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Device Free Occupant Activity Sensing using Internet of Things for Security Purpose

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ABSTRACT

Intelligent occupancy sensing is becoming a vital underpinning for various emerging applications in smart homes, such as security surveillance and human behavior analysis.However, prevailing approaches mainly rely on video camera, ambient sensors or wearable devices, which either requires arduous deployment or arouses privacy concerns.In this

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paper, we present a novel real-time, device-free and privacy-preserving WiFi-enabled IoT platform for occupancy sensing, which can promote a myriad of emerging applications. It is designed to achieve an optimal tradeoff between performance and scalability.Our system empowers commercial off-the-shelf (COTS) WiFi routers to collect Channel State Information (CSI) measurements and provides an efficient cloud server for computing via a lightweight communication protocol.To demonstrate the usefulness of our platform, an occupancy detection system is developed by exploiting the CSI curve of human presence. Furthermore, we also design an innovative activity recognition system based on our platform and machine learning techniques with high availability and extensibility.In the evaluation, the experimental results show that our platform enables these applications efficiently, with the accuracy of 96.8% and 90.6% in terms of occupancy detection and recognition respectively.

Index Terms—Occupancy sensing, WiFi, channel state information, human activity recognition.

CHAPTER I

1 INTRODUCTION

OCCUPANCY information plays an essential role in smart building and homes in terms of energy consumption estimation, human behavior analysis and indoor security monitoring. With the rapid development of the Internet of Things (IoT), this information can be obtained by the cognitive computing technologies, which are introduced into the smart homes by the

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integration of sensors, actuators, controllers and artificial intelligence. To develop a IoT based home automation system with Arduino-UNO Board and an Android application.

1.1 GENERAL

Various applications are enabled, of which the occupancy sensing is a significant one. It refers to estimating the occupancy information and simulating the situation of indoor environments by means of the analysis of data from kinds of sensor networks deployed in smart buildings. With occupancy sensing using IoT devices, the systems in smart building or homes are able to actively obtain the information of occupancy, such as identification, activity and even gestures. For instance, occupancy detection and human identification help to detect the intruders automatically.

In smart homes, the system can adjust the light and temperature according to the occupancy, which conserves the energy. For children and the elderly, it can monitor their activities such as falling to prevent potential hazard. Generally speaking, IoT based occupancy sensing provides an active detected input for the smart system, so that it can make judgment or feedback accordingly. The conventional approaches to perceive the occupants mainly resort to kinds of sensors, such as ultrasound, CO2 and thermal sensors

These works focus on coarse sensing including occupancy detection or counting , but as the machine learning techniques fortify the development and applications of artificial intelligence, more fine-grained sensing comes in existence. Researchers utilize sensors or wearable devices to achieve remarkable results.However, the challenge in fine-grained sensing lies in finding a tradeoff between performance and availability. For instance, it is crucial to

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leverage a device-free manner due to convenience concern. In general, most prevailing solutions rely on dedicated sensors such as cameras RF tagsand accelerometers .

These solutions demand either toilsome installations or use of wearable devices. The camera-based methods provide highest granularity of activity recognition via computer vision algorithms, but the camerabased approaches are highly impacted by illumination and occlusion.More importantly, due to privacy concerns, it is usually not so acceptable in smart homes. Another good solution applies accelerometer equipped in most smart phones.Nevertheless, people do not necessarily carry cellphones or particular devices all the time under indoor circumstances. Radio frequency based approaches show their advantages in low consumption and device-free manner.

However, this kind of system requires many RF links in a single room, and the installation cost decreases its flexibility and availability. Some other solutions such as location-based methods need auxiliary information so that they cannot recognize precise activity happening in the same place.

Recently, it is observed that the motions of occupants impact the WiFi signals to some extent. Based on this insight, researchers manage to use Received Signal Strength Indicator (RSSI) and Channel State Information (CSI) to depict the human activity. WiFi based technology has three advantages compared with other methods. Firstly, it is tailored for practical deployment as a ubiquitous system.

