LITERATURE SURVEY

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Hand Gestures Recognition Using Radar Sensors for Human - Computer Interaction

Abstract: Human–Computer Interfaces (HCI) deals with the study of interface between humans and computers. The use of radar and other RF sensors to develop HCI based on Hand Gesture Recognition (HGR) has gained increasing attention over the past decade. Today, devices have built-in radars for recognizing and categorizing hand movements. In this article, we present the first ever review related to HGR using radar sensors. We review the available techniques for multi-domain hand gestures data representation for different signal processing and deep-learning-based HGR algorithms. We classify the radars used for HGR as pulsed and continuous-wave radars, and both the hardware and the algorithmic details of each category is presented in detail. Quantitative and qualitative analysis of ongoing trends related to radar-based HCI, and available radar hardware and algorithms is also presented. At the end, developed devices and applications based on gesturerecognition through radar are discussed. Limitations, future aspects and research directions related to this field are also discussed.

Keywords: hand-gesture recognition; pulsed radar; continuous-wave radars; human–computer interfaces; deep-learning for radar signals

Introduction

In recent years, computing technology has become embedded in every aspect of our daily lives and man–machine interaction is becoming inevitable. It is widely believed that computer and display technology will keep on progressing further. A gateway which allows humans to communicate with machines and computers is known as the human– computer interface (HCI) . Keyboard and mouse and touch-screen sensors are the traditional HCI approaches. However, these approaches are becoming a bottleneck for developing user friendly interfaces . Contrary to this, human gestures can be a more natural way of providing an interface between humans and computers. Short-range radars have the ability to detect micro-movements with high precision and accuracy . Radar sensors have shown potential in several research areas such as presence detection , vital sign monitoring , and Radio Frequency (RF) imaging purpose . Choi et al. used an Ultra-Wideband (UWB) Impulse Radar for indoor people counting.

Similar research presented by used milli-metric-wave radar for occupancy detection. In addition to this, radar sensors have shown their footprints in hand-motion sensing and dynamic HGR . The interest in radar-based gesture recognition has surged in recent years. Recently, radar sensors have been deployed in a network-fashion for the detection and classification of complex hand gestures to develop applications such as the wireless keyboard .

In the aforementioned study , in-air movement of the hand was recorded with three UWB radars and a tracking algorithm was used to type 0–9 counting digits in the air. Another study published by same authors presented a continuous alphabet writing based on the gestures drawn in front of two radars . A work presented by Ahmed and Cho (2020) demonstrated a performance comparison of different Deep Convolutional Neural Network (DCNN)-based deep-learning algorithms using multiple radars. In addition to that, hand gesture recognition through radar technology also found application in the operating room to assist medical staff in processing and manipulating medical images .

Based on the transmitted signal, short-range radar sensors used for HGR can broadly be categorized as pulsed radar and continuous-wave (CW) radar. This categorization has been adopted previously in several radarprelated review articles for applications other than HGR . Pulsed radar, such as Ultra-Wideband Impulse-Radar (UWB-IR), transmits short duration pulses, whereas continuous-wave radar, such as Frequency Modulated Continuous Wave (FMCW) radar, transmits and receives a continuous wave. Both these radars are widely used for HGR purposes.

Understanding Human Gestures

Prior to making HCI, an understanding of the term “Gestures” is important. Researchers in defined a gesture as a movement of any body part such as arms, hands and face in order to convey information. This nonverbal communication constitutes up to two thirds of all communication among the humans . Amongst the different body parts, hand gestures are widely used for constructing interactive HCIs . 44% of studies focused on developing HCIs using hand, multiple hand and finger movements. Hand gestures are an important part of non-verbal communication in our daily life, and we extensively use hand gestures for communication purposes such as pointing towards an object and conveying information about shape and space. Utilizing hand movements as an input source instead of a keyboard and mouse can help people to communicate with computers in more easy and intuitive way. HGR systems have also found many applications in environments which demand contactless interaction with machinery, such as hospital surgery rooms to prevent the spread of viruses and germs. As a result, contactless HCI can be a safe means of man–machine interaction in epidemiological situations such as MERS and the recent and ongoing COVID-19 outbreaks.

