A Low-cost Sensor Module for In-Building Monitoring and Threat Detection

1 Introduction

The project aims to develop a low-cost hardware system for in-building environmental monitoring and potential threat detecting [1]. It provides an entry-level prototype for highly integrated low-cost monitoring system suitable for large-scale deployment. Three main contributions, both research- and commerical-wise are listed as follows. (1) Acquire data and knowledge for in-building environmental factors and energy matters [2]; (2) Based on the abundant data collected, enable the potential for better building structural design and improve the daily operational strategies [2]; (3) Lower system cost can potentially lead to higher deployment rates for not only research but also commercial use [1][2]. As stated in [1], this project would eventually benefit those who are working in areas like building security, management and estates. It can also provide a low-cost monitoring system solution for researchers focusing on in-building environmental performance analyses [2].

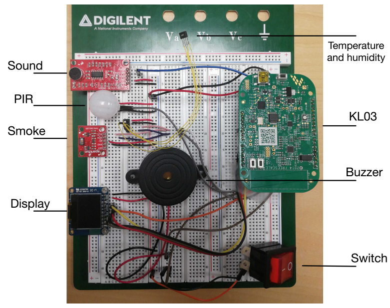

Figure 1: The updated system breadboard view.

2 Current state-of-art

Most of the commercial off-the-shelf (COTS) building monitoring systems face three key issues: high cost, inconvenience and limited capability [3]. For example, Monnit, a remote monitoring system manufacturer produces systems that can monitor and control environmental parameters, including but not limited to temperature, humidity, motion and light detection and so on [4]. However, the drawback of their systems is the lack of sensor integration. In order to obtain various parameters monitoring capability, end-users have to purchase and deploy more than one system on-site. This leads to the direct increase of cost and labour for maintenance.

3 The project approach

In order to counteract the drawbacks the prototype system is designed with low-cost and ease-of-implementation considerations in mind. Unlike the current high-end commercial products, the proposed system considers open-source and modularity design the most important characteristics. This engineering solution gives the researchers and other potential audiences a certain degree of freedom to adjust and modify the system to suit their own needs with a low-cost fashion. The below Table 1 concludes the current cost of the system, which is still high given the fact that COTS sensor and hardware evaluation boards are used. It is anticipated once custom printed circuit boards (PCB) that integrate all the components together are used, the cost can be further reduced, making the system at least 1-2 orders of magnitude lower in cost as compared to higher end products.

with LMV324
electret microphone capsule

Table 1: The bill of materials (BOM) for the in-building monitoring system

Component	Part number	Supplier	Cost in pounds
Freedom development board	FRDM-KL03Z	NXP Semiconductors	17.79
OLED breakout	SSD1331	Adafruit	28.00
Piezo buzzer	KPEG-350	Kingstate	1.54
PIR motion sensor	EKMC1603111	Panasomic	9.98
Temp, Humidity Sensor	HIH8120-021	Honeywell	7.08
Smoke sensor breakout	SEN-14045	Sparkfun	15.44
Sound detector breakout	SEN-12642	Sparkfun	10.79
Mechanical rocker switch	C1353ATNAN	Arcolectric	4.47
Through-hole capacitor	0.1 uF	In house supply	$0.18 \times 3 = 0.54$
Wires, jumpers and headers			
		Total cost	95.63

Smoke sensor
MAX30105

4 The system development

The hardware development of the system includes schematic design and breadboard construction. As shown in Figure 2, the interconnections between components demonstrate the ease of implementation since most sensor communications are carried out via I2C channels. Current design requires the use of USB cables to provide power supply and data retrieval functionality. The firmware development includes the driver write-ups as well as the design of basic signal processing algorithm. Due to the limited time and resource available, the full functionality of the system was not achieved. The piezo buzzer and OLED display were configured such that when abnormal events occur both of the two components would be able to create alerts (flashing red display and continuous sound alarm) to the end user.

