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An IoT-driven smart cafe solution for human traffic management

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An IoT-Driven Smart Cafe Solution for Human Traffic Management

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***Abstract*—In this study, we present an IoT-driven solution for human traffic management in a corporate cafe. Using IoT sensors, our system monitors human traffic in a physical cafe located at a large international corporation located in Singapore. The back-end system analyzes the streaming data from the sensors and provides insights useful to the cafe visitors as well as the cafe manager.**

Keywords—smart cafe, Internet-of-Things, sensors, analytics

I. INTRODUCTION

In recent years, the Internet-of-Things (IoT) sensors are transforming many industries [1, 2]. In collaboration with a large international corporation located in Singapore, our study examines the design and implementation of a 'smart' cafe. The relatively new cafe quickly became a favorite meet-up spot for the corporate staff. While it was good news for the cafe's owner revenue-wise, frustration grew amongst the corporate staff – as they would take an elevator down from high floors only to find out that the first floor cafe ran out of seats and tables. To tackle these challenges, we proposed an IoT-based solution for monitoring human traffic within the cafe and provide that information near real-time to the corporate staff. The aim was to make the information accessible from anywhere via Internet web browsers. This greatly benefits the corporate staff – as they can monitor the traffic first before making the decision to travel down to the cafe. Additionally, this greatly enhances the cafe owner's ability to understand just how busy the cafe is – in terms of table and seat usage. Insights from our analyses help the cafe owner better plan the floor, table and seat layout - towards improved customer experience and increased sales.

II. SOLUTION DESIGN

In our preliminary solution setup, we focus on tracking the total number of people and seat occupancy in the cafe throughout the day during the business hours. The next phase of this study will delve into tracking movements within the cafe as well as queue management.

Fig. 1. Key Measurements for Human Traffic Management in Smart Cafe

The corporate cafe has a total seating capacity of 66 (Fig. 2). There are 10 4-seater tables and 13 2-seater tables. In the middle of the cafe, there is a bookshelf and a wall with two flat screen monitors attached to the wall. There is only one entrance, and it is located next to the kitchen. Near the kitchen, there is a cashier's counter and a pastry refrigerator. To meet the objective of tracking and analyzing human traffic movement in the cafe, we researched on available methods.

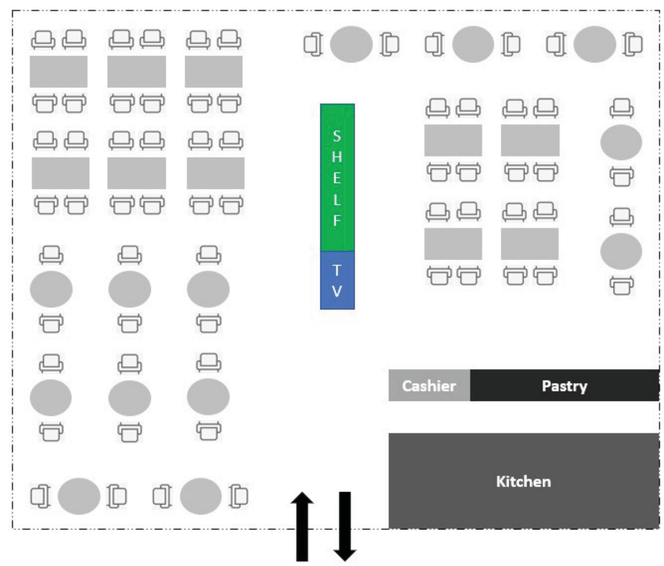

Fig. 2. Physical layout of the corporate cafe

Point-of-Sales (POS) Data

From the order details, we can gauge the total number of people. For example, we assume that one drink is for one person. However, observations at the cafe reveal that not everyone visiting the cafe orders (e.g. they bring their own drinks). Further, some visitors only order pastry. The POS data do not indicate time spent at the cafe. Some may just take the order to go and exit the cafe without occupying any tables or seats. It is difficult to access the POS data from external systems/applications. Currently, the only way to pull the data is to submit a data pull request to a third-party vendor and the results are sent to the cafe owner at a later time.

