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CHARACTERIZATION OF PASSIVE INFRARED SENSORS FOR MONITORING OCCUPANCY PATTERN

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Abstract: Monitoring the occupancy pattern of elderly people can reveal changing trends in their health status. In this paper, we investigate the spatial characteristics of a pyro-electric infrared sensor at different walking speeds at different distances to design and develop a low cost and low power unobtrusive monitoring system. The pyro-electric infrared sensor has high performance for infrared radiation detection at room temperature. The choice of pyro-electric infrared sensor for the design of unobtrusive activity monitoring system is due to the fact that they are inexpensive and consume very low power. As these sensors are passive and are wall mounted, the system is relatively unobtrusive. An occupancy monitoring system using ZigBee wireless technology and infrared sensors has been developed by Biomedical System Laboratory at university of New South Wales, Australia. The analog signal from the sensor is proportional to the surface temperature, velocity of movement and the distance of the object from the sensor. Experimental results show that the sensor output is non uniform at different distances and at different angles for different walking speeds.

I. Introduction

The aging of the population is a main concern for many developed countries. Planning for aging population has become a priority for them. There is a need to refocus public health priorities to address the changing needs of an aging population [1]. Researchers and technologists are helping governments to address the issues concerning aging population by developing technologies so that elderly people can live healthy and longer life in their own homes [2],[3]. The design and development of an unobtrusive occupancy monitoring system by the Biomedical Systems laboratories at the University of New South Wales, Australia is a step in this direction. The main and most important component of the unobtrusive occupancy monitoring system is passive infrared sensor.

II. Development of an Unobtrusive Occupancy Monitoring System

The unobtrusive monitoring system consists of a transmitter and a receiver unit as shown in the block diagram in fig.1. The transmitter unit consists of a passive infrared sensor, a microcontroller and a ZigBee transceiver. The passive infrared sensors used in this system are standard commercially available sensors primarily intended for security alarms or lighting control systems. The microcontroller samples the output of the motion sensor via its analog to digital converter (ADC) at a rate of 20 Hz. This digitized data is then subject to a motion detection algorithm embedded in the flash memory of the microcontroller, which determines whether activity has occurred or not.

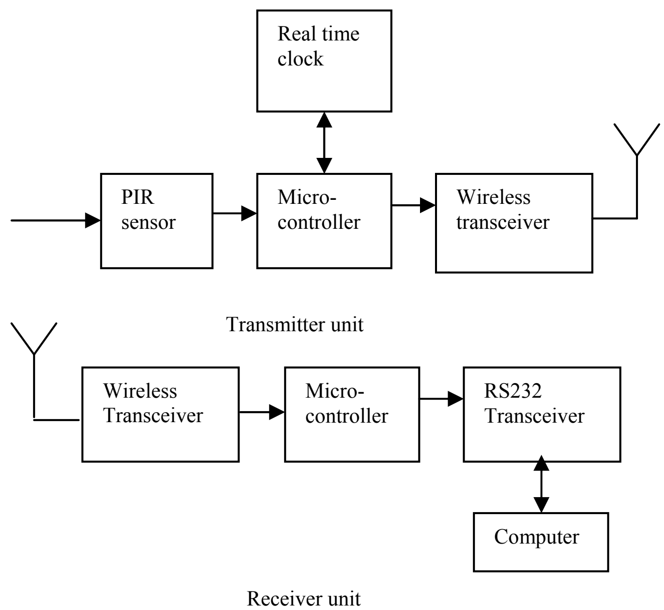

Fig 1: Block diagram of transmitter and receiver unit

When motion is deemed to be of significance the relevant data is time stamped by accessing the real time clock (RTC) and sent to the wireless transceiver module for transfer to the receiver unit. Upon receipt of this data by the receiver unit's wireless transceiver, the local micro-controller retrieves and forwards the data to the computer base station via an RS232 transceiver module and a serial port connection as shown in fig.1 The spatial sensitivity of the sensor at different distances depends on the orientation of the sensor, type of the lens used and the number of elements used in the sensor.