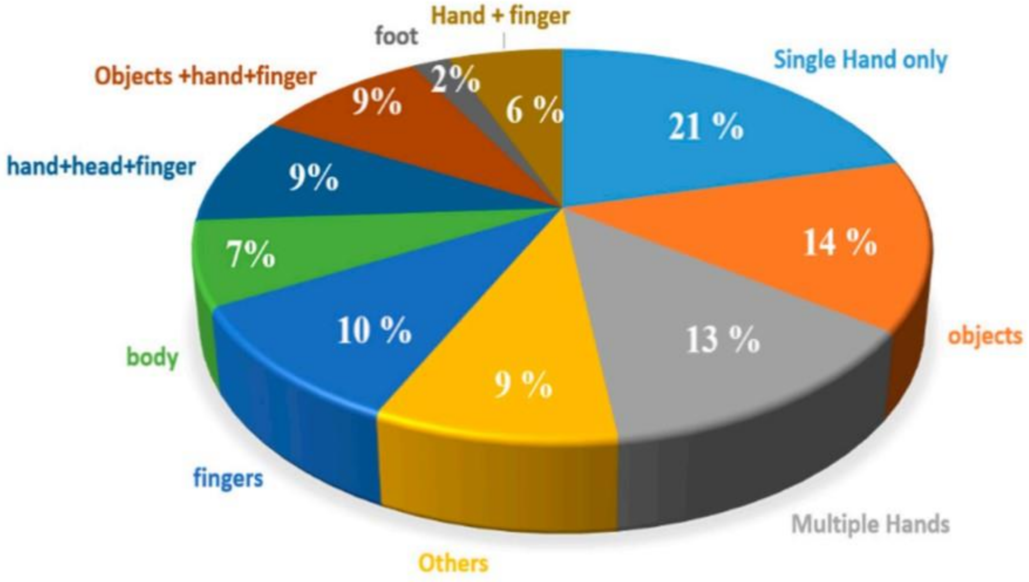

Figure 1. Usage of different body parts to make a human–computer interface (HCI)

Hand-Gesture Based HCI Design

The system overview of hand-gesture-based HCI development. First, a neural spike is produced in the brain, which generates a signal that results in a voluntarily motion of the hand. Various studies have tried to decode the brain signal corresponding to hand movement and these signals can be seen through electrocorticography . To detect the hand movements, several sensors exist, such as camera, depth camera, and radio sensors. The signal at the output of these sensors is analyzed using suitable algorithmic techniques to detect a predefined hand gesture. Researchers have either used signal-processing-based techniques , or machine-learning- and deep-learning-g-based techniques . After successfully recognizing the desired hand-movements, these gesture-based systems can be used to build different applications such as gaming and robot controller. a wide range of sensors are available for acquiring signals against the performed hand gesture, and radar sensor is one of the candidate solutions. Traditionally, optical sensors (camera), and wearable sensors (gloves) are widely used. These sensors can be classified as wearable and non-wearable

