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Editorial

Advanced Sensing Techniques for Intelligent Human Activity Recognition Using Machine Learning

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1. Introduction

State-of-the-art network architectures ensure fast and dependable real-time communication with abundant data and minimal delays [1,2]. This technology has the potential to transform various fields, such as remote healthcare monitoring, agriculture technology, cyber security, transportation, and so on.

In the healthcare domain, radio sensing is progressing towards achieving reliable detection, specifically for human activity recognition [1,3], detecting events such as falls, respiratory rate, cardiac activity, and so on. Radio-based communication systems offer capabilities such as high data rates, elevated carrier frequencies, expanded system capacities, adaptable hardware systems [4–6], and the ability to focus energy radiation in specific areas, such as beamforming.

Indoor localization encounters challenges stemming from environmental factors such as noise, signal distortions, and physical obstructions such as furniture. These complexities must be carefully considered when implementing indoor localization systems.

In recent years, significant progress has been made in indoor localization, driven by advancements in wireless communication, computational capabilities, and various sensing techniques [7]. Context-aware systems, wearable technologies, and non-contact methods represent notable approaches for recognizing human activities within indoor environments [8,9].

One intriguing approach involves leveraging devices worn by users to detect their behaviors while preserving their privacy. Context-aware systems employ an array of sensors, including microphones, cameras, and other sensor types. However, these systems face limitations in tracking activities once a user exits the surveillance zone. Notably, video surveillance systems fall within the context-aware technology category, but pose privacy concerns for patients, particularly in healthcare settings.

Conversely, outdoor localization has benefited from cutting-edge satellite positioning technologies like GPS, delivering highly accurate location services. However, indoors, the precision of location services diminishes due to weak signals and limited signal penetration.

To address indoor localization challenges, researchers have proposed various technologies, including RF identification (RFID), Ultra-Wideband (UWB), Bluetooth, Wi-Fi, light-based solutions, and audio-based methods. Given the prevalence of Wi-Fi infrastructure in many households, this article opts for RF-based Wi-Fi sensing [10] to obviate the need for additional sensing technologies. RF sensing systems exhibit variations in hardware requirements, operating frequencies, classification techniques, monitored activity types, and target subjects.

Two prominent methods employed by tracking systems for RF-based activity identification are Channel State Information (CSI) and Received Signal Strength Indicator (RSSI).

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These techniques [11] enhance the accuracy and effectiveness of indoor localization systems by harnessing the properties of radio frequency signals.

This Special Issue's editorial review process accepted 12 high-quality manuscripts focusing on human activity recognition using different technologies, algorithms, systems and so on. Notable articles include:

2. Article: RL-SSI Model: Adapting a Supervised Learning Approach to a Semi-Supervised Approach for Human Action Recognition: Published in [12]

This article takes into account, the action recognition task requires a vast amount of labeled data, which represents a time-consuming human annotation effort. To mitigate the dependency on labeled data, this study proposes Semi-Supervised and Iterative Reinforcement Learning (RL-SSI), which adapts a supervised approach that uses 100% labeled data to a semi-supervised and iterative approach using reinforcement learning for human action recognition in videos. The JIGSAWS and Breakfast datasets were used to evaluate the RL-SSI model, because they are commonly used in the action segmentation task. The same applies to the performance metrics used in this work-F-Score (F1) and Edit Score-which are commonly applied for such tasks. In JIGSAWS tests, we observed that the RL-SSI outperformed previously developed state-of-the-art techniques in all quantitative measures, while using only 65% of the labeled data. When analysing the Breakfast tests, we compared the effectiveness of RL-SSI with the results of the self-supervised technique called SSTDA. We have found that RL-SSI outperformed SSTDA with an accuracy of 66.44% versus 65.8%, but RL-SSI was surpassed by the F1@10 segmentation measure, which presented an accuracy of 67.33% versus 69.3% for SSTDA. Despite this, our experiment only used 55.8% of the labeled data, while SSTDA used 65%. We conclude that our approach outperformed equivalent supervised learning methods and is comparable to SSTDA, when evaluated on multiple datasets of human action recognition, proving to be an important innovative method to successfully building solutions to reduce the amount of fully labeled data, leveraging the work of human specialists in the task of data labeling of videos, and their respectives frames, for human action recognition, thus reducing the required resources to accomplish it.