As WiFi technique has been developed rapidly, the indoor coverage of wireless networks has become more and more widespread. Thus, we do not need to install specific sensors or RF

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links.Secondly, WiFi-based approaches employ thepattern extracting of wireless signals in the physical layer, and thus do not raise issues of privacy. Thirdly, it is able to provide relatively accurate sensing with minimal infrastructure

CHAPTER 2

2.1 BLOCK DIAGRAM: -

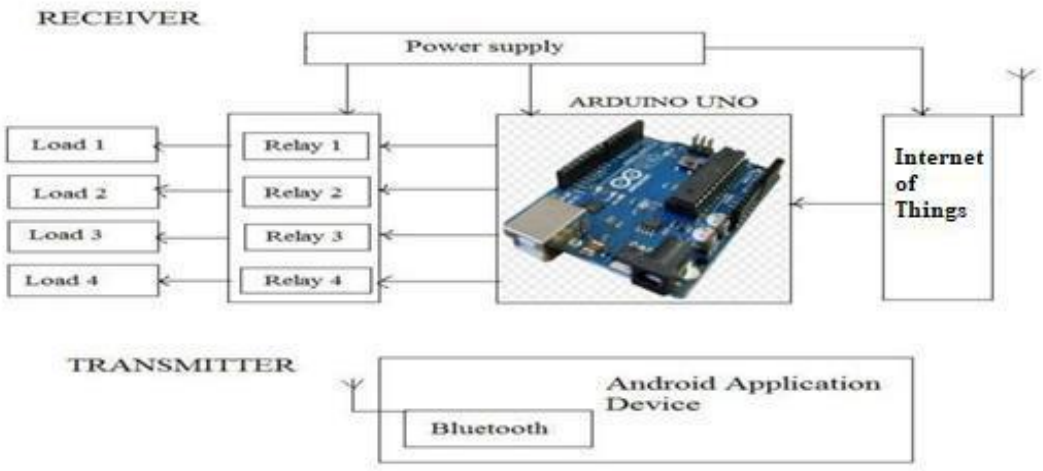

Fig:1 Block diagram

2.2 BLOCK DIAGRAM EXPLANATION: -

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which is a sensible trade-off between availability and performance. When WiFi-based methods are applied to practical use, there still remain several challenges such as scalability of platforms, and lack of resolutions of wireless signals, etc. In this paper, we address these challenging problems and present a novel technology that utilizes commercial off-theshelf

(COTS) Wi-Fi enabled IoT devices for occupancy sensing in smart homes. Our system employs the fine-grained CSI data from physical layer in the wireless connection between the transmitter (Tx) and receiver (Rx). It is designed for occupancy sensing with high scalability and performance, and it is composed of three parts, including an innovative IoT platform for sensing, cloud server for computing and user end for notification. We firstly upgrade OpenWrt system and enable it to report exquisite CSI on the IoT devices. Then according to different application, the data can be processed in either a coarse or fine-grained way. To demonstrate the performance of our system, we then develop and realize two challenging applications, referring to occupancy detection and human activity recognition. For applications of coarse sensing such as occupancy detection, we utilize CSI curve similarity to achieve the goal. It is completely implemented on the IoT devices.

For applications of fine-grained sensing such as activity recognition, we extract the features of activity by Class Estimated Basis Space Singular Value Decomposition (CSVD) and then conduct the classification using Nonnegative Matrix actorization (NMF).

CHAPTER 3

3.1 ARDUINO KIT: -

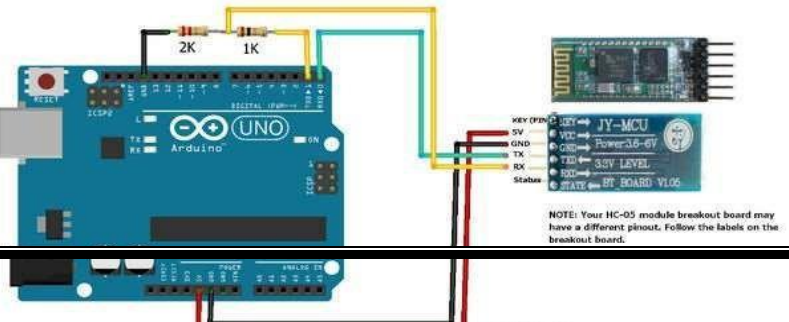

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Fig : 3.1 ARDUINO KIT

The evaluation in typical indoor environments shows that two applications achieve sensible performance in real time. Contributions: We summarize the main contributions of our work as follows: We design a WiFi-enabled IoT system for occupancy sensing. To the best of our knowledge, it is the first platform which completely integrates CSI-based WiFi devices, cloud server and user end. It makes a good tradeoff between performance and availability.