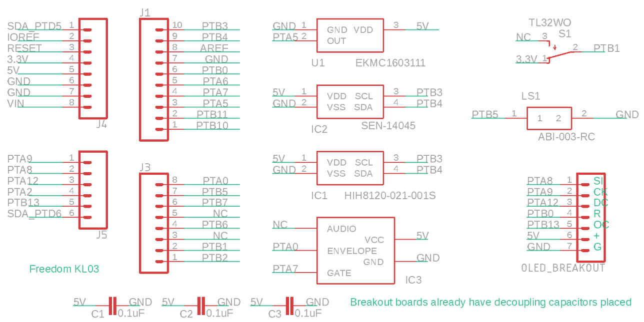

Figure 2: The schematic diagram of the system. Retrieved from [2].

4.1 Power consumption analysis

Measurements were taken in order to understand the power consumption characteristic of the system. For each sensor, the current flowing through the component was measured using a true RMS digital multimeter. Results of the measurements are shown below. The main FRDZ-KL03Z evaluation board draws an average of 72.30 mA current when the on-board light emitting diodes (LED) are switched on and is not connected to sensor peripherals. The measurement is done using a Keithley 2450 source measure unit (SMU). The power supply during the measurement approximates to 5.0 V.

Future improvements: ① First activate smoke detector
② Custom PCB design → cut down cost
remove unnecessary wiring complexity

③ Should be ideally battery powered
also → wireless communication.

components,

As was measured during previous coursework item 4, the organic light emitting diode (OLED) display consumes an average of 67.06 mA of current when it is fully powered on and displaying the brightest green on the screen. This value can be considered the maximum power consumption the OLED display module would have during normal operations.

Individual current measurements were carried out for the remaining sensor breakout boards and peripheral devices using a UNI-T UT139C true root-mean-square (RMS) multimeter. The humidity and temperature sensor when in operation consumes 0.28 mA of current. A maximum of 1.01 mA of current is distributed to the passive infrared (PIR) sensor. A constant 1.76 mA current flows through the piezo buzzer when fully powered on. The MAX30105 smoke detector module consumes more than 2.31 mA of current when the on-board red LED is turned on. The sound detection unit consumes even more power, reaching up to 2.19 mA when it generates a maximum of 4.56 V output, this is also due to the fact that there is a small red LED on the Sparkfun evaluation board which constantly consumes power when noticeable environment noise is detected. Figure 3 shows how the current drawn by the system is distributed towards various components. The largest portion is consumed by the KL03 microcontroller evaluation board, taking up as high as 51% of the total current. It should be noted that this is due to the configuration that sets the processor to run in full power mode. The OLED display unit, in comparison, consumes 44% of the total current.

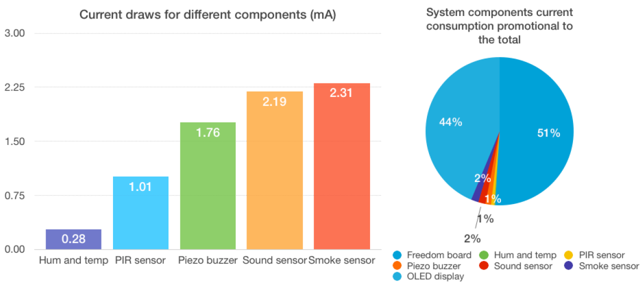

Figure 3: The bar chart and pie chart demonstrating the portion of power consumed by individual components. The largest portion is consumed by the microcontroller module, and then followed by the OLED display unit.

4.2 Sensor data analysis

Raw data was collected in a normal office environment based in Centre for Advanced Photonics Engineering (CAPE) building, west Cambridge site. The temperature and relative humidity data was captured using the developed system, and outputs (equivalent to 23 minutes, with 4 seconds intervals) were read from a MacOS terminal running JLink client.