3. Article: Wi-Fi-Based Location-Independent Human Activity Recognition with Attention Mechanism Enhanced Method: Published in [13]

This article takes into account, Wi-Fi-based human activity recognition is emerging as a crucial supporting technology for various applications. Although great success has been achieved for location-dependent recognition tasks, it depends on adequate data collection, which is particularly laborious and time-consuming, being impractical for actual application scenarios. Therefore, mitigating the adverse impact on performance due to location variations with the restricted data samples is still a challenging issue. In this paper, we provide a location-independent human activity recognition approach. Specifically, aiming to adapt the model well across locations with quite limited samples, we propose a Channel–Time–Subcarrier Attention Mechanism (CTS-AM) enhanced few-shot learning method that fulfills the feature representation and recognition tasks. Consequently, the generalization capability of the model is significantly improved. Extensive experiments show that more than 90% average accuracy for location-independent human activity recognition can be achieved when very few samples are available.

4. Article: Effective Voting Ensemble of Homogenous Ensembling with Multiple Attribute-Selection Approaches for Improved Identification of Thyroid Disorder: Published in [14]

This article takes into account, Thyroid disease is characterized by abnormal development of glandular tissue on the periphery of the thyroid gland. Thyroid disease occurs when this gland produces an abnormally high or low level of hormones, with hyperthyroidism (active thyroid gland) and hypothyroidism (inactive thyroid gland) being the two most common types. The purpose of this work was to create an efficient homogeneous

ensemble of ensembles in conjunction with numerous feature-selection methodologies for the improved detection of thyroid disorder. The dataset employed is based on real-time thyroid information obtained from the District Head Quarter (DHQ) teaching hospital, Dera Ghazi (DG) Khan, Pakistan. Following the necessary preprocessing steps, three types of attribute-selection strategies; Select From Model (SFM), Select K-Best (SKB), and Recursive Feature Elimination (RFE) were used. Decision Tree (DT), Gradient Boosting (GB), Logistic Regression (LR), and Random Forest (RF) classifiers were used as promising feature estimators. The homogeneous ensembling activated the bagging- and boosting-based classifiers, which were then classified by the Voting ensemble using both soft and hard voting. Accuracy, sensitivity, mean square error, hamming loss, and other performance assessment metrics have been adopted. The experimental results indicate the optimum applicability of the proposed strategy for improved thyroid ailment identification. All of the employed approaches achieved 100% accuracy with a small feature set. In terms of accuracy and computational cost, the presented findings outperformed similar benchmark models in its domain.

5. Article: Human Action Recognition of Spatiotemporal Parameters for Skeleton Sequences Using MTLN Feature Learning Framework in [15]

This article takes into account, Human action recognition (HAR) by skeleton data is considered a potential research aspect in computer vision. Three-dimensional HAR with skeleton data has been used commonly because of its effective and efficient results. Several models have been developed for learning spatiotemporal parameters from skeleton sequences. However, two critical problems exist: (1) previous skeleton sequences were created by connecting different joints with a static order; (2) earlier methods were not efficient enough to focus on valuable joints. Specifically, this study aimed to (1) demonstrate the ability of convolutional neural networks to learn spatiotemporal parameters of skeleton sequences from different frames of human action, and (2) to combine the process of all frames created by different human actions and fit in the spatial structure information necessary for action recognition, using multi-task learning networks (MTLNs). The results were significantly improved compared with existing models by executing the proposed model on an NTU RGB+D dataset, an SYSU dataset, and an SBU Kinetic Interaction dataset. We further implemented our model on noisy expected poses from subgroups of the Kinetics dataset and the UCF101 dataset. The experimental results also showed significant improvement using our proposed model.

