Contactless Sensing Using Intelligent Walls

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***Abstract*—Human activity monitoring is a fascinating field of study that can help the disabled and/or elderly patients to live independently. Different ways have been proposed to identify human activities, including using sensors, cameras, wearables, and non-contact microwave sensing. Microwave sensing has recently attracted a great deal of attention because of its ability to resolve the privacy problems associated with cameras and the discomfort produced by wearables. Existing microwave sensing approaches, however, have the fundamental problem of requiring regulated and perfect conditions for high-accuracy activity detections, which limits their widespread application in non-line-of-sight (Non-LOS) contexts. Intelligent wireless walls (IWW) are proposed to enable high-precision activity monitoring in complicated areas where standard microwave sensing is ineffective. The IWW is a reconfigurable intelligent surface (RIS) capable of beam steering and beamforming and incorporated with machine learning algorithms, can accurately and automatically recognise human behaviours. Two complicated environments were considered for the experiment: a corridor junction scenario in which the transmitter and receiver are located in distinct corridor sections and a multi-floor situation in which the transmitter and receiver are located on various building levels. Three separate bodily movements are evaluated in each of the environments: sitting, standing, and walking. Two individuals, one male and one female, performed these tasks in both scenarios. It is shown that IWW provides a maximum detection increase of 28% in a multi-floor situation and 25% in a corridor junction scenario when compared to conventional microwave sensing without RIS.**

Keywords—Intelligent Reflective Surface, RF sensing, Activity Monitering

I. INTRODUCTION

Contactless RF sensing is a promising technology that allows for the detection of objects without the need for physical contact. Hence, the technology can be utilized to monitor the activity of elderly and/or disabled patients . For example, it can be used to monitor a patient's vital signs [1], such as their heart rate and breathing rate, without the need for sensors to be attached to their body [2].

Existing RF sensing experiments rely on line-of-sight (LOS) between transmitter and receiver for macro-activity monitoring. This becomes challenging when both the transmitter and reciever are placed in the NLOS. The transmitted signal is backscattered from human body and due to the dielectric nature of the human body, the reflected signal tends to be noisy and extracting the variation from the signal can become extremely difficult. It becomes more challenging in a home environment because of the strong stationary clutter reflections. This would require advanced signal processing technique to extract the useful information making the system computationally intensive.

These limitations can be overcome by beamforming towards the target to enhance the sensing range and avoid interference. To this aim, a concept of intelligent wireless walls (IWW) is presented, which is based on reconfigurable intelligent surfaces (RISs) and machine learning algorithms to detect human activities with high resolution [3]. RIS are electromagnetic (EM) metasurfaces whose electrical and optical properties (i.e., surface-averaged susceptibility) are dynamically controlled, allowing EM waves to be steered in a desired direction.

II. RIS ARCHITECTURE

The RIS utilised during the experimental work is based on the unit cell recently published by the authors(s) in [4] and is depicted in Fig. 1a. The unit cells consist of 5 copper patches connected by 3 PIN diodes and a capacitor. The patches are etched onto a grounded F4BM-2 dielectric substrate with relative permittivity ε = 2.65 and loss tangent tanδ = 0.001. Fig.1c illustrates the 3-bit phase and magnitude response utilized for beamsteering.

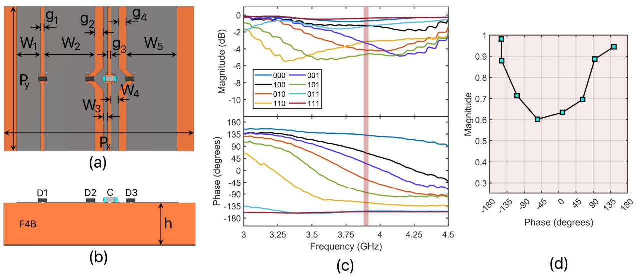

Fig. 1. Unit cell design for the IWW [4]: a) Front view, (b) PCB stackup, c) Measured reflection response versus frequency for eight phase states and (d) Phase versus magnitude response at 3.9 GHz

III. EXPERMENTAL SETUP

An activity monitoring experiment consisting of sitting, standing, walking and stationary position was performed. These activities were performed in two different scenarios, i.e., a right angled corridor junction and a multifloor environment with transmitter and receiver on different floors. In both the scenarios the transmitter and receivers were in the NLOS. The RIS was used as an intermidate node to direct the beam from the transmitter towards the reciever.

