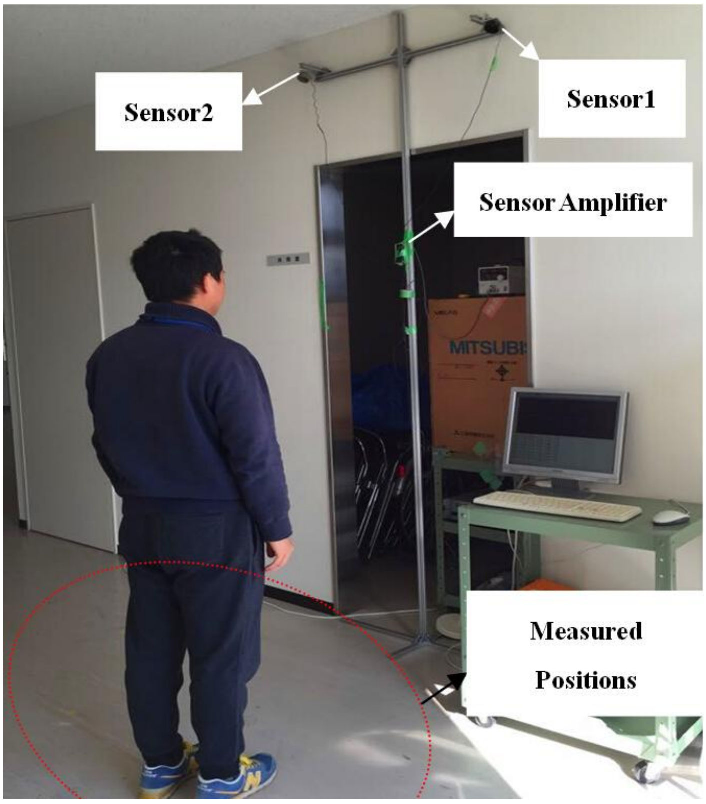


Fig. 12 Experimental scene by tilted sensors

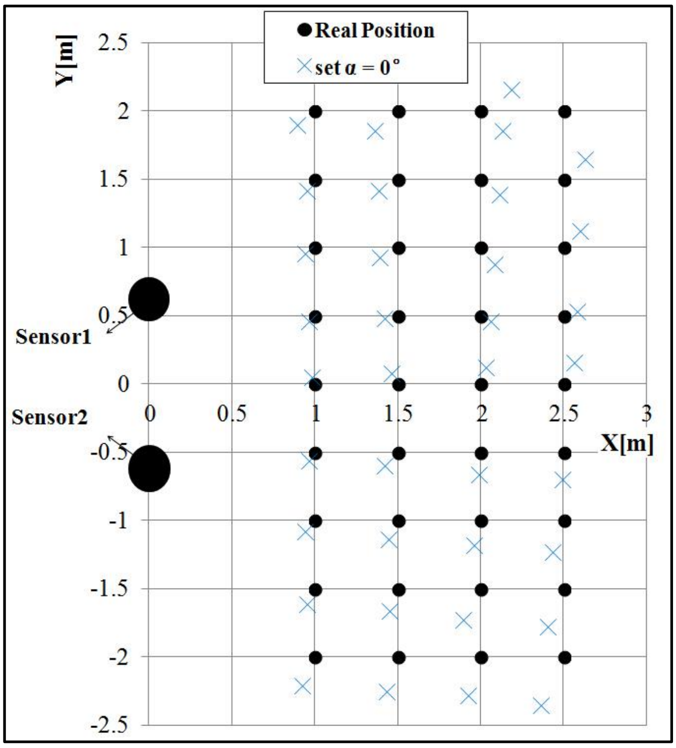


Fig. 13 Result about detection of human position by tilted sensors

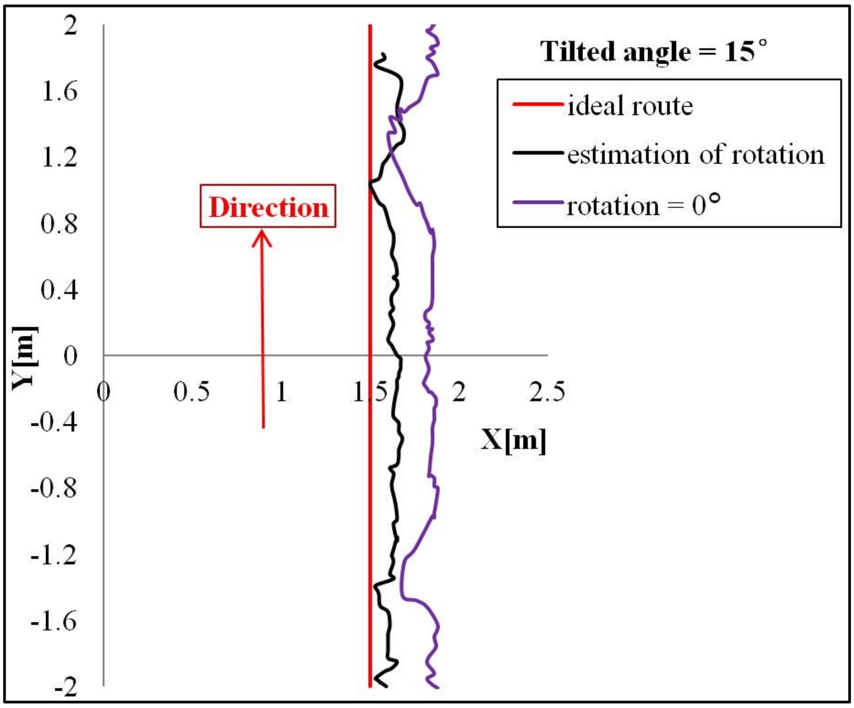


Fig. 14 Result about detection of human motions by tilted sensors

6 Conclusions

In conclusion, through vast experiments about three systems, we have known that accuracy is very high in case1 system, which error is within 0.1m. And in case2 system, which can judge human motion situation well, that is, when human come, it works and detects human position in real-time, even when human stop in detectable area, system only obtains human position but not obtain the motion direction; when human goes away, it does not work and stores sensor output in order to calculate in the next time. Meanwhile, we knew that the detectable area is when x is [0.4,2] and y is [-2,2] and error is about 0.1m through comparison result. And in case3 system, its function is almost same with case2, but its detectable area is larger, which is, x is [0.5,3], y is [-2.5,2.5], and error is about 0.2m. In a word, three systems about human detection was successfully designed, created and verified.