6. Article: Noninvasive Detection of Respiratory Disorder Due to COVID-19 at the Early Stages in Saudi Arabia in [16]

The Kingdom of Saudi Arabia has suffered from COVID-19 disease as part of the global pandemic due to severe acute respiratory syndrome coronavirus 2. The economy of Saudi Arabia also suffered a heavy impact. Several measures were taken to help mitigate its impact and stimulate the economy. In this context, we present a safe and secure WiFi-sensing-based COVID-19 monitoring system exploiting commercially available low-cost wireless devices that can be deployed in different indoor settings within Saudi Arabia. We extracted different activities of daily living and respiratory rates from ubiquitous WiFi signals in terms of channel state information (CSI) and secured them from unauthorized access through permutation and diffusion with multiple substitution boxes using chaos theory. The experiments were performed on healthy participants. We used the variances of the amplitude information of the CSI data and evaluated their security using several security parameters such as the correlation coefficient, mean-squared error (MSE), peak-signal-to-noise ratio (PSNR), entropy, number of pixel change rate (NPCR), and unified average change intensity (UACI). These security metrics, for example, lower correlation and higher entropy, indicate stronger security of the proposed encryption method. Moreover, the NPCR and UACI values were higher than 99% and 30, respectively, which also confirmed the security strength of the encrypted information.

7. Article: Arm Swing Asymmetry Measurement from 2D Gait Videos in [17]

Arm swing during gait has been positively related to gait stability and gait efficiency, particularly in the presence of neurological disorders that affect locomotion. However, most gait studies have focused on lower extremities, while arm swing usually remains ignored. In addition, these studies are mostly based on costly, highly-specialized vision systems or on wearable devices which, despite their popularity among researchers and specialists, are still relatively uncommon for the general population. This work proposes a way of estimating arm swing asymmetry from a single 2D gait video. First, two silhouette-based representations that separately capture motion data from both arms were built. Second, a measure to quantify arm swing energy from such a representation was introduced, producing two side-dependent motion measurements. Third, an arm swing asymmetry index was obtained. The method was validated on two public datasets, one with 68 healthy subjects walking normally and one with 10 healthy subjects simulating different styles of arm swing asymmetry. The validity of the asymmetry index at capturing different arm swing patterns was assessed by two non-parametric tests: the Mann–Whitney U test and the Wilcoxon signed-rank test. The so-called physiological asymmetry was observed on the normal gait sequences of both datasets in a statistically similar way. The asymmetry index was able to fairly characterize the different levels of asymmetry simulated in the second set. Results show that it is possible to estimate the arm swing asymmetry from a single 2D gait video, with enough sensitivity to discriminate anomalous patterns from normality. This opens the door to low-cost easy-to-use mobile applications to assist clinicians in monitoring gait condition in primary care (e.g., in the elderly), when more accurate and specialized technologies are often not available.

8. Article: A Bra Monitoring System Using a Miniaturized Wearable Ultra-Wideband MIMO Antenna for Breast Cancer Imaging in [18]

This paper represents a miniaturized, dual-polarized, multiple input–multiple output (MIMO) wearable antenna. A vertically polarized, leaf-shaped antenna and a horizontally polarized, tree-shaped antenna are designed, and the performance of each antenna is investigated. After designing the MIMO antenna, it is loaded with stubs, parasitic spiral, and shorting pins to reduce the coupling effects and remove the unwanted resonances. Afterward, the two-port MIMO cells are spaced by 2 mm and rotated by 90° to create three more cells. The antennas are designed using two layers of denim and felt substrates with dielectric constants of 1.2 and 1.8, and thicknesses of 0.5 mm and 0.9 mm, respectively, along with the ShieldIt™ conductive textile. The antenna covers a bandwidth of 4.8–30 GHz when the specific absorption rate (SAR) meets the 1 g and 10 g standards. Isolation greater than 18 dB was obtained and mutual coupling was reduced after integrating shorting pins and spiral parasitic loadings. A maximum radiation efficiency and directive gain of 96% and 5.72 dBi were obtained, respectively, with the relatively small size of $11 \times 11 \times 1.4$ mm^3 for the single element and final dimensions of $24 \times 24 \times 1.4$ mm3 for the full assembly. The antenna's performance was examined for both on-body (breast) and free space conditions using near-field microwave imaging. The achieved results such as high fidelity, low SAR, and accuracy in localization of the tumour indicate that the MIMO antenna is a decent candidate for breast cancer imaging.