We upgrade the OpenWrt operating system with CSI reporting for COTS routers. The fine-grained CSI data and scalable platforms provides a good opportunity to promote existing applications of WiFi-based systems.

To demonstrate our framework, we elaborate a coarse sensing case, occupancy detection, based on similarity measurement of CSI curves, and realize it on the IoT device. As far as we know, it is the first WiFi-based application purely implemented on the router. _ For fine-grained sensing, we present an innovative CSVD-NMF based activity recognition algorithm.It provides a solution to automatically extract features and conduct classification in an efficient manner.

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We evaluate both the detection and recognition systems in terms of accuracy, robustness and scalability. The experimental results show the superiority of our platform. The rest of the paper is organized as follows. Section II gives a brief introduction to CSI and motivations for our work. Section III precisely describes the framework of our IoT platform. In section IV and V, we present our occupancy detection and recognition systems based on our platform and machine learning techniques.

Then the experiments and evaluations are conducted in terms of accuracy, robustness and scalability, illustrated in section VI. We compare our work with a few related advanced human sensing works in section VII. At last, we conclude our work and highlight some future trends in Section VIII.

3.2 PIN SPECIFICATION OF ARDUINO KIT :-

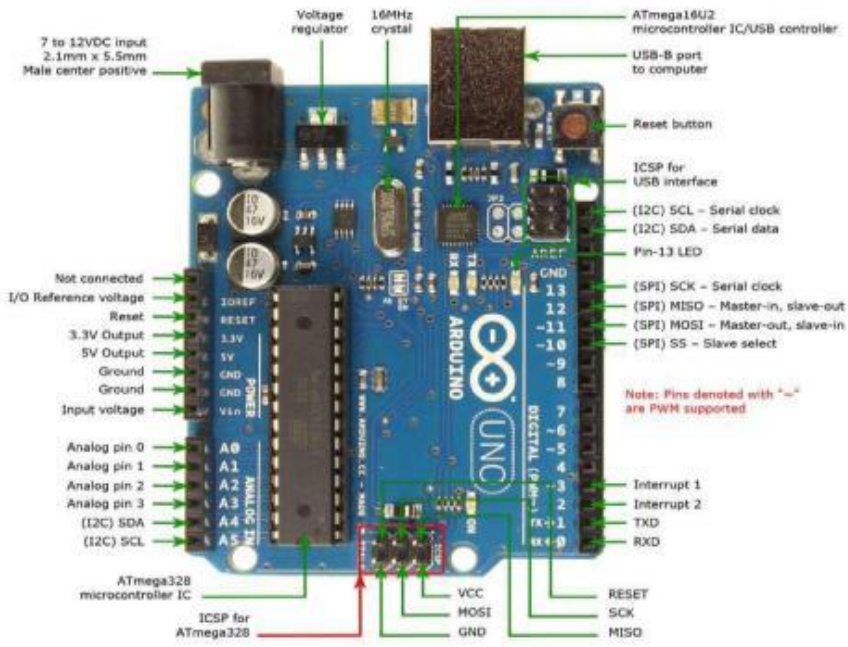

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Fig :3.2 PIN SPECIFICATION OF ARDUINO KIT

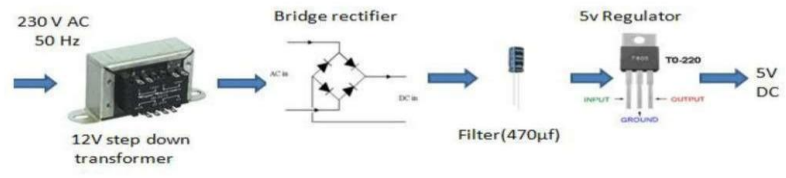
3.3 PRELIMINARY INVESTIGATIONS ON WIRELESS SIGNALS:

