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ORIGINAL ARTICLE

Development of Low Cost Crowd Sensor

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ABSTRACT – This paper presents the development of crowd sensor nodes monitoring system for analysis purposes and estimating human occupancy in a closed room application. This system utilises Arduino Uno microcontroller for measuring surrounding parameters such as carbon dioxide (CO2) concentration, temperature, relative humidity (RH) and carbon monoxide (CO) levels. The CO2, temperature, RH and CO sensors are integrated into the data acquisition system. Data were collected at a fixed tutorial room in Universiti Sains Malaysia. Multiple prototype models were developed for analyzing the data from multiple divided grids in one single room. The results clearly suggested the capability of detecting human occupancy from minimum into larger data scales. Deployed sensor nodes show the potential of this system for certain application in closed room where monitoring crowd density is needed.

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Introduction

Detecting and identifying crowd density in an arena is a crucial element for wide range of applications; Erickson & Cerpa proposed a well defined occupancy model, and the availability of an occupancy monitoring system [1]. Human sensing system focuses on creating an environment that will mechanically react with human presence in certain area, especially in crowded scene. It is possible to implement occupancy density into heating, ventilation, and air conditioning (HVAC) controls strategies [1]. Mumma provides an estimation of occupancy by using occupancy sensors based on indoor CO2 concentrations [2]. Meanwhile, Chang and Yang, designed wireless sensing system based on Zig-Bee technology for monitoring of ventilation in the car space [3]. However, high density scene could be highly challenging due occlusion, varied parameter etc.

This paper also delivers a comprehensive review regarding today existing human sensing application along with fairly elaborate their advantages and disadvantages from each sensing modality. This contribution is to serve as a guideline for future reference and development of designed system.

Overview

This paper is divided into two main parts First part will cover type of human sensing modality literature review. Meanwhile part 3 cover designed model. The following section is to expose the existing literature especially based on sensor's capability in detecting human presence, count and locate, rather than elaborate the exact algorithm and solution. Figure 1 shows currently available human sensing approaches such as binary sensor, radio and acoustic sensors, imager and chemo sensor.

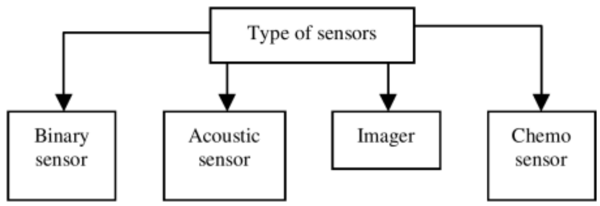

Figure 1. Type of sensing modalities.

Literature Review

Huge arsenals of sensing modalities are already available in the market, each of them can sense in a great amount of traits from human presence in certain place or location. This paper represents the small number of approaches of detecting human.

The proposed in this review is immense. In fact, it is an impossible task to describe them all, only several selected approaches are selected. Most selected sensors are based on intrinsic human traits, which either from scent and heat (static) or vibration, motion and voice (dynamic). This paper does not include extrinsic traits sensing modality like tag or any device carried by a person, as part of finding new approaches

Binary sensor

Binary sensor can be interpreted as those sensors that return their result or reading input as a logic number. In term of human sensing, it will represent either presence or not. PIR and capacitive sensors are the example of binary sensor modality.

Chowdary et al. developed pyro-electric sensors. It was developed with an electric signal in response to a change in the thermal radiation. Every living body emits low level radiations. It is operating if any warm body passes that will cause positive differential change and vice versa. PIR sensor still have common false alarm error, incapability of detecting human in stationary state and always ignored by researcher due to single person detection [4].

Valtonen et al. developed a passive indoor tracking of human being based on low frequency electric field approach by measuring the capacitance between multiple floor tiles and a receiving electrode. The standing test shows 10 cm accuracy in 80 % of the cases. Overall, it provides much better accuracy compare with other passive sensor [5].

Acoustic sensor

Wagner and Timmerman, introduced device-free localization (DFL) passive RFID without using tag. RFID reader antennas are placed directly behind the high mounted passive transponder lines that were placed around measurement area. This technique leads to high localization result and high computation time. So, clustering algorithm compensates this system trade-off between measurement speed and localization precision [6].