9. Article: Discrete Human Activity Recognition and Fall Detection by Combining FMCW RADAR Data of Heterogeneous Environments for Independent Assistive Living in [19]

Human activity monitoring is essential for a variety of applications in many fields, particularly healthcare. The goal of this research work is to develop a system that can effectively detect fall/collapse and classify other discrete daily living activities such as sitting, standing, walking, drinking, and bending. For this paper, a publicly accessible dataset is employed, which is captured at various geographical locations using a 5.8 GHz Frequency-Modulated Continuous-Wave (FMCW) RADAR. A total of ninety-nine participants, including young and elderly individuals, took part in the experimental campaign.

During data acquisition, each aforementioned activity was recorded for 5–10 s. Through the obtained data, we generated the micro-doppler signatures using short-time Fourier transform by exploiting MATLAB tools. Subsequently, the micro-doppler signatures are validated, trained, and tested using a state-of-the-art deep learning algorithm called Residual Neural Network or ResNet. The ResNet classifier is developed in Python, which is utilised to classify six distinct human activities in this study. Furthermore, the metrics used to analyse the trained model's performance are precision, recall, F1-score, classification accuracy, and confusion matrix. To test the resilience of the proposed method, two separate experiments are carried out. The trained ResNet models are put to the test by subject-independent scenarios and unseen data of the above-mentioned human activities at diverse geographical spaces. The experimental results showed that ResNet detected the falling and rest of the daily living human activities with decent accuracy.

10. Article: Hybrid Workload Enabled and Secure Healthcare Monitoring Sensing Framework in Distributed Fog-Cloud Network in [20]

The Internet of Medical Things (IoMT) workflow applications have been rapidly growing in practice. These internet-based applications can run on the distributed healthcare sensing system, which combines mobile computing, edge computing and cloud computing. Offloading and scheduling are the required methods in the distributed network. However, a security issue exists and it is hard to run different types of tasks (e.g., security, delay-sensitive, and delay-tolerant tasks) of IoMT applications on heterogeneous computing nodes. This work proposes a new healthcare architecture for workflow applications based on heterogeneous computing nodes layers: an application layer, management layer, and resource layer. The goal is to minimize the makespan of all applications. Based on these layers, the work proposes a secure offloading-efficient task scheduling (SEOS) algorithm framework, which includes the deadline division method, task sequencing rules, homomorphic security scheme, initial scheduling, and the variable neighbourhood searching method. The performance evaluation results show that the proposed plans outperform all existing baseline approaches for healthcare applications in terms of makespan.