Café's Own Public Wireless Network Data

The cafe offers free public wireless network service to its visitors. It is not clear what percentage of cafe visitors are corporate staff versus guests. We assume that most corporate staff use the corporate wireless network (which is available all throughout the corporate building) instead of connecting to the cafe's public wireless network. Also, it is not clear whether guests (non-corporate staff) use their own mobile network or the cafe's public wireless network. Hence, it appears that the cafe's public wireless network usage data may not reflect all visitors to the cafe. Further, it may indicate the total number of people inside the cafe (as network data are time-stamped) but it does not clearly indicate seat occupancy. They may be using the public wireless network while waiting in the queue or standing outside the cafe (we tested that it was indeed accessible from outside the cafe).

Cameras & Image Recognition

To use camera and to analyze captured images, the location of cameras will determine the kinds of image we can capture. Fig. 3 shows the cafe's layout with three cameras indicated with “X” symbol. Assume that the cameras are mounted to the ceiling (the height is approximately three meters). Each camera faces the interior of the café diagonally from the corner. We simulated this setup by attaching a wide-angle lens to a digital camera, mounted the camera onto a long selfie stick, took several photos from each of the three “X” locations, and inspected the photos.

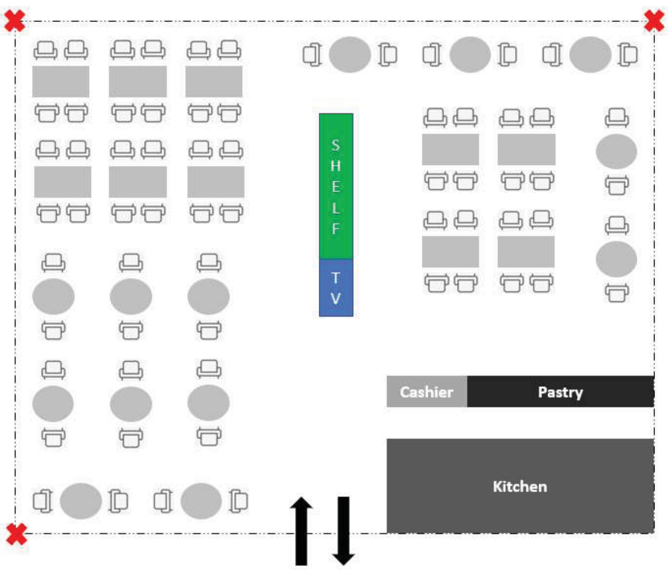

Fig. 3. Mounted cameras for capturing images of visitors

We learned that using cameras for tracking human traffic comes with challenges. First, this method requires extensive design trials by changing cameras’ locations and angles in order to capture images where objects can be clearly recognized using image processing algorithms. From the photos we captured during peak business hours on weekdays, many images contain people appearing overlapped – such that image processing algorithms cannot accurately detect multiple people as separate objects. Secondly, if our solution were to capture human traffic information dynamically and quickly – so as to provide near-real-time information to the corporate staff, capturing images and performing image processing have to be executed fast. While accuracy is important, speed is critical – as the cafe experiences dynamic human movements especially during peak hours. The total execution time of uploading images to a server for image processing and making the analysis results (e.g. number of seats available, number of tables available, etc.) available to the corporate staff must be short. And to make this whole process run fast (and accurately), this method would require extensive resources including wiring and network bandwidth (to enable fast image upload to the server – potentially on an on-going and frequent basis throughout the year). Lastly, our client expressed concerns about privacy – the cafe visitors may not feel comfortable with the idea of being filmed continuously.

Given these challenges, we proposed an IoT-based solution (Fig. 4). The solution leverages Bluetooth Low Energy (BLE) beacons and ultrasonic sensors. The BLE beacons can sense proximity, and we use it for tracking the movement of humans. We use the ultrasonic sensors to monitor seat occupancy. The sensor data are sent to the central database hosted in Amazon Web Services. We used Node-Red to create a pipeline – connecting all the devices and the central database.