Sabatier et al. introduced passive acoustic sensor is sensitive to the sound from sliding contacts. The active method utilizes continuous wave ultrasonic Doppler sonar which involves the transmission of electromagnetic waves to the human body and registration of the backscattered waves by the radar. The combination between two technologies makes it more reliable [7].

Damarla et al. considered multiple sensors; ultrasonic, acoustic and seismic sensors for border crossing. Data were fused together using Dempster-Shafer fusion paradigm. Their results show a count of only six targets instead of seven. Fusion features is the key for detection with high percentage of correct modalities [8].

Imager

Camera does provide better result of detection, gathered more information and offer high spatial resolution compare with other type of sensor. Despite from these advantages, it still has room to be improved.

Rodriguez et al. introduced visual crowd sensing camera with tracking-by-detection framework and does not required manual initialization compared with silhouette detection camera. Density estimator provides better result than usual head detection by minimize error detection. Visual cameras can detect human presence and track with more than 100 people in crowded scene. It is quite effective of estimating people in crowded but processing time and cost might increase linearly with the number of camera [9].

Rahmalan et al. discussed the important of implementing crowd sensing estimation method. Multiple methods were used and categorized into a range of density via Self Organizing Map (SOM). Overall, all these techniques still have minor problems such as presence of shadow and misrecognition of surface floor which could refer as images noise [10].

Chemo sensor

Chemo sensor is a relatively new area for human-sensing lies in scent detection. It is still new and little well-known for person-detection. Scent-based systems are highly uncommon and will further investigate in this survey.

Leephakpreeda et al. presented an occupancy-based demand control ventilation (DCV) in order to determine the changeable occupancy for the ventilation control regarding the CO2 concentration measurements of the air entering and leaving the place [11]. Costanzo et al. emphasized on indoor air quality in ventilation system. People breathe out CO2 depending on their activity level and could be used as indicator for room’s occupancy level. So, it can be apply on certain application where needs to control particular features such as energy consumption [12].

Prasad et al. stated the effect of temperature and humidity sensors needed to be considered with CO2 sensor modality for accurate readings [13]. Dougan and Damiano, stated the preferred multiple locations sensor testing in the occupied zones. Rate of CO2 production against human metabolic activity is directly proportional and linear [14].

Wendt et al. and Mika Raatikainen et al. stated CO2 continuously increased during the high-occupancy period. Longer decay time is associated with a tighter construction [15-16]. Nassif provided an alternative CO2-based DCV strategy. The most possible scenario is where the number of people varies randomly and required no accurate information based on 100%, 75% and 50% of the design occupancy profile [17].

Fusion sensor designed

This section provides the benefit of combining multiple sensors based on different type of modality of sensing component. The reason of this attempt is to get a better result by combining different modality and possibly eliminating or reducing those unrelated elements that were happen for a specific sensing modality.

Bing Dong and Burton Andrews implemented an algorithms for sensor based modelling. The environmental sensor network combining acoustics, temperature, relative humidity, CO2, motion sensors were used for the model of occupancy behavioural patterns [18].

Structure design of the crowd sensor prototype

Prototype of the crowd sensor system mainly consists of two base boards; sensor node unit as receiving analogue data and proto-shield as base station board. The sensor node unit contains four sensors for environmental parameters such as CO2 sensor, temperature sensor, humidity sensor and CO sensor.

Proto-shield board includes memory data storage and multiple connectors for connecting with other modules. This board also could connect directly into Arduino Uno microcontroller through below aligned pin header. Arduino Uno is used for computation purposed. Other modules that connected into main board are LCD for displaying data purposes, real time clock and SD card module for data logging purposes. Figure 2 below shows the overview of the main components used in the system prototype.

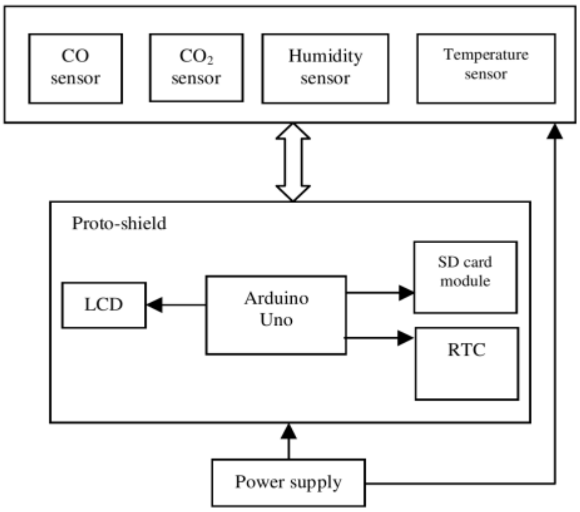

Figure 2. Block diagram architecture.