11. Article: Intelligent Non-Contact Sensing for Connected Health Using Software Defined Radio Technology in [21]

The unpredictable situation from the Coronavirus (COVID-19) globally and the severity of the third wave has resulted in the entire world being quarantined from one another again. Self-quarantine is the only existing solution to stop the spread of the virus when vaccination is under trials. Due to COVID-19, individuals may have difficulties in breathing and may experience cognitive impairment, which results in physical and psychological health issues. Healthcare professionals are doing their best to treat the patients at risk to their health. It is important to develop innovative solutions to provide non-contact and remote assistance to reduce the spread of the virus and to provide better care to patients. In addition, such assistance is important for elderly and those that are already sick in order to provide timely medical assistance and to reduce false alarm/visits to the hospitals. This research aims to provide an innovative solution by remotely monitoring vital signs such as breathing and other connected health during the quarantine. We develop an innovative solution for connected health using software-defined radio (SDR) technology and artificial intelligence (AI). The channel frequency response (CFR) is used to extract the fine-grained wireless channel state information (WCSI) by using the multi-carrier orthogonal frequency division multiplexing (OFDM) technique. The design was validated by simulated channels by analyzing CFR for ideal, additive white gaussian noise (AWGN), fading, and dispersive channels. Finally, various breathing experiments are conducted and the results are illustrated as having a classification accuracy of 99.3% for four different breathing patterns using machine learning algorithms. This platform allows medical professionals and caretakers to remotely monitor individuals in a non-contact manner. The developed platform is suitable for both COVID-19 and non-COVID-19 scenarios.

12. Article: Classification of Hand Movements Using MYO Armband on an Embedded Platform in [22]

The study proposed the classification and recognition of hand gestures using electromyography (EMG) signals for controlling the upper limb prosthesis. In this research, the EMG signals were measured through an embedded system by wearing a band of MYO gesture control. In order to observe the behavior of these change movements, the EMG data was acquired from 10 healthy subjects (five male and five females) performing four upper limb movements. After extracting EMG data from MYO, the supervised classification approach was applied to recognize the different hand movements. The classification was performed with a 5-fold cross-validation technique under the supervision of Quadratic discriminant analysis (QDA), support vector machine (SVM), random forest, gradient boosted, ensemble (bagged tree), and ensemble (subspace K-Nearest Neighbors) classifier. The execution of these classifiers shows the overall accuracy of 83.9% in the case of ensemble (bagged tree) which is higher than other classifiers. Additionally, in this research an embedded system-based classification approach of hand movement was used for designing an upper limb prosthesis. This approach is different than previous techniques as MYO is used with an external Bluetooth module and different libraries that make its movement and performance boundless. The results of this study also inferred the operations which were easy for hand recognition and can be used for developing a powerful, efficient, and flexible prosthetic design in the future.

13. Article: Design of Portable Exoskeleton Forearm for Rehabilitation of Monoparesis Patients Using Tendon Flexion Sensing Mechanism for Health Care Applications in [23]

Technology plays a vital role in patient rehabilitation, improving the quality of life of an individual. The increase in functional independence of disabled individuals requires adaptive and commercially available solutions. The use of sensor-based technology helps patients and therapeutic practices beyond traditional therapy. Adapting skeletal tracking technology could automate exercise tracking, records, and feedback for patient motivation and clinical treatment interventions and planning. In this paper, an exoskeleton was designed and subsequently developed for patients who are suffering from monoparesis in the upper extremities. The exoskeleton was developed according to the dimensions of a patient using a 3D scanner, and then fabricated with a 3D printer; the mechanism for the movement of the hand is a tendon flexion mechanism with servo motor actuators controlled by an ATMega2560 microcontroller. The exoskeleton was used for force augmentation of the patient's hand by taking the input from the hand via flex sensors, and assisted the patient in closing, opening, grasping, and picking up objects, and it was also able to perform certain exercises for the rehabilitation of the patient. The exoskeleton is portable, reliable, durable, intuitive, and easy to install and use at any time.

14. List of Contributions

1. dos Santos, L.; Winkler, I.; Nascimento, E. Adapting a Supervised Learning Approach to a Semi-Supervised Approach for Human Action Recognition. *Electronics* 2022, 11, 1471. this service allows you to tailor content to your own needs and *interests* 2022, 312, 47.

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7. Mahmood, S.N.; Ishak, A.J.; Jalal, A.; Saeidi, T.; Shafie, S.; Soh, A.C.; Imran, M.A.; Abbasi, Q.H. A Bra Monitoring System Using a Miniaturized Wearable Ultra-Wideband MIMO Antenna for Breast Cancer Imaging. *Electronics* 2021, 10, 2563.

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