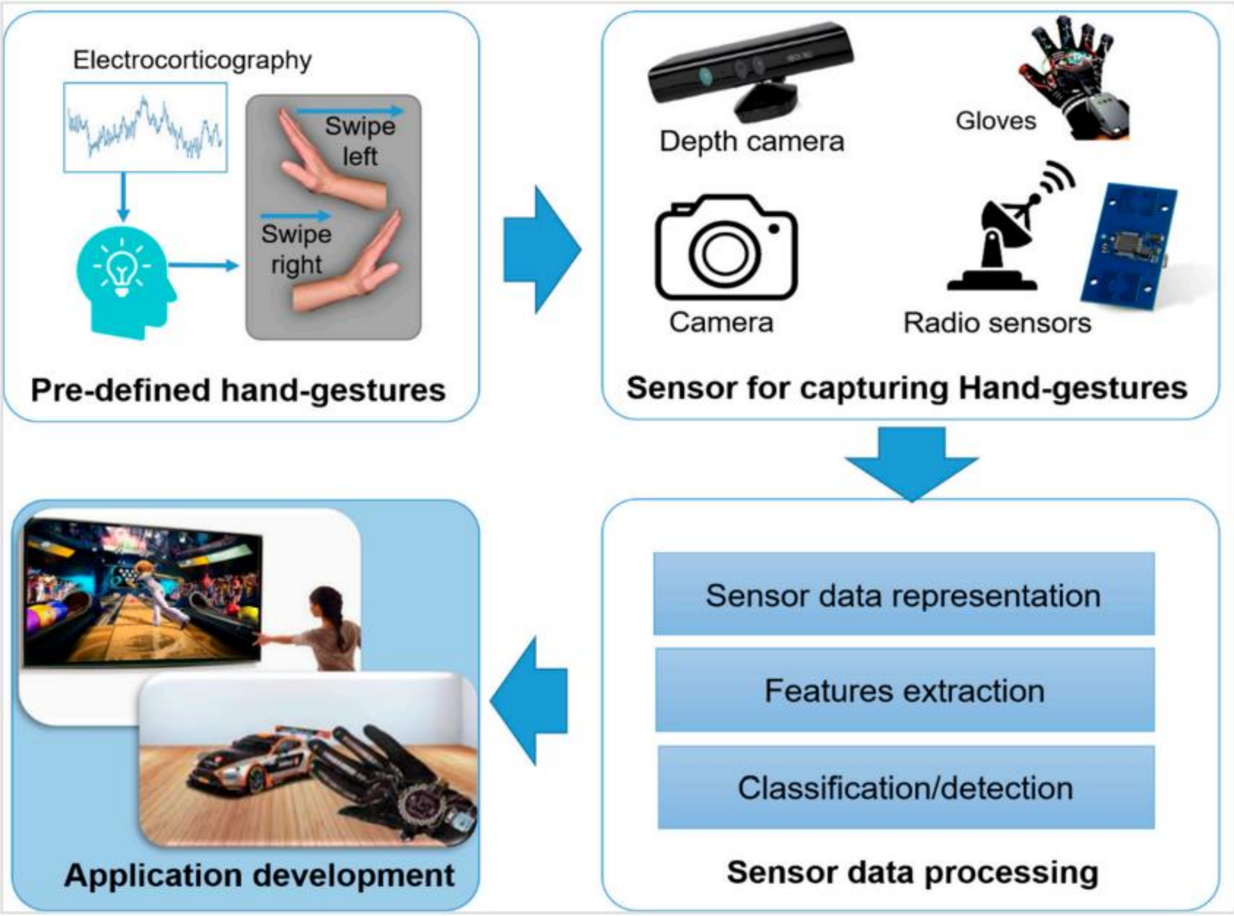

Figure 2. Pipeline of hand gesture recognition (HGR)-based HCI design. User performs pre-defined hand gestures, the performed gesture is captured with different sensors, sensor data are digitized and formatted in an appropriate way and finally, the devices are controlled.

The comparison of existing wearable and non-wearable (wireless) sensors used for recognizing hand gestures. It can be seen that both types of technology possess their own strengths and weaknesses and can be selected according to the requirements of the application in consideration. Both the radar and the cameras provide a wireless interface for gesture recognition. Radar sensors have several benefits over camera-based recognition systems for gesture recognition. Radar sensors have several benefits over camera-based recognition systems . Radar is not affected by lightning condition.

After data acquisition, the next step is processing the data and recognizing hand gestures. This includes data representation, useful features extraction, and classification. The classification can be performed by using signal-processing approaches, traditional machine-learning approaches or deep-learning approaches . One of the earliest uses of radar for gesture recognition was introduced in 2009 . This research primarily focused on activity classification along with gesture classification. Zheng et al. in 2013, presented hand gesture classification using multiple Doppler radars. In the beginning, for detection and recognition, researchers relied heavily on techniques based on the analysis and manipulation of the received radar signal and, later, the focus shifted towards machine-learning- and deep-learning-based classification techniques .The overall workflow of HGR through radar.

Based on the literature survey, it was observed that the task of radar-based HGR can be further classified into three different sub-tasks:

1. Hand-gesture movement acquisition, where one of the available radar technologies is chosen.

2. Pre-processing the received signal, which involves pre-filtering followed by a data formatting which depends on step 3. For example, the 1D, 2D, and 3D deep Convolutional Neural Network (DCNN) will, respectively, require data to be in a 1D, 2D or 3D shape.