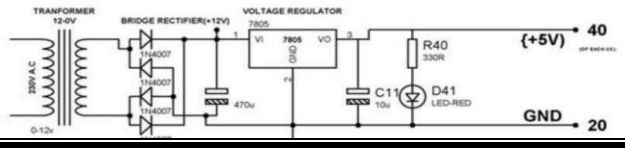
At the physical layer of wireless communications, RSSI and CSI are two kinds of useful information for environment perception. As RSSI only exhibits the propagation process by simple signal strength, the RSSI-based occupancy sensing cannot achieve satisfactory results.

Though state-of-the-art methods such as PAWS 15 make full use of RSSI, the accuracy of human activity recognition only reaches over 70%. In comparison, CSI is more fine-grained.which achieves effective result of recognition by training more than 1000 samples. However, in practice, some relatively static activities, such as sitting and lying, should also be considered, and the training phase is too tedious. In this section, we start with a brief introduction to CSI and expand the knowledge of how human activity affects wireless signals

CHAPTER 4

4.1 CIRCUIT DIAGRAM





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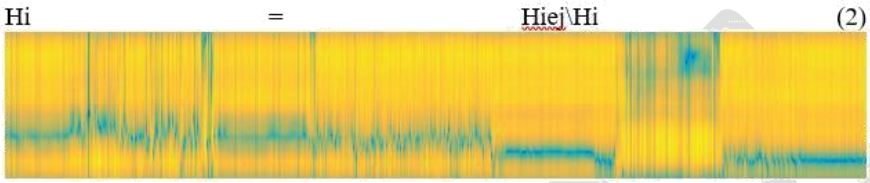

Fig :4.1 CIRCUIT DIAGRAM

Empty Walking Sitting Running Lying Standing Walking

A. Channel State Information In wireless communication, channel state information is a representation of the channel properties of a communication link. During the propagation of wireless signals, they are affected by physical environment, which leads to reflections, diffractions and scattering 21 .

These phenomena can be described by CSI. Modern WiFi devices adopt Orthogonal Frequency Division Multiplexing (OFDM) at the physical layer and obey IEEE 802.11n/ac standard that permits multiple transmit and receive antennas for multiple input, multiple output (MIMO) communication. Therefore, CSI reveals finegrained characteristics of wireless signals

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combining effect of time delay, amplitude attenuation and phase shift of multiple paths on each communication subcarrier.

Since RSSI is only a superimposition of multi-path signals, CSI naturally owns higher resolution. TheWiFi signals can be modeled as Channel Impulse Response (CIR) h in frequency domain:

h =XLl=1 _lej_l_ (l);X

where _l and _l represent the amplitude and phase of the l- th multi-path component respectively, _l is the time delay, L indicates the total number of multi-path and _(_) denotes the Dirac delta function. However, only clusters of multipath components are differentiable because of limited WiFi bandwidth.

In this case, the OFDM receiver provides a sampled version of the signal spectrum at subcarrier level, which comprises amplitude attenuation and phase shift via complex number. These estimations can be represented by: Hi = Hiej\Hi (2)

where Hi and \Hi are the amplitude and phase of i-th subcarrier respectively. Theoretically, CSI phase information is supposed to be more robust with less variations. Nevertheless, it is opposite due to hardware imperfections and environmental variations 22 .

The carrier frequency of a device can drift by up to 100kHz for 5GHz band. In practical applications, it brings about extreme complexity to accomplish calibration and denoising. Thus, we employ amplitude information to design our system. B. Insights: How Human Activity Affects Wireless Signals Due to multi-path effects, human motion causes the variations of

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wireless signals that are characterized by CSI amplitude To link the variation to common human activities, we conduct a preliminary experiment.

We deploy two TPLink N750 routers, each with one antenna, as transmitter (TX) and receiver (RX). The TX generates and sends packet every 2 milliseconds and the same frequency of reception in RX. The distance between them is 1.5 meters, and the number of subcarriers is 114 in 40Mhz bandwidth with 5G mode. As shown in Figure 1, a series of activities, including walking, sitting, running, lying and standing, can be revealed from the CSI stream, in which kinds of activities exhibit distinct statistical characteristics.