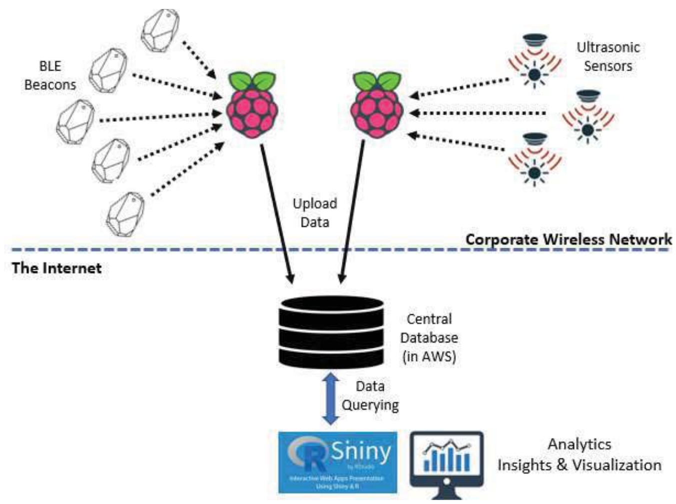

Fig. 4. System Architecture

The cost of the BLE beacon is relatively low. It is simple to implement, and each sensor is uniquely identifiable. It can be tagged to an employee pass in a rather non-intrusive manner. With an effective range of 10 meters, the beacons can be detected by two Raspberry Pi devices. The beacons have a battery life of approximately one year. The BLE beacons send data to Raspberry Pi devices every second. This data transfer leverages the corporate wireless network. Data are consolidated and sent to the central database every five seconds. BLE beacons require low energy, hence, from cost perspective, it is deemed a sustainable solution.

Next, we used ultrasonic sensors for proximity sensing. It detects presence of people at a given table or seat. This can be deployed in a non-intrusive way onto walls near tables or seats in the cafe. These sensors constantly monitor the presence of objects in proximity. Each ultrasonic sensor is wired to a Raspberry Pi + GrovePi set. Ultrasonic sensors capture sensor data every second, and the Raspberry Pi devices send the data to the central server immediately. To detect the presence of an object in proximity, we set the minimum distance threshold to be 70 centimeters.

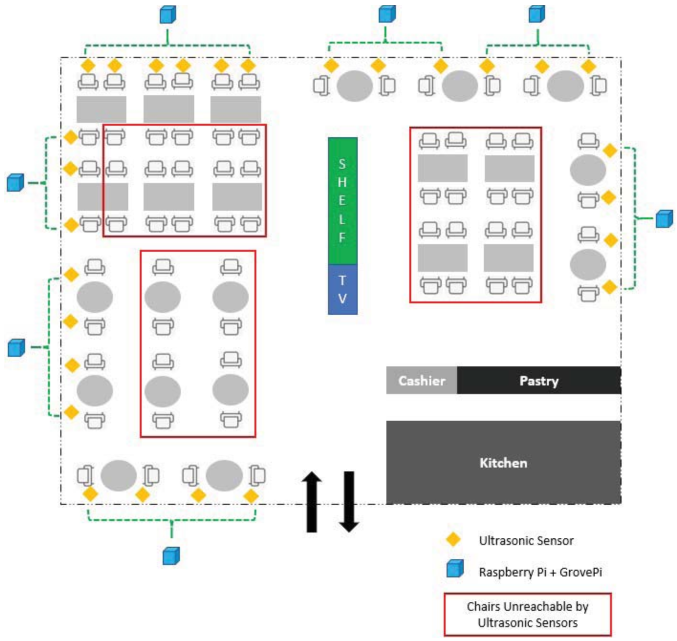

Fig. 5. Monitoring seat occupancy using ultrasonic sensors

Fig. 5 shows our first proposed configuration of ultrasonic sensors and their installation locations. Each Raspberry Pi is equipped with a GrovePi. This setup requires a nearby power socket, and several sensor cables can connect to it. Our configuration requires seven sets of Raspberry Pi + GrovePi. And each set has multiple ultrasonic sensors connected to it (wired). We observe that there are many seats (in the center of the cafe) whose occupancy cannot be tracked by sensors (they are indicated inside red rectangles). This results in some 48% of the seats in the café that cannot be monitored.