3. The final step of hand-gesture classification is similar to any other classification problem, where the input data are classified using a suitable classifier.

Main Contribution and Scope of Article

This article provides a comprehensive survey and analysis of the available literature for HGR through radar sensors. Previously, Li et al. discussed a couple of studies related to the use of radar for gesture recognition while reviewing applications of portable radars. However, to the best of the authors' knowledge, there is no review article for HGR through radar sensor. Researchers have previously reviewed camera- and optical-sensor based HGR systems only . The main contributions and scope of analysis can be defined as follows:

• We provide a first ever comprehensive review of the available radar-based HGR systems.

• We have discussed different available radar technologies to comprehend their similarities and differences. All the aspects related to HGR recognition, including data acquisition, data representation, data preprocessing and classification, are explained in detail.

• We explained the radar-recorded hand-gesture data representation techniques for 1D, 2D and 3D classifiers. Based on this data representation, details of the available HGR algorithms are discussed;

• Finally, details related to application-oriented HGR research works are also presented;

• Several trends and survey analyses are also included.

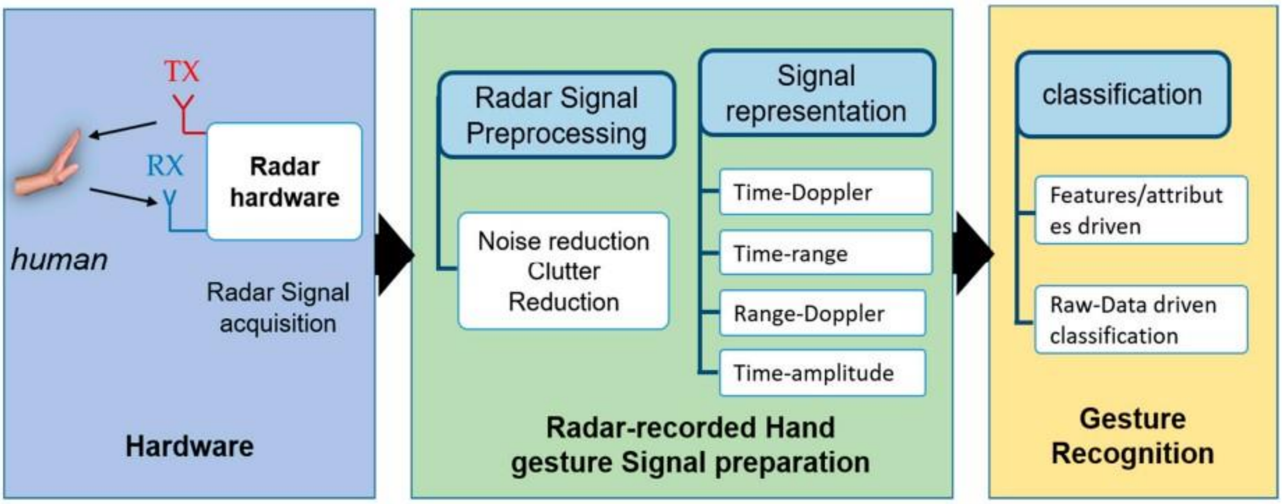

Figure 3. HCI with radar-recorded hand-gestures as an input: Predefined hand gesture is performed by users in radar cross-sectional area. This signal is passed through a clutter reduction filter and the signal is represented in any of the mentioned signal representation schema. Finally, recognition is performed.

Conclusion

A huge upsurge and rapid advancement of radar-based HGR was witnessed in the past decade. This paper reviewed some of the research related to HGR applications using radars. Currently, the researchers rely heavily on the commercially available radars made by tech companies such as Infenion, Novelda and Texas Instrument. With these systems being on chips, much attention has been paid to develop the gesture detection and recognition algorithms. In recent years, interest is shifting from signal-processing-based HGR algorithms to deep-learning-based algorithms. Particularly, variants of CNN have shown promising applicability. Although radar sensors offer several advantages over the other HGR sensors (i.e., wearable sensors and cameras), the adoption of radar-based HGR in our daily lives is still lagging behind these competing technologies. Attention must be paid to miniature hardware development and real-time recognition algorithms' development.