Real-time In-store Insights Cloud-based Solution using Radar Tracking Sensors and Demographic Analytics

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Abstract

We present real-time in-store insights (RII) solution which enables retailers to construct contextual insights on in-store shopper behavior in a cost-effective and scalable way. The solution consists of IoT sensors for tracking and CNN-powered demographic detection, IoT Gateway, and Microsoft Azure for insights analytics and reporting. This paper describes the system design and key components.

keywords: IoT, radar tracking, clustering, CNN, demographic, in-store insights, MQTT

Introduction

Given that the shoppers today have unlimited choices and rapidly changing preferences, it is imperative for brick & mortar stores to offer personalized shopping experience. E-tailers have mastered this art, however, brick & mortar stores lag behind as they don't have the scalable and cost-effective solution to capture in-store shopper insights.

Our real-time in-store insights (RII) solution enables retailers to construct contextual insights on shoppers' in-store behavior so that they can offer personalized shopping experience to shoppers as well as reduce cost by matching store operations (merchandise inventory, staff, promotion) to near real-time demand.

The solution consists of IoT sensors for tracking and CNN-powered demographic detection, IoT Gateway to parse data stream, and Microsoft Azure for in-store shopper insights and an interactive dashboard app.

System Design

As depicted in Figure. 1, IoT devices for tracking and demographic module feeds data stream either via IoT Gateway, where data are parsed and cleaned and forwarded, or directly into Microsoft Azure for insights analysis operation.

Tracking

We chose Texas Instrument (TI) 60 GHz millimeter-wave radar sensor(IWR) to achieve high-accuracy without privacy concern and light-of-sight limitation[1].

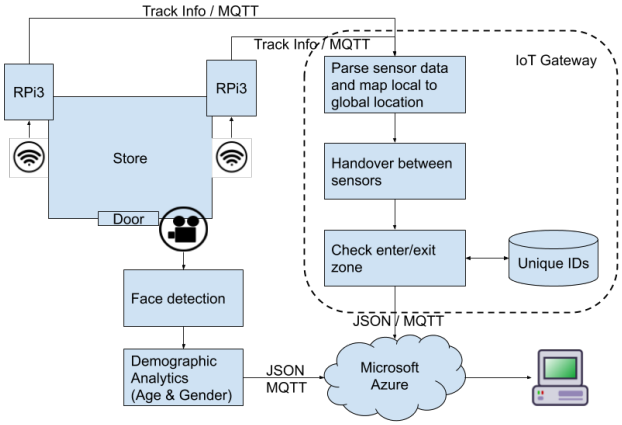

Figure 1: RII System Diagram

The radar sensor transmits adaptive beamforming around and receives the point cloud of the distance, angle, and radial speed measured from objects. The point cloud is processed by unsupervised clustering and Kalman filter to locate both obscured and line-of-sight targets and estimate their speed and direction. Both TI's built-in and our customized algorithms are available to meet various target size, resolution, and speed requirements.

Raspberry Pi 3 fetches tracking data over UART and forwards to IoT Gateway over MQTT/WiFi. The specification of tracking devices and IoT Gateway is summarized in Table. 1.

Gateway

The IoT Gateway parses incoming data from tracking devices and drops the duplicates[2]. Then, it inspects the entrance/exit zone to assign/remove UUID on

[1] Among indoor positioning systems, infrared/lidar requires line-of-sight and BLE/WiFi requires users to possess a BLE/WiFi device.

[2] It's similar to the cellular network handover, where an identical object is tracked by multiple sensors at the same time.

Table 1: Tracking Sensor and Gateway Specification

Model	Task	Connectivity	Processor (OS)
IWR6843 60GHz Radar Sensor	Cartesian location, direction, and speed	UART	C674 DSP, ARM (TI-RTOS)
Raspberry Pi 3	Fetch and forward data to Gateway	UART, WiFi	ARM (Raspbian)
DELL IoT Gateway	Parse into JSON and ingest into Cloud	Ethernet, WiFi	Intel Atom (Ubuntu)

Table 2: Demographic Modules

Model	Inference Platform	Age Output	Accuracy Metric
Opt-out[4]	NA	NA	NA
SightHound.com	Web API	Regression	MAE 5.76
RasNet54	Raspberry Pi 3	4-Age-Group class	Accuracy 60.48%
VGGFace16	Nvidia Jetson Xavier	Regression	MAE 7.42

incoming/leaving objects before ingesting into the Cloud. Note that MQTT is used for all connections to IoT Gateway so that the solution can integrate any IoT device compatible with MQTT protocol.

