Real-Time Gesture Detection Based on Machine Learning Classification of Continuous Wave Radar Signals

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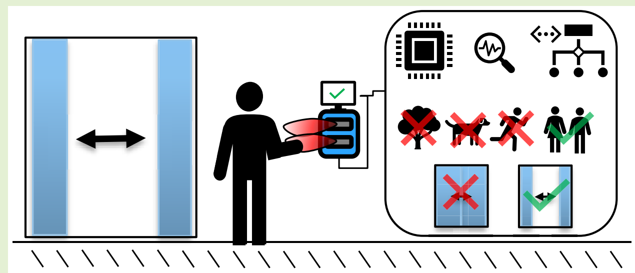
***Abstract*—Classical signal processing methodologies have been infiltrated by machine learning (ML) approaches for a long time, where the ML approaches are in particular applied when it comes to gesture recognition. In this paper, we investigate naïve gesture recognition methodologies and compare classical and novel machine learning (nML) algorithms. The considered gestures are simple human gestures such as swiping a hand or kicking with a foot. For the sake of comparability, the algorithms are assessed with respect to their true positive rate (TPR), false-positive rate (FPR), their real-time capability together with the required computational power, and their implementability on low-cost hardware. Two different data sets are utilized separately for the training process of the ML algorithms, where both have been recorded by making use of low-cost radar hardware. The results show that all ML approaches are superior to naïve gesture recognition methodologies, e.g., threshold detection. ML algorithms allow almost assured gesture detection. However, our primary contribution is a design approach for scalable neural networks (NNs) that allow such gesture recognition algorithms to be executable on low-cost microcontroller units (MCUs).**



***Index Terms*—Gesture recognition, radar, machine learning, neural networks, real-time, embedded hardware.**

I. Introduction

Gestures are an essential yet mostly unrecognized part of our daily lives, most of the time they are utilized automatically and without any thinking. Every day we wave a friend good-bye, or we say no by a small finger-swing. All of these gestures and countless more are easy to recognize and interpret by humans and many of them even by animals (naturally apart from cultural and/or geographical gesture-conflicts and/or -ambiguities). The field of human gesture recognition does not only offer human-to-human or human-to-animal interaction and communication but also human-to-machine. Motion based gestures, such as a hand wave, can be recognized by machines with different sensor principles. A gesture can, for example, be detected optically with cameras [1]–[7], by employing lasers [8], [9], or by hybrid systems [10]–[12] which combine both approaches. Furthermore, it is possible to detect gestures based on radar echoes [13]–[24]. The advantage of radar systems compared to optical systems is complex: on the one hand, camera-based gesture recognition is more computationally expensive and, on the other hand, cameras are heavily dependent on weather and light conditions. Furthermore, radar systems are robust against light and weather conditions and the signals can be evaluated efficiently due to their lower resolution and are in no way inferior to cameras in terms of evaluation performance with simple gestures [25]. In general, gesture recognition by using radar signals is in the process to revolutionize the interaction of people with all kinds of electronic devices. Recently published patents, in particular by *Google LLC* [18], [20], make it irrevocably clear that in the future we might be able to control all of our computer programs, apps, games, and all imaginable systems comfortably with our hands, contactless. This can efficiently be performed with all three introduced sensor principles (camera, laser, radar), where this work is going to focus on realizing gesture recognition with radar systems. Categorizing gestures is a complex task, since gestures can be fundamentally different dependent on the

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