Both the sound sensor and the PIR sensor outputs were collected using a Salae logic analyser, in order to properly record the output voltages of the two sensors during two separate 1000 seconds experiments. The PIR sensor outputs indicate the presence of human activities in the first 100 seconds and the last 50 seconds. These outputs are read by checking the value of one general purpose input/output (GPIO) pins in the Freedom board. Unfortunately, due to the limited time and resource, the analogue data capture for the sound sensor had not been integrated within the system, a gate output detection was implemented instead. It should also be noted that due to the limited resource, smoke sensor calibration could not be carried out, therefore the smoke sensor had been integrated to date only to indicate its working functionality.

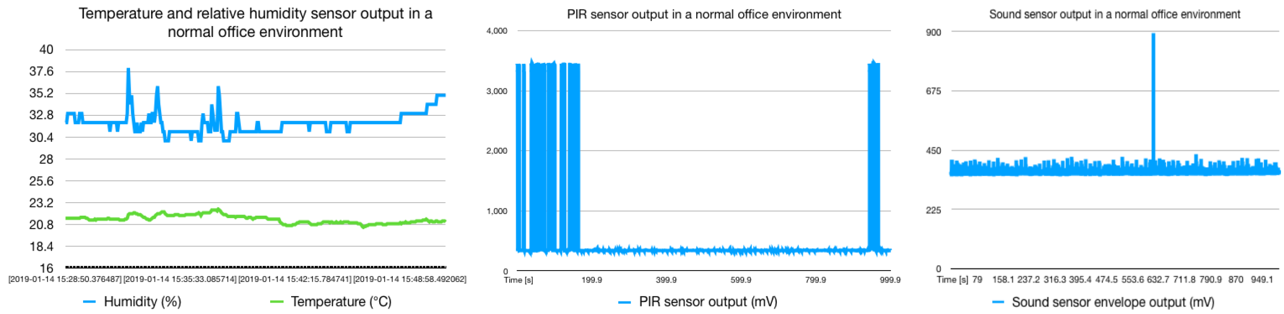

Figure 4: Charts showing the collected data from sensors. The temperature and humidity data was collected in a 30 minutes time-frame, whereas 1000 seconds of data was collected for both PIR and sound sensor.

5 Conclusion

The project to date has demonstrated that a highly-integrated low-cost environmental monitoring system suitable for in-building deployment can be designed and produced. This unfolds the great potentials of having multiple low-cost sensors and embedded system solutions deployed on-site. Low-cost sensors with less accurate and precise readings, as compared to the high-end products, implemented within the system could be deployed in vicinity of each other. This provides the chance by applying advanced signal processing techniques to cross-validate the sensor readings among different deployed platforms, in order to counteract the effect of receiving less satisfying outputs. It is foreseen that a fully customized printed circuit board (PCB) design would not only reduce the cost of building such a system but also add to the implementation and deployment flexibility. Future work should also be focusing on minimizing the power consumption of the system such that it could be battery-powered for a long time period. Moreover, wireless communication techniques would be also beneficial since this will eliminate the need for cabled connections. Wireless solutions such as Zigbee, Lora and Bluetooth low-energy (BLE) once implemented, could offer long-battery-life communication support to the system.

Since the capsule is effectively a voltage divider sitting across the power rails and will transcribe any noise on the supply lines into capsule output.

References

[1] Y. Wang, "A Low-cost Sensor Module for In-Building Monitoring and Threat Detection Project Proposal for 4B25 Embedded Systems," tech. rep., Cambridge, 2018.

[2] Y. Wang, "A Low-cost Sensor Module for In-Building Monitoring and Threat Detection Interim Report for 4B25 Embedded Systems," tech. rep., Cambridge, 2018.

[3] A. Owens, V. Gungaram, T. Z. Kai, C. Duff, and S. Collings, "Secure Wireless Networked Sensor Array for Building Monitoring (GCHQ) Final Report," tech. rep., University of Manchester, 2017.

[4] Monnit, "Monnit Site," 2018. [Online]. Available: https://www.monnit.com/. [Accessed: 2019-01-13].

sound sensor requires careful choosing of power pins