平成２８年　２月　２日

学位論文審査報告書（甲）

１．学位論文題目（外国語の場合は和訳を付けること。）

Detection of Human by Thermopile Infrared Sensors

（サーモパイル型赤外線センサによる人検出に関する研究）

２．論文提出者　(1) 所　　属　システム創成科学　専攻

(2) 氏　　名（ふりがな）　張（ちょう）　西（さい）　鵬（ほう）

３．審査結果の要旨（600～650字）

当該学位論文に関し，平成28年２月２日に第１回学位論文審査委員会を開催し，提出された学位論文及び関係資料について詳細に検討した．さらに，同日に行われた口頭発表後に，第２回学位論文審査委員会を開き，協議の結果，以下のように判定した．

近年，インテリジェントな装置やロボット用の人の検出技術の重要性が増している．画像は様々な情報を検出できるが，プライバシーやコストに問題がある．焦電型赤外線センサは，基本的には人が動いた時に反応する．そこで，本論文ではサーモパイル型赤外線センサを用いて，有無だけでなく，人の位置や移動を検出する新しい方法を提案している．まず，広範囲をとらえるため，温度検出時に用いられるようなレンズを使用せず，センサ出力を高増幅し，素子をゴムカバーで覆ってドリフトを減らした．距離を離してセンサを２個取り付け，人との相対位置姿勢によってセンサ出力が変化することを利用して，人の２次元位置を検出した．これを，壁から水平の場合，天井から垂直の場合，天井の隅から斜めの場合の３つのセンサ取付位置について議論している．その際，センサの指向性，距離特性，温度特性，体の向きの特性などを詳細な実験式で表現し，それらを最急降下法で解くことで位置を求めている．人の移動量から体の向きの影響を補正する方法や長時間のドリフトにも対応する方法も工夫し，検出精度の分布，衣服や個人差の影響などにも言及し，実験により人の検出には十分な精度で位置や移動が推定できることを示した．

以上のように，本論文は人の検出技術に関して有用な知見を得ており，メカトロニクスやロボット工学分野への貢献が期待でき，工学的な価値が高く，博士（工学）に値するものと判定した．

４．審査結果　(1) 判　　定（いずれかに○印）　（合　格）・　不合格

(2) 授与学位　博　士（　工　学　）