Demographic Analytics

The demogrphic analytic module estimates age and gender information on the facial image extracted from IP camera streaming video. The facial images are extracted by the "dlib" open source library, then fed into an age-gender estimation CNN (Convolutional Neural Networks) module.

The available modules include opt-out, 3rd party web API, and standalone embedded inference as summarized in Table 2. The VGGFace16 regression model output is the expected value from Softmax activation of 100-class (age 0 to 99) as described in DEX(Rothe, Timofte, and Van Gool 2015). The classification model output layer is Softmax layer of 4-age-groups[3]. Both models are fine-tuned from pretrained Tensorflow models and deployed on Nvidia Jetson Xavier and Raspberry Pi 3.

Cloud Platform

Microsoft Azure hosts IoT Hub and Virtual-Machine/Storage services to provide in-store insights across retailer clients and their sites.

Footfall Analytics Azure IoT Hub collects data across IoT Gateways and VM/Storage services perform the analytics operations listed as:

- Retrieve - Read IoT Hub messages into temporal database
- Fuse - Merge tracking and demographic data
- Aggregate - Generate hourly, daily, weekly statistics

[3]Centennial (< 18), Millenial ($18-35$), GenX ($36-54$), Baby-boomer (> 55)

[4]Opt-out is available for privacy or cost reason. Price-Chopper retailer has chosen opt-out for the prototype deployment

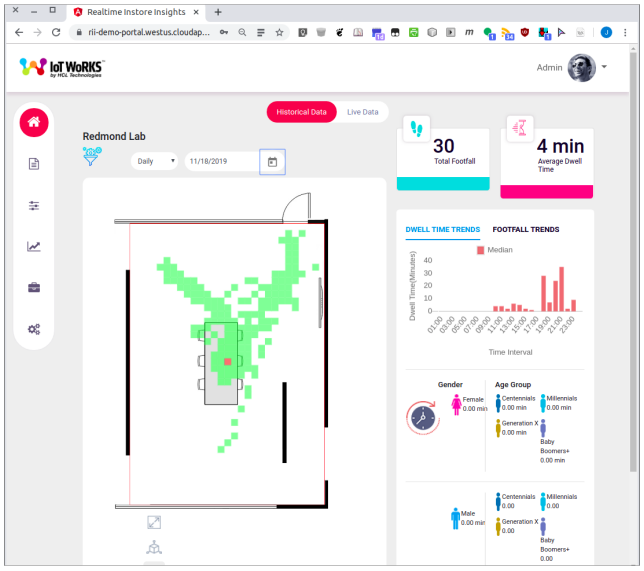

Figure 2: RII Interactive Dashboard

Dashboard Figure 2 depicted the dashboard which demonstrates the footfall heatmap and statistics of our lab site. It shows that the light footfall around the table marked in green and the corresponding trends and demographic information based on historical data. It can also switch to live data.

Deployment

Prototype

A prototype solution is deployed on our lab site to demonstrate the key features. The dashboard is accessible in http://rii-demo-portal.westus.cloudapp.azure.com/.

Demo Plan

We will provide the commented end-to-end video and deploy one radar sensor, a demographic module, and an IoT Gateway to demonstrate the real-time in-store scenario.

Summary

We presented the RII solution to construct insights on in-store shopper behavior so that the retailers can offer personalized shopping experience as well as reduce cost by matching store operations near real-time demand. IoT Gateway and Microsoft Azure orchestrate radar tracking sensors and CNN-powered age-gender estimation to capture in-store footfall in cost-effective and scalable way.

References

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Rothe, R.; Timofte, R.; and Van Gool, L. 2015. Dex: Deep expectation of apparent age from a single image.