III. Passive Infrared Sensor

All objects constantly exchange thermal energy in the form of electromagnetic radiations with their surrounding. The characteristics of the radiations depend on the object and its surroundings' absolute temperature and can be analyzed using black body radiations curve governed by Plank's law [4]. Human bodies also emit radiation and the wavelength of these radiations can be calculated using Wein's law which is given by (1),

$\lambda = 2898$ microns / T (1)

Where λ is wavelength of the emission in nano meter
T is absolute temperature in K

Substituting T = 310 K (37^0 C normal human body temperature) in (1), yields a value for λ of 9348 nm or approximately 10µm. In fact, radiation from the human body is considered to lie in the range of 8-14µm, hence infrared sensors that are sensitive in this range would be able to detect humans within their detection area. The standard infrared detectors photodiodes, phototransistors etc. work well outside this range, hence not suitable for human detection. A patterned fresnel lens or a mirror is placed in front of the infrared sensor that is sensitive to the radiations emitted by human bodies. The passive infrared sensor works on the principle of pyro-electricity. The principle is based on the fact that certain crystals become electrically charged when their temperature changes. They are essentially capacitors whose dielectric is made from a crystal that has been spontaneously polarized. When the dielectric absorbs infrared radiations, increase in temperature reduces the polarization and the voltage across the sensor changes. These sensors are sensitive to the changes in the infrared energy rather than their absolute levels [5]. The infrared sensor cannot sustain its own current, therefore, it is coupled as a source follower circuit in combination with a band pass filter [6]. The infrared sensor used in the occupancy monitoring system works well in a low frequency range typically between 0.01-10 Hz.[7]

IV. Experimental arrangement

The output voltage from the sensor depends upon the optical characteristics of the sensor, distance of the moving object from the detector, walking speed and thermal irradiance. The PIR detector sensitivity is investigated for the movement of human body (i) across the detection area at different distances for different walking speeds (ii) walking towards the detector and (iii) walking away from the detector at different angles.

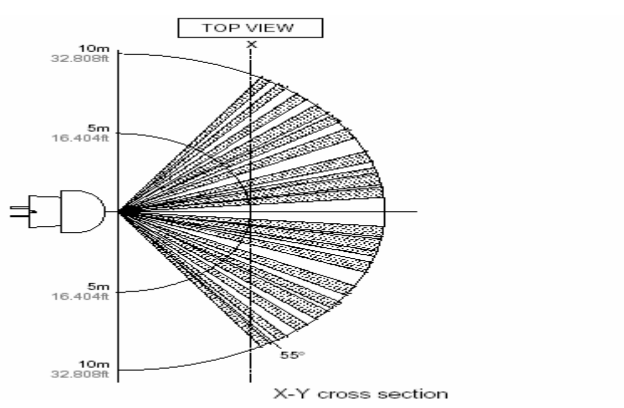

Fig 2: According to manufacture sensor detection area

The pyro-electric sensor used in the unobtrusive occupancy monitoring system has a transparent Fresnel lens and an integrated amplifier. It has quad elements and is designed to cover 110^0 horizontally and 93^0 vertically at a 10 m radius as shown in fig 2. The detection zone patterns as shown in fig.3 are indicative of the projections of the 20 lenses with single focal point and with five optical axes [8]. The use of dual or quad elements makes the sensor insensitive to interference from the ambient temperature. The experiment was carried out in an air conditioned room of size 7mx7m. The temperature was set at 25^0 C. The PIR sensor is mounted on a tripod stand at a distance of 2.1m. The arcs are drawn at a distance of 1m, 2m, 3m etc. from the PIR sensor and radial lines are drawn at an angle of 10^0 each on the floor. The geometry of the walking is shown in the fig 4. A digital metronome was used to select the walking speed of 0.4m/sec slow walking), 1m/sec (normal walking) and 1.8m/sec (fast walking).

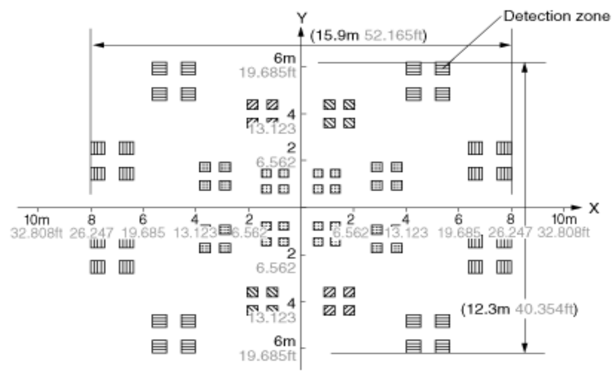

Fig 3: X-Y cross section

Fig 4: Experimental set-up

V. Result

As the subject walks through the different detection zones, the thermal radiation is focused on the sensor elements and produces an alternating signal as shown in the fig.5. Figure 5 shows that the output frequency of the output signal is inversely proportional to the distance from the detector for a constant walking speed. The frequency of the output signal is an important parameter for the design of associated circuitry of unobtrusive monitoring system. The root mean square value (rms) of the detector output for different movements in fig.6 and table 1 show that the sensitivity of the PIR detector is almost constant up to 5m for normal walking and starts reducing as the distance from the detector increases.