Based on Fig. 2, the sensor units have four main sensors; CO2 sensors (Figaro TGS4161), CO sensor (Figaro TGS2442), temperature sensor (LM35DZ). The specification of CO2 sensor offers in a very small size component and practically low power consumption. CO2 gas concentration can be measured by monitoring the change of electromotive force (EMF) generated between two electrodes.

From the datasheet, it has linear relationship between ΔEMF and CO2 gas concentration on a logarithmic scale. The typical detection range is in between 350 ~ 10000 ppm (parts per million). This sensor can operate as low as 5V DC supply. Its current draw is approximately 50mA in average and need 1.5 minutes response time. It requires more than 12 hours for warming up before it is stable to sense CO2 in the atmosphere.

TGS 2442 sensor is a resistive sensor to the changes in carbon monoxide (CO). It varies according to the graph which presents significant variations. It is recommended to choose the load resistance and calibrate it before finally apply it into the circuit. This sensor can be characterized by high sensitivity, low current draw (3 mA) consumption, fast response time (1s), small size and low dependence from moisture. The typical detection range is between 30 ~ 1000 ppm.

LM35DZ is a capacitive, cheap and economical analogue temperature sensor manufactured by National Semiconductor. The output voltage is linearly proportional to the temperature in Celsius. It does not need any external calibration in order to get highly accurate values because of low output impedance (0.1Ω at 1mA) and linear output representation (0.2 °C) on the graph. It varies of 10 mV / ° C scale factor with 0.5° C of accuracy. The absolute range for this sensor is 0 to +100° C. Reasonable detection range, small size, cheap and low power consumption (60µA) make this component an ideal choice for this type of application.

HIH-4000 is humidity sensor series manufactured by Honeywell. It has linear voltage output vs. % Relative humidity (RH) this features could enhanced its accuracy (±3.5% RH). The interchangeability of this capacitive sensor itself reduces or eliminates Original Equipment Manufacturer (OEM) calibration cost. The operating range detection is 0 – 100% RH. It only draws 200 µA, low drained typical current. Its fast response time (5s) make this is a good selection.

Methodology

The test grid room (4.3 m x 4.3 m) is situated. The room is divided into multiple grids as part of the experimentation, as shows in Fig. 3. From Fig. 3, it can be seen that only the middle part of the room was considered. Those grids are labelled as Grid 1, Grid 2, Grid 3 and Grid 4. The dimensional of every grid is 3.65 meter (top) x 3.35 meter (side). Grid 1 and 2 are the only grids that were involved air conditioning system.

During the test is conducted, both doors at the front and the back of the room were closed. It only opens once the participant entered the room. The doors were not leave open during test or teaching sessions. Because of the surrounding buildings, very little direct sunlight shines through the back windows. During conducting an experiment, sensor nodes were placed at the centre of every grid. Sensor nodes were hanging 15 cm away from the ceiling.

To simulate the distribution of all for 3 parameters; temperature, relative humidity (RH) and carbon dioxide (CO2), test was conducted during the teaching session after the room was leave with air conditioners is switched on with fix setting by user.

ACs was switched on 20 to 30 minutes earlier with level 1 out of 3 speed of fan. Meanwhile, temperature from air conditioning was leaved at level 3 out of level 5. The average temperature across the room is 21.6 degree Celsius, 75.0 % relative humidity and 368 ppm CO2. This could be called as ambient condition.