A. Corridor Junction

In this experiment the IWW was placed at the intersection of two corridors-namely zone A and zone B. The tranmistter was placed in zone A while receiver in zone B as shown in

Fig.2 The activites were performed in zone A near the receiver.

Fig. 3 illustrates the confusion matrix of ET algorithm in classifying all seven classes, i.e. sitting, standing, and walking of both participants and empty.

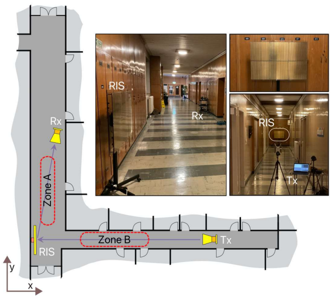

Fig. 2. NLOS corridor junction scenario [5]

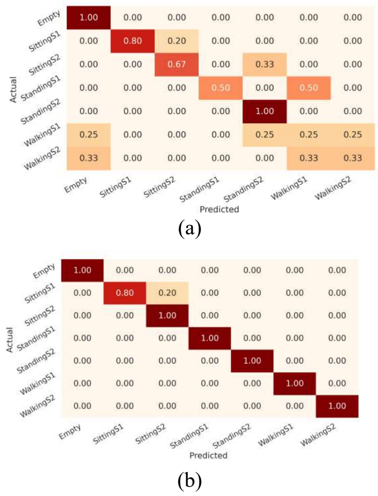

Fig. 3. Normalized confusion matrix of combined data samples in corridor junction scenario using train test evaluation method: a) RIS-off and b) RIS-on scenario

It can be noted from the confusion matrix that while RIS is off (Fig.3a) only a few classes are rightly classified. Further, walking activities of both participants are mostly wrongly classified. On the other hand, with RIS in the ON state, the classification accuracy increases for all classes (Fig. 3b). The maximum wrongly classified accuracy is for sitting activity of S1, which has only 20% incorrect classification.

B. *Multifloor Scenario*

In the second experiment the transmitter and receiver were placed on different floors. The IWW was placed on the same floor with the receiver. This can be seen in Fig.4. The same activities were repeated as in corridor junction scenario The results obtained are shown in Fig.5.

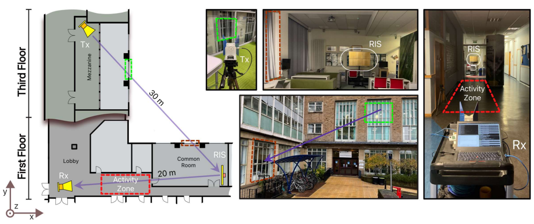

Fig. 4. NLOS multifloor scenario [5]

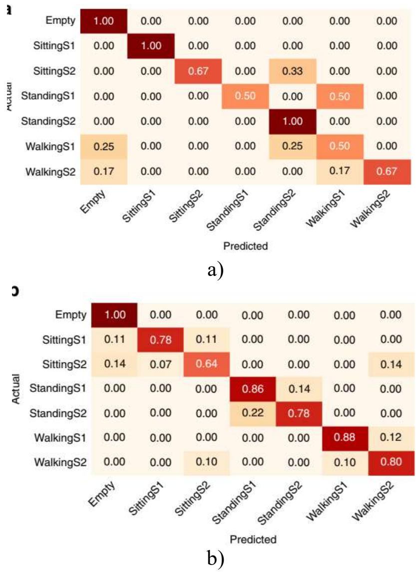

Fig. 5. Normalized confusion matrix of combined data samples in multifloor scenario using train test evaluation method: a) RIS-off and b) RIS-on scenario

Fig 5a represents the normalised confusion matrix while RIS is off and Fig. 5b represents the normalised confusion matrix while RIS is on. It can be noted from the confusion matrix that while RIS is off only few classes are rightly classified. Further, walking and standing activities of S2 are mostly wrongly classified. On the other hand, once RIS is turned on, the classification accuracy increases for all classes (Fig. 5b). In this case, the maximum wrongly classified accuracy is for sitting activity of S2, which has 26% incorrect classification

IV. Conclusion

This work demonstrates human activity monitoring experiment performed in NLOS scenarios. Four different activities including sitting, standing, walking and stationary movements were carried out. A IWW was used to direct the beam from transmitter to the receiver. The collected data from different activities were analyzed using machine learning algorithm. The result showed the efficacy of the IWW as an enabler to distinguish the various activites in NLOS and complex environment.

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