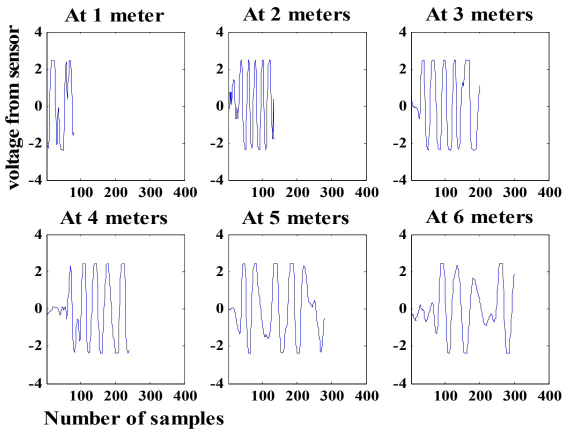

Fig 5: Sensor when walking across the sensor at slow speed x-axis shows the number of samples captured and y-axis shows the voltage output from the sensor

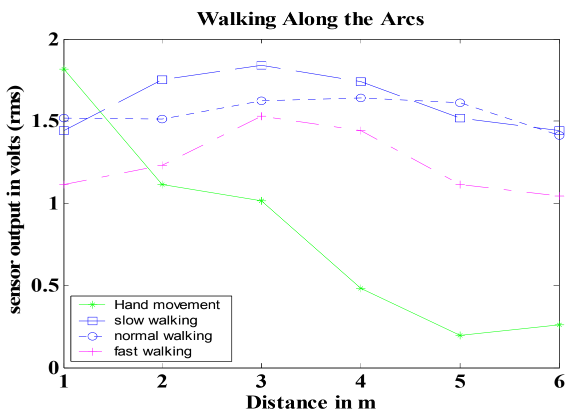

Fig 6: The root mean square value of detector voltage at different distances at different walking speed

Table 1
Mean value and standard deviation of detector output when walking through each arc at different speed

Arc Radius in meters	Hand Movement	Slow walking	Normal Walking	Fast Walking
1	1.81	1.44	1.52	1.12
2	1.11	1.75	1.51	1.23
3	1.02	1.84	1.62	1.53
4	0.48	1.74	1.64	1.44
5	0.2	1.52	1.61	1.11
6	0.26	1.44	1.41	1.04
Mean	0.81	1.62	1.55	1.24
Median	0.75	1.63	1.56	1.17
Std. deviation	0.62	0.19	0.14	0.20

For small horizontal hand movements, the standard deviation of 0.62 indicates a wide variation in the detector output with distance, and the signal strength reduces very sharply as the distance from the detector increases. For slow and fast walking speeds, the detector output is reduced compared to normal walking speed. At closer distances, detector sensitivity reduces with the increase in the walking speed.

Sensitivity at different angles:

The sensitivity of the detector for the movements *towards* and moving *away* from the detector was tested for slow, normal and fast walking speed.

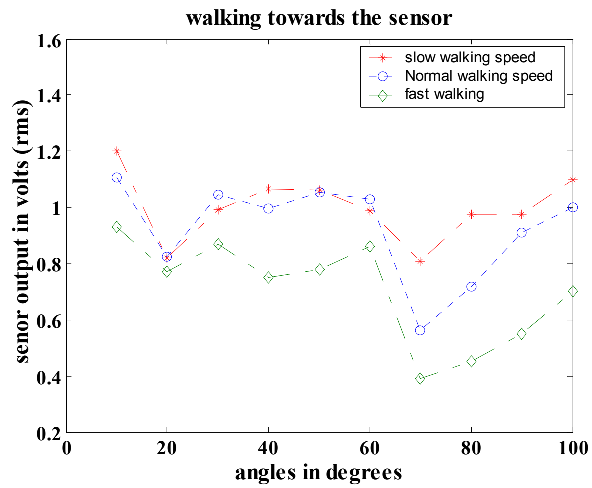

Fig 7: Detector sensitivity at different angles when the subject walked *towards* the detector at different walking speeds