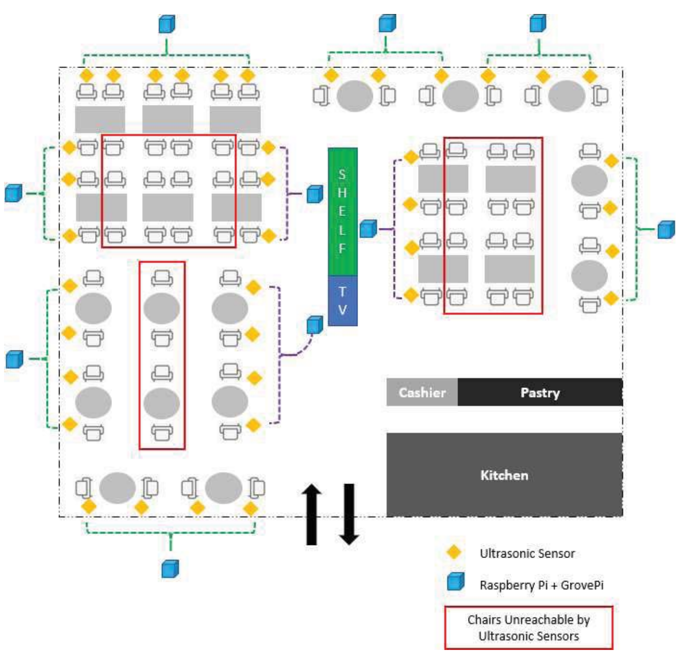

Fig. 6. Monitoring seat occupancy using ultrasonic sensors (improved)

While the wall supporting the shelf and the TV panels has enough power sockets to which Raspberry Pi + GrovePi sets can plug into, our client initially thought that it was not a good idea to have ultrasonic sensor cables running on the floor right in the middle of the cafe. As shown in Fig. 6, if three more sets of Raspberry Pi + GrovePi can be installed in the center of the cafe and ultrasonic sensors monitor the seats near the Shelf and the TV panels, 72% of the seats can now be successfully monitored.

One challenge with this new configuration is that finding suitable locations for ultrasonic sensors can be challenging. If there is a wall nearby, Raspberry Pi + GrovePi and ultrasonic sensors can be all mounted onto the wall (Fig. 5). However, in the new configuration (Fig. 6), ultrasonic sensors cables can run on the floor (after proper taping is done so as to prevent customers tripping) from Shelf/TV wall and the sensors can be placed on the floor near chairs. There is a risk of customers stepping on the sensor. Another option is to mount Raspberry Pi + GrovePi sets onto the ceiling (assuming there are power sockets in the ceiling). Then, ultrasonic sensors can be connected to these sets where each sensor will monitor a seat below the ceiling.

This will potentially require new interior renovation, which can be costly for the cafe. Hence, in the next phase of this project, we will focus on fully testing out the currently proposed configuration (Fig. 5) and demonstrate that all the devices work as per the requirements. In our preliminary experiment, we chose a) the three 4-seater tables in the top left corner of Fig. 5 and b) the two 2-seater tables in the bottom left corner of Fig. 5. We installed the devices accordingly and conducted many tests to figure out the optimal minimum proximity threshold for ultrasonic sensors. Because different people sit differently on chairs – and they can change their positions, we conducted tests where subjects were told to perform different activities (e.g. using laptop computer, eating, drinking, using mobile phone, relaxing, napping, etc.) while ultrasonic sensors attempted to sense them. After a series of tests, we determined that 70 centimeter is the optimal minimum proximity threshold.

III. CONCLUSION & FUTURE DIRECTIONS

In this study, we designed an IoT-driven smart cafe solution for human traffic management in a busy corporate cafe. We plan to conduct a comprehensive experiment. We also plan to look into other types of sensor such as pressure sensor. A wide range of pressure sensors (and costs vary widely as well) are available in the market today. Pressure sensors can be installed on a chair – below the seat cushion, and it is capable of sending sensor data via wireless network. Lastly, once our comprehensive testing is done and our system launches, it will collect a lot of data. We plan to analyze the human movement data from BLE beacons. This will help the cafe owner better understand whether the current layout of tables and seats are optimal.

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