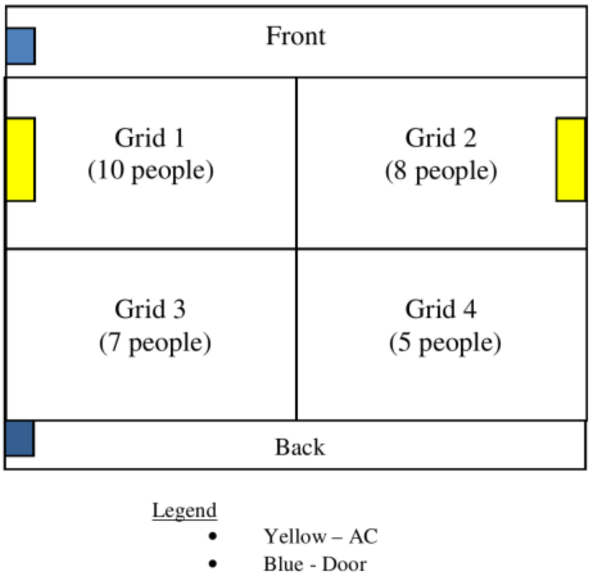

Figure 3. Floor plan of the test room.

Each measuring point is identified as in Table 1. Participants enter the room from 1.55 pm until 3.30 pm.

Table 1. Test procedure for measuring parameters.

Grid	1	2	3	4
Number of participants	10	8	7	5
Air-condition	ON	ON	NA	NA
Ambient temperature (°C)	21.8	22.0	25.0	24.0
Ambient humidity (%)	77.0	77.0	72.0	74.0
Ambient CO2 level (ppm)	361.7	382.0	364.0	365.0

Results and Discussion

The efficiency of the sensor nodes during occupancy session was evaluated. Stable pre-conditions of indoor temperature, relative humidity (RH) and carbon dioxide (CO2) concentration were established by initial setting air conditioner the indoor air. The test room is kept running with the two air conditioner units for 30 minutes prior to starting the test. The high occupancy condition was established by having 30 people inside the tutorial room involved in sedentary activity (i.e. lecture session). The high occupancy was abruptly reaching steady state after 50 minute.

During occupancy period, sensor nodes are recording the temperature, RH, carbon monoxide (CO) and CO2 particular concentrations for every five minutes. The data acquisition systems measurements were started at 1.30 pm until 3.40 pm. Based from 30 people in this room, 10 of them were seated in Grid 1, 8 participants in Grid 2, 7 participants in Grid 3 and 5 participants in Grid 4.

The test procedure produced certain episodes of CO2 concentration, humidity and temperature in the room can be seen in the figures. Figure 4 shows relative humidity during 100 minutes that encompasses the high-occupancy event. 30 participants entered the room at 1.55 pm until 3.15 pm. From the graph (Fig. 4), immediately 10 minutes later during occupancy session all ambient specification from every grid is gradually decreasing for over 45 minutes until it reach steady state condition, where humidity measurement reach stability.

Steady state stays in this state for over 30 minutes later until all participants leave the room. Relative humidity was gradually increased back at 3.20 pm. As expected, Grid 1 and Grid 2 do have differences against Grid 3 and Grid 4 because of Grid 1 and 2 do have air conditioner compared with grid 3 and 4. Grid 1 and 2 in average relative humidity is 66 % respectively, meanwhile grid 3 and 4 have approximately 60 % relative humidity respectively. Overall, it seems occupancy does have noticeable effect on humidity generally in the room.

Figure 5 illustrates the impact of high occupancy on CO2 concentration. An increasing in CO2 from ambient condition, 330 – 380 ppm until it reaches high occupancy state. From the graph, grid 2 (green), and grid 4 (blue) do look similar in gradual increase along the way. Grid 3 (orange) does have much lower increase rate compare with the other 3 grid due to low occupancy in that particular grid with only 5 people in it and it reached until 900 ppm.

Among the higher increasing rate is CO2 concentration at grid number 1. Grid 1 seems to be only reaching nearly 1500 ppm in 10 minutes steady state due to 10 people actually sitting on that grid. Grid 2 and 3 respectively recorded similar effect on occupancy with nearly 1100 ppm.

Grid 2, 3 and 4 need approximately 55 minutes in order to reach steady state, meanwhile, grid 1still getting increase for over 1 hour. After 3.20 pm, all concentrations are continuously depleted during the time where participant are leaving the room.

It can be noticed, right after participants leave the grid CO2 drastically decreasing and need more time to reach back ambient condition. Longer decay time is associated with tighter construction. Overall occupancy seem to be continuously increasing the CO2 concentration but the number of participant seated in the grid could differentiate between high and low steady state as well as the its increasing rate.

