

On Edge Human Action Recognition Using Radar-Based Sensing and Deep Learning

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Abstract—In this article, we propose a radar-based human action recognition system, capable of recognizing actions in real time. Range-Doppler maps extracted from a low-cost frequency-modulated continuous wave (FMCW) radar are fed into a deep neural network. The system is deployed on an edge device. The results show that the system can recognize five human actions with an accuracy of 93.2% and an inference time of 2.95 s. Raising an alarm when a harmful action happens is a crucial feature in an indoor safety application. Thus, the performance during the binary classification, i.e., fall vs nonfall actions, is also assessed, achieving an accuracy of 96.8% with a false-negative rate of 4%. To find the best tradeoff between accuracy and computational cost, the energy precision ratio of the system deployed on the edge is measured. The system achieves a 1.04 energy precision ratio value, where an ideal ratio would be close to zero.

Index Terms—Action recognition, deep neural networks (DNNs), edge deployment, frequency-modulated continuous wave (FMCW) radar.

I. INTRODUCTION

FALLS are a major public health concern and the main cause of accidental death in the senior population worldwide. Timely and accurate detection permits immediate assistance after a fall and, thereby, reduces complications of fall risk [1]. Edge-based approaches are essential to support time-dependent healthcare applications [2].

Due to the advantages of portability, low cost, and availability, wearable devices are regarded as one of the key types of sensors

for fall detection and have been widely studied [3], [4], [5], [6]. The main drawback of these systems is the battery life which can limit the usability of the wearable devices. The second drawback is that the monitored subjects must always wear them, causing obvious discomfort, especially for the elderly.

Vision-based fall detection is another prominent method. Extensive effort in this direction has been demonstrated, showing promising results [7], [8], [9]. Although cameras are not as portable as wearable devices, they offer other advantages that deem them as decent options depending on the scenario: most static RGB cameras are not intrusive and wired, hence there is no need to worry about battery limitations. One major drawback of vision-based detection is the potential violation of privacy due to the levels of detail that cameras can capture, such as personal information, appearance, and visuals of the living environment. The second drawback is the high sensibility to clutters and environmental conditions (e.g., smoke, light, etc.). In addition, a vision-based approach could introduce issues related to color bias [10].

Ambient sensors (e.g., ultrasonic, WiFi antennas, radars, etc.) provide another nonintrusive means of fall detection. Ambient sensing is drawing more attention which can be attributed to being device-free for users and can solve the problem of people's privacy and color bias. Ultrasonic sensor network systems are one of the solutions for fall detection [11]. One drawback is that the waves are affected by environmental factors, such as humidity and smoke. These would affect the accuracy of the measurement. In [12], a fall detection approach uses WiFi signals, showing promising results in detecting falls. This approach is susceptible to security threats and has a limited range of efficiency.

Radars have become popular in recent years, proving to be an effective sensor to recognize human actions in cluttered environments [13]. In [14] and [15], the human action recognition is performed by a machine learning (ML) algorithm trained on hand-crafted features extracted from the radar signals. The main drawback is the time and effort required for the processing of the data and the feature extraction operation. Some other works propose deep neural networks (DNNs) to automatically extract features for human action recognition and fall detection. In [16], stack autoencoders (AEs) are used to automatically extract the features from the gray-scale spectrogram and to classify four activities including the fall. In [17], the authors combine convolutional neural networks (CNNs) and AEs to classify 12 actions based on micro-Doppler signatures. In [18], two DNNs

Manuscript received 3 August 2022; revised 6 March 2023; accepted 28 August 2023. Paper no. TII-22-3382. The paper has been submitted on 3rd August 2022 and accepted on 28th August 2023. (Corresponding author: Ammar Mohanna.)

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All the codes and data used in the work are available on GitHub: <https://github.com/cosmiclabunige/ActionRecognition>.

Color versions of one or more figures in this article are available at <https://doi.org/10.1109/TII.2023.3316164>.

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Table of Contents Edge Of Human

1. Understanding the eBook Edge Of Human
 - The Rise of Digital Reading Edge Of Human
 - Advantages of eBooks Over Traditional Books
2. Identifying Edge Of Human
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Edge Of Human
 - User-Friendly Interface
4. Exploring eBook Recommendations from Edge Of Human
 - Personalized Recommendations
 - Edge Of Human User Reviews and Ratings
 - Edge Of Human and Bestseller Lists
5. Accessing Edge Of Human Free and Paid eBooks

-
- Edge Of Human Public Domain eBooks
 - Edge Of Human eBook Subscription Services
 - Edge Of Human Budget-Friendly Options
6. Navigating Edge Of Human eBook Formats
 - ePub, PDF, MOBI, and More
 - Edge Of Human Compatibility with Devices
 - Edge Of Human Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Edge Of Human
 - Highlighting and Note-Taking Edge Of Human
 - Interactive Elements Edge Of Human
 8. Staying Engaged with Edge Of Human
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Edge Of Human
 9. Balancing eBooks and Physical Books Edge Of Human
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Edge Of Human
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Edge Of Human
 - Setting Reading Goals Edge Of Human
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Edge Of Human
 - Fact-Checking eBook Content of Edge Of Human
 - Distinguishing Credible Sources
 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

-
- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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



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

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