Table 2
Walking *towards* the detector at different angles

Angle in degrees	Slow walking	Normal Walking	Fast Walking
10	1.20	1.10	0.93
20	0.82	0.82	0.77
30	0.99	1.05	0.87
40	1.06	1.00	0.75
50	1.06	1.05	0.78
60	0.99	1.03	0.86
70	0.81	0.56	0.39
80	0.98	0.72	0.45
90	0.98	0.91	0.55
100	1.10	1.00	0.70
Mean	1.00	0.92	0.70
Median	0.99	1.00	0.76
Std. deviation	0.12	0.17	0.18

Fig. 7 shows that the detector sensitivity is relatively constant from 30^0 to 60^0 when the movement is *towards* the detector at slow and normal walking speed and is quite poor at the extreme ends. The sensor output is reduced for fast walking speed compared to the normal or slow walking. Table 2 shows that the sensor output is quite consistent for slow walking speed when the subject walks *towards* the sensor. In fig.8 and table 3, the standard deviation of approximately 0.17 demonstrates more signal variations at different angles when the subject is walking *away* from the detector.

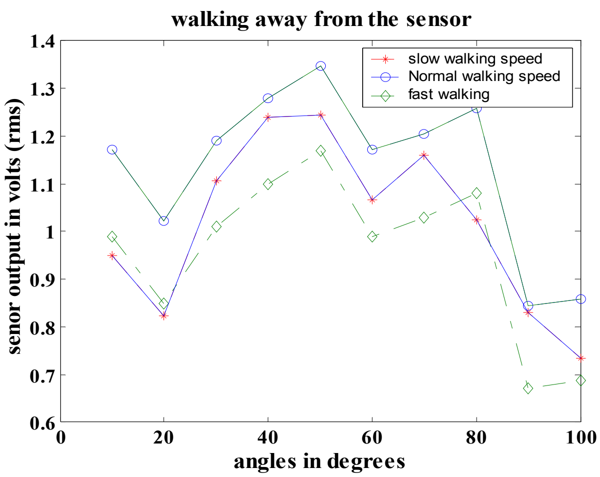

Fig 8: Detector sensitivity at different angles when the subject walked *away* from the sensor at slow and normal speed

Table 3
Walking *away* from the sensor at different angles

Angle in degrees	Slow walking	Normal Walking	Fast Walking
10	0.95	1.17	0.99
20	0.82	1.02	0.85
30	1.10	1.19	1.01
40	1.23	1.28	1.10
50	1.24	1.35	1.17
60	1.06	1.17	0.99
70	1.16	1.21	1.03
80	1.02	1.26	1.08
90	0.83	0.84	0.67
100	0.73	0.86	0.69
Mean	1.02	1.13	0.96
Median	1.04	1.18	1.00
Std. deviation	0.18	0.17	0.17

VI. Conclusion

The characteristics and spatial sensitivity of PIR detector is investigated to use it in a monitoring system so that the occupancy pattern of elderly people can be monitored to assess their functional health status. It is found that the detector output is proportional to the velocity of slow movements (hand movement and slow walking) and does not exhibit proportionality for normal and fast movements. The spatial sensitivity of the detector was found to be non-uniform. For a detector using a 10m type analogue sensor, the sensitivity distribution shows that it is relatively constant up to a distance of 5m between 30^o to 60^0 for different velocities although the detector output voltage reduces with increase in walking speed. Therefore it can be concluded that if the detectors are used in a room smaller than sensor's maximum detection range, it is possible to use the sensor output to discriminate between different movements and to provide a rough estimate of energy expenditure.

References:

[1] Aging in Australia, ACT Community and Health Services, in *Aging in Australia*. 2004, Aged and Community Services Australia.

[2] Celler BG, Earnshaw W, Izutsu T, BetbederM, Harris MF, ClarkR, Hasketh T, and Lovell N H, Remote Monitoring of Health status of the elderly at home: A multidiscplinary project on aging at University of UNSW. *International Journal of Bio-Med Comp. 40*, 1995: p. 147-55.

[3] Johnson, Remote continuous physiological monitoring in the home. *Journal of Telemedicine and Telecare*, 1996. **2**: p. 107-13.

[4] M. Plank, On the law of distribution of energy in the normal spectrum. *Annalen der Physik*, 1901. **4**: p. 533.

[5] Wright HC, *Infrared Techniques*. 1973: oxford University Press, London.

[6] Optex America INC., PIRs A to Z. 2003, available online at www.optexamerica.com.

[7] Global Corporation, Infrared Parts Manuual, http://www.global.com/pirparts/infrared.html.

[8] Matsushita Electric Works Ltd., http://www.nais-e.com/sensor/.