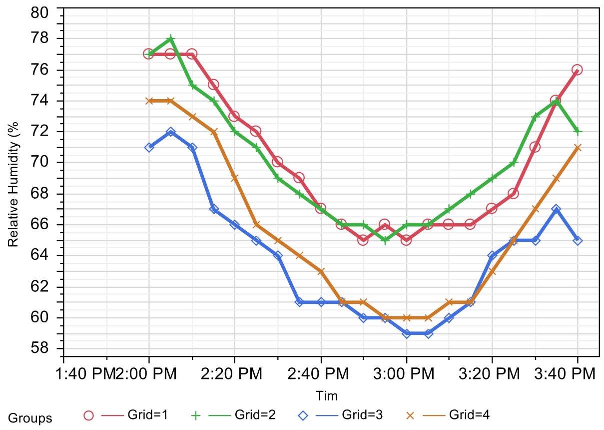

Figure 4. Relative humidity (%) over time (min).

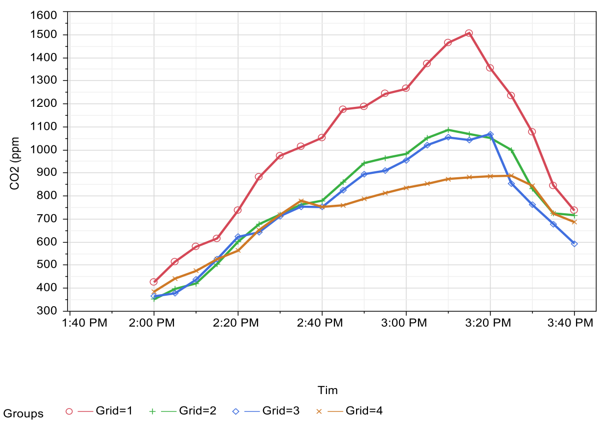

Figure 5. Carbon dioxide (ppm) over time application.

Figure 6 shows temperature over 100 minutes testing session. If recalled back the average ambient temperature, all grids measured with 21 – 25 ° Celsius. Right after participants entered the room grid 1 (red) and 2 (green) recorded measurements with 22 and 21 degree Celsius respectively, meanwhile grid 3 (blue) and 4 (orange) happen to be the same as ambient.

It is possibly because of the existence of air conditioner in grid 1 and 2. Air conditioner could make particular grid stable in temperature. Based from the results above, it seems like the temperature measurement do not actually having impact on human occupancy. Based on the conducted experiment, temperature measurement does not have impact on human occupancy; it is more effect on the time when conducting an experiment, morning or evening session.

Humidity has noticeable effects during high occupancy period. Early measurements will gradually descending over a 50 minute period of time until it reaches steady state condition and raises back after 30 minutes. CO2 sensor definitely affected by the existence of people in the room, there are some major differences between number of people and this could be group as part of estimation process rather than identifying the exact number of participant in certain grid due to variation cause by the environmental itself and also to reduce identification error.

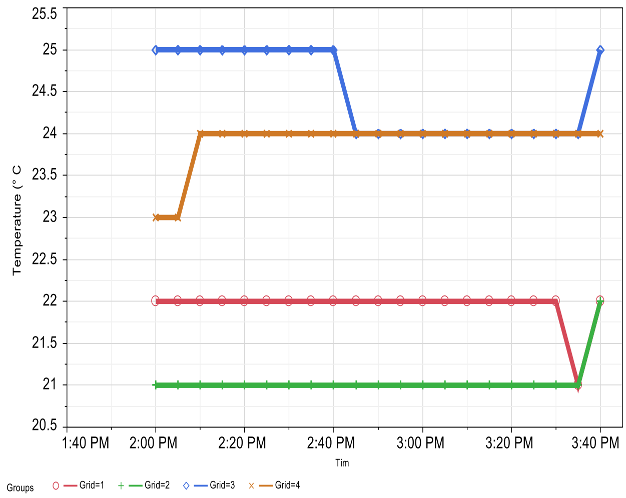

Figure 6. Temperature (ºC) over time (min).

Conclusion

The sensor node that was deployed at multiple grids with nearly two meters height in single tutorial room has been developed and tested. The embedded system operates for data gathering and stores it in to memory storage for analysis purposes which is potentially to monitor carbon dioxide, temperature and humidity during high occupancy period. By comparing this type of environmental sensing modality, it provides such as low cost, low computing and it could an alternative method of detecting and possibly estimating human occupancy

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