Moreover, we can even coarsely distinguish different activity from signals of a single noisy subcarrier. However, different part of human body impacts different subcarrier in one Tx-Rx pair, so we have to make full use of CSI data to recognize the activities more accurately.

However, in Figure 1, the human presence or not, such as empty and sitting, cannot be distinguished by time-domain variations. Inspired by multi-path effect and previous indoor localization work, we investigate the subcarrier difference of static activities shown in Figure 2. It reveals the frequency information of signal propagation and describes the static activities to some extent. We also find that as long as the layout of the room is fixed, this characteristic is pretty robust. Also, for more considerations, we ever test what degree of activity can result in the changes of wireless signals.

The dogs or cats movings are too subtle, which can be regarded as noise. In summary, the above results indicate that CSI is a finegrained reflection of the surrounding environment. We can summarize two key insights:

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1) Shape of CSI curve ! human presence: The subcarrier curve keeps stable under static circumstances but the occupancy presence affects it to some extent.

2) Time domain ! human activity information: Time domain analysis of CSI reveals the influence of different activities. Thus, statistical features can be extracted and used for representative learning.

CHAPTER 5

5.1 SYSTEM ARCHITECTURE: -

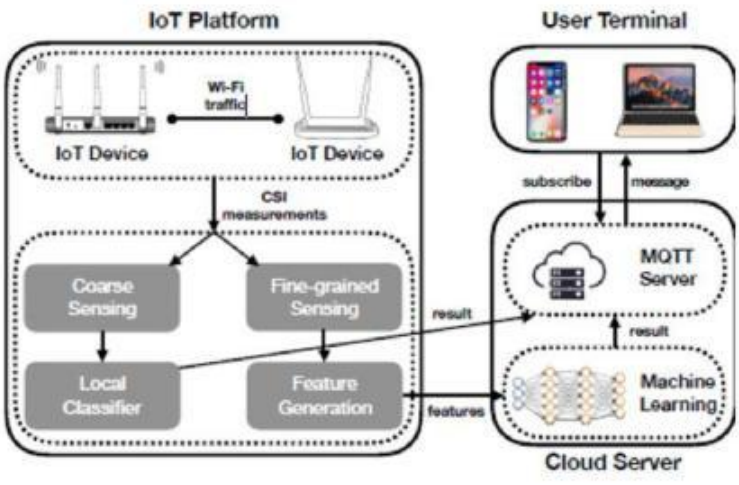

Fig : 5.1 SYSTEM ARCHITECTURE

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These insights will be utilized for occupancy detection in section IV and human recognition in section V respectively. To enable the applications built on the insights, we firstly present an agile IoT platform which optimizes the calculation and transmission resources.

5.2 AGILE WIFI-ENABLED IOT PLATFORM FOR

5.2.1 OCCUPANCY SENSING

In this section, we introduce our agile WiFi-enabled IoT platform for occupancy sensing, which consists of an IoT platform for WiFi device, cloud server for complex computations and user terminal for display of results. In the platform design, it is significant to ensure the real time with the consideration of network and computing overload. For example, if CSI measurements are transmitted to the server at a high sampling rate, the successive transmission will put a great deal of burden on the network of the server. Meanwhile, if we process every frame of CSI in the server, it may cause computing resource starvations. After initial experiments and investigations, we design our real-time occupancy sensing system shown in Figure 3, integrating embedded operating system OpenWrt, lightweight messaging prototype MQTT and cloud server.

The IoT platform refers to two devices supporting WiFi communication, which is installed our innovative OpenWrt firmware to get the capacity of reporting CSI from physical layer directly. To reduce the pressure on network transmission, we conduct some reasonable calculations on the device according to various applications, and these results are transmitted to the server for further processing. The cloud server is responsible for machine learning framework and message distribution as MQTT broker. The sensing results are finally displayed on the user terminal, such as laptops and mobile phones.

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A. IoT Platform the IoT platform takes charge of real-time collection of CSI and primary computations, which enables rapid and scalable deployment. Conventional CSI tools used in almost all researches of CSI based sensing, such as Intel 5300 NIC tool 16 or Atheros 9390 tool 23 , consist of a commodity.router as transmitter and a mini PC or specific devices with WiFi NIC card as receiver. Generally speaking, they are sufficient for research but not for practical applications.

There exist two limitations in terms of these platforms. Firstly, the receiver has to be laptops with specific network card, which restrains the practicability and scalability. For instance, Wang et al. employ more than 10 laptops as receivers in the implementation of an indoor localization system. The situation leads to high cost and inconvenience of maintenance, impeding the realization of large-scale systems. The second limitation lies in the resolution of CSI measurements.

Intel 5300 NIC tool 16 only provides CSI for 30 out of 56 subcarriers with 20Mhz bandwidth for each TX-RX pair. The CSI measurements are sampled which irreparably loses much necessary information in the physical layer. To deal with these bottlenecks, we upgrade the Atheros CSI Tool and develop a new firmware for OpenWrt system, which can be deployed in many COTS routers. Our platform only requires two devices with Atheros WiFi module, such as laptop, router and development board, which boosts the convenience and reduces the cost substantially. The CSI can be directly reported in the OpenWrt system.

We choose OpenWrt for it supports a great number of routers and boards. It is so lightweight that much redundancy of normal operating systems is removed. Equipped with the

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new firmware, the IoT devices have the ability to report fine-grained CSI with complete 114 subcarriers with 40Mhz bandwidth under 5Ghz.Moreover, we can directly conduct some essential computations on the IoT devices.

We aim at building a generic platform where kinds of applications can be developed without involving lots of efforts. Thus, we classify the tasks of occupancy sensing in smart homes into two categories, coarse and fine-grained sensing. To make full use of the computing resources on IoT devices and cloud server, we render our platform in two modes. For coarse sensing tasks including room-level localization and occupancy detection, the computational complexity is tolerable for IoT devices. We manage to implement the algorithms such as local classifier on the board to complete the task.

Then the device directly transmits the result to the server and let the users obtain real-time information without using the computing resources of the server. Fine-grained sensing tasks mainly refer to activity recognition and even gesture recognition.These works require advanced signal processing and machine learning techniques to achieve better performance, but it costs enormous computing resources. Furthermore, real-time transmission of CSI measurements can bring about network overload.

To tackle these challenges, we propose our recognition approach in Section V, which extracts features from selected CSI data in Equation 7 for transmission. Then the NMF-based classification is conducted in the cloud server.

This approach also works as for other state-of-the-art methods, which mostly extract statistical features (such as mean, minimum, entropy) on the device and then transmit them. B.

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Cloud Server and User Terminal With the rapid development of cloud computing, the cloud server has huge advantages in workload resiliency and stability. In our system, we employ the cloud server, which presides over machine learning computations as well as message forwarding. In order to optimize network communication between lightweight OpenWrt and the server, MQ Telemetry Transport (MQTT) is introduces in our system.

MQTT is an extremely simple lightweight messaging protocol, which is designed especially for constrained devices and low-bandwidth or high-latency networks. It has been successfully deployed in satellite links, medical and miniaturized devices 26 . With the help of MQTT, we manage to overcome the network overload.

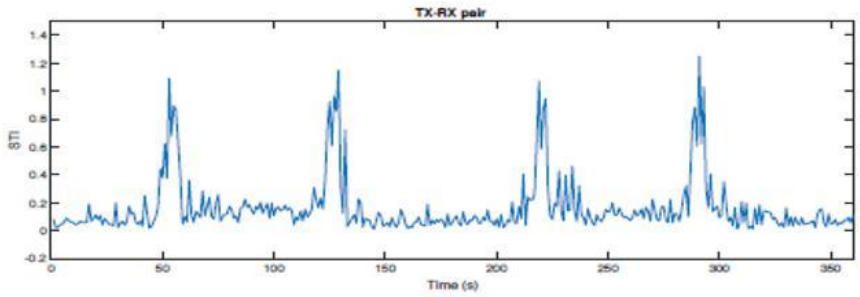

Fig :5.2.1

In MQTT, the message is transmitted via TCP/IP protocol and it provides bi-directional connections in order without prejudice. The MQTT is integrated in our system as follows:

There are three roles in MQTT, including publish, broker and subscribe. The cloud server, IoT platform and user terminal play the role of broker, publish and subscribe respectively. The cloud server (broker) forwards the specific message to the user (subscribe) when IoT

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platform (publish) pushes information to the cloud server. Our IoT platform (publish) generates sensing results and transmit the results to cloud server. Then the users (subscribe) are able to obtain required message. In our test, MQTT ensures the real-time notification in terms of IOS, Android and Web terminals.

For MQTT broker, it offers quality of service (QoS) regarding different clients. In our system, we enable the highest quality of service for transmission. _ MQTT messages are delivered via matching topic name, which is a tag in each message. The IoT and subscribed devices of same user share same topic name. By this way, we make it possible to deploy our system in large scale of users. After the MQTT pushes the message to the user terminal, the user interface should display real-time sensing results and be compatible with multi systems. In light of this, we develop the user interface based on Web, which supports most smart phones and laptops. Based on our innovative platform, we propose two novel approaches to realize real-time applications. The occupancy detection is regarded as coarse sensing case, and it is purely implemented on the IoT device. In comparison, human activity recognition is a fine-grained occupancy sensing technology, and its machine learning framework is running on the server.

5.3 COARSE SENSING: OCCUPANCY DETECTION

Precise detection of occupancy is indispensable to improve the efficiency of building management system (BMS) 27 . It can be utilized for intrusion detection in commercial area, thermal comfort adjustment in smart building and elderly monitoring at home. Traditional methods mostly rely on light, temperature and CO2 measurements 3 . Based on our IoT platform, we propose an occupancy detection application as a case study of coarse sensing.As mentioned

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in section II, we can know the situation of human presence by CSI subcarrier curves in Figure 2. Through further validation, the curve without any demising is stable, so we only need to explore a method to compare the shape similarity between adjacent CSI curves in time series. Hence, we employ signal tendency index (STI) 28 to compare the shape similarity of CSI curves. It owns the invariance of translation and scale so that it can compare the tendency and waveform from the statistical point of view. Suppose Ht1 ;Ht2; :::;Htn Is a CSI vector at timestamp t. STI superimposes these curves by optimally translating and uniformly scaling The translation step produces Ht1 _ Ht; Ht2

Ht;:::; Htn

H_t; (3)

where Ht = 1

n

Pn

i=1 Ht

i . Then comes the scaling step as

follows:

cHt = Ht1

_ Ht;Ht2 _ Ht; :::;Htn

H_t =_(Ht); (4)

where _(Ht) =

q

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i=1(Ht

i H_t)2. The transformed

object cHt can be used for similarity comparison. As we can derive Ht 1

in the same manner, it is simple to compute STI to compare two shapes

of vectors: St =

cHt Ht 1

(5)

where k_k denotes the Euclidean norm. Small S suggests that the two curves are similar while large one indicates that they are uncorrelated. As shown in Figure 4, the STI values with human presence are much higher than those under the unoccupied situations. We can infer that the shape similarity of CSI curves indeed makes a distinction between occupied and unoccupied situations. An empirical threshold thd = 0:8 selected through cross-validation is introduced to classify the situations. The whole algorithm of occupancy detection is described in Algorithm 1. We implement the prototype on the IoT device and demonstrate that each time of similarity computing can be completed at a frequency of 10Hz, which is sufficient for occupancy detection. The detailed evaluation in Section VI validates its robustness and effectiveness.

6.1 RELATED WORK

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In the recent few decades, occupancy sensing, especially human activity recognition, has aroused a great deal of attention in many research fields and its major objective is to sense and recognize occupant activities by extracting features from environmental sensors. Many approaches are proposed and they can be classified by their devices including wearable sensors, computer vision and WiFi. Each approach has advantages and disadvantages.

Wearable sensors such as accelerometer sensor are commonly used in mobile devices. Due to its high frequency and convenience, Chen and Zhu developed an effective algorithm to recognize human activities based on Principal Component Analysis (PCA) and Support Vector Machine (SVM) 12 . However, people may not carry mobile devices all the time. With the rapid development of computer vision, vision-based methods emerge and achieve high accuracy using deep learning and convolutional networks 7 , 36 . Though it achieves high accuracy of recognition, it can only detect a pretty limited range and it is easily affected by illumination and occlusion. In smart building, kinds of sensors are collected for human sensing including thermal sensors, CO2 sensors, etc 37 . Nevertheless, this kind of system requires large installing scale of sensors and thus brings about high cost. To attain a better trade-off between accuracy and cost, WiFibased methods come into existence.

They employ ubiquitous WiFi devices for activity recognition with high scalability and practicability. We present a brief summary and comparisons of several state-of-the-art methods in Table IV. We compare both RSSI-based and CSI- based methods in terms of activity, methodology, complexity, performance, scalability and practicability. RSSI-based methods, such

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as PAWS 15 , WiSee 38 , WiGest 39 , are effective ways to detect human activity but the accuracy is not satisfactory due to the restriction of resolution of RSSI.

Although our platform makes the CSI-based occupancy sensing take a stride forward, it is still limited by inherent characteristics of WiFi signals. Firstly, the sensing range is restricted by the coverage of WiFi signals. Secondly, for the activity recognition, multi-user cases require more TXRX pairs. For instance, the current settings in our multi-user experiment employ many routers, which are not cost-effective.

Whether one pair can detect multiple users will be one of our major work in the future. Anyway, this technology can be integrated with other systems such as camera-based methods, which can complement each other. We believe that a fusion solution could be convincing in achieving occupancy sensing with reliable performance.

6.2 Except these limitations, some concerns should also be noticed as follows:

Firstly, we might be worried about the health problem addressed by wireless signals. On the one hand, the health problem is a side effect indeed, as well as mobile phones and PCs. On the other hand, we leverage existing WiFi router deployed in smart homes, which can not only provide Internet connection but also sense the humans. The commercial routers accord with the international safety standard. If we install other devices such as RF or radar, the radiation will be more severe. Considering the existing WiFi infrastructures in homes, we believe that this technology is rather acceptable in reality. _ Secondly, the sensing data may occupy the network bandwidth.

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This can hamper the availability of our technology. Actually, the network traffic will suffer from our transmission and there exists a bandwidth loss. However, this is relevant to our package transmission rate. When we only extract CSI with 40Hz such as our method, we have not found any side effects of network traffic. Specifically, for 802.11n, the practical transmission speed is 100Mbps while our extraction of CSI with 342 subcarriers occupies only about 0.1Mbps. However, existing approaches improve the performance by increasing the transmission frequency, and consequently the traffic becomes worse.

For instance, previous methods 29 , 30 employs data with at least 2000Hz, which occupies at least 5Mbps and is not so acceptable using existing WiFi infrastructures.

7 CONCLUSION:-

In this paper, we design a CSI-enabled IoT platform for occupancy sensing in smart homes, and present two innovative applications based on it. Our platform only employs commodity WiFi routers and thus can be easily deployed in smart homes. It consists of three parts, referring to IoT platform, cloud server and user end.We firstly integrate OpenWrt system with CSI tools and then the CSI reported in the IoT devices will be transmitted to cloud server for processing. Finally, the results are displayed in the user end. To demonstrate the availability, we implement two cases including occupancy detection and human activity recognition. We present the coarse case, occupancy detection, by means of exploiting the CSI curve features in terms of the presence of persons.

It is completely realized in the IoT device and the evaluation shows an accuracy of 96.8% with 22Hz. For more fine-grained case, we present a CSVD-NMF based human activity

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recognition method, which aims to improve the extendability and robustness. The evaluation demonstrates that our method achieves more than 90% accuracy with only 20 training samples for each class. As a result, our platforms provide a significant opportunity to enable many CSI-based applications.

For the future work, we mainly consider multi-user situations and data fusion approach. It is possible to employ very costly access points and network cards, mini-controllers such as ESP8266. This can provide more connections and more detailed sensing data. As various sensing technologies can compensate for each other, it is believed that fine-grained sensing can be achieved by fusion of these approaches.

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