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Human Activity Recognition (HAR) Using Machine Learning: A Comprehensive Review

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***Abstract*– Human Activity Recognition (HAR) in smartphones. It has appeared as a crucial area of research with applications spanning healthcare, sports, security, and smart environments. Machine learning techniques have played a vital role in HAR systems, assisting the automatic detection and classification of human activities based on sensor data. This review paper provides a comprehensive overview of recent developments in HAR using machine learning techniques. We discuss various sensors used in HAR systems, datasets commonly used for evaluation, and the challenges associated with real-world implementation. Additionally, we survey different machine learning algorithms and architectures utilized for HAR, highlighting their strengths and limitations. Furthermore, we analyze recent trends, open challenges, and future research directions in the field of HAR using machine learning.**

***Index Terms*– HAR, Machine Learning, Algorithms, Applications, Challenges, Accelerometers, Gyroscopes, Barometer, Magnetometer and Future Directions**

I. INTRODUCTION

IDENTIFICATION of human behavior is essential to developing exchanges and human-to-human contact. However, because it provides information on a person's identity, mental health, and temperament, this assignment is challenging to differentiate. Human Activity Recognition (HAR) predicts daily activities like walking, running, cooking, and office work. The ability of humans to recognize another person's activities is one of the key areas of research in scientific domains like computer vision and machine learning.

As a result of this work, numerous implementations have been made, such as mechanical technology for human representation, human-computer interaction, and video monitoring systems. This paper examined various machine-learning techniques for identifying human activities.

Human activity recognition (HAR) objective is to automatically identify and classify human activities based on sensor data collected from wearable devices or environmental sensors on smartphones. The extensive availability of smartphones, smartwatches, and IoT devices has facilitated the collection of rich sensor data, driving the development of HAR systems. Machine learning techniques have proven effective in processing and analyzing this data to infer human activities accurately. In this review, we provide a comprehensive analysis of machine learning-based HAR systems, covering various aspects such as sensors, datasets, algorithms, and applications [1]. Machine learning is a field of artificial intelligence that focuses on the development of algorithms and statistical models that enable computers to learn and improve their performance on a specific task without being explicitly programmed. In essence, it allows machines to learn from data, identify patterns, and make predictions or decisions based on that learning. Machine learning plays an important role in agriculture, healthcare, and industry. Demand for machine learning is increasing day by day because a large amount of data is generated by users in the form of e-commerce purchases and websites [2].

Classification of machine learning: Machine learning is classified into three categories first one is supervised machine learning which includes classification and regression the second is unsupervised learning which includes clustering, dimensionally reduction, and association rule learning and the third one is reinforcement learning which is further categorized as Q-learning Markov Decision Processes called as decision making. In supervised learning the data is labeled and the output variable will be numeric and in unsupervised data, data is not labeled and the output variable will be categorial on the other hand in reinforcement learning, The agents learn from the environment through sensors and then make perceptions and take decisions with the help of actuators [[2]] (Fig. 1).

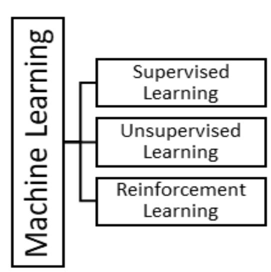

Fig. 1: Overview of machine learning's classification

Objectives: The main objective of this research is to analyze human activity recognition using machine learning and its algorithms. The significance of machine learning includes automated data visualization and resolving complex problems. In advancement of machine learning algorithms used in HAR, including Support Vector Machines, Random Forests, Decision Trees, Neural Networks, Convolutional Neural Networks (CNN), Logistic Regression, Deep Learning models and Recurrent Neural Networks (RNN). The strengths and weaknesses of each algorithm are discussed in the context of smartphone-based activity recognition.

Smartphone Sensor Data:

The smartphone is equipped with embedded inertial sensors such as an accelerometer and a gyroscope, which are then used to capture the movements and vibrations associated with different activities. Human activity recognition is to be analyzed by using wearable sensors in smartphones including an accelerometer and gyroscope. (Ehsan, 2021). Human activity recognition (HAR) aims to automatically identify and classify human activities based on sensor data collected from wearable devices or environmental sensors. The widespread availability of smartphones, smartwatches, and IoT devices has facilitated the collection of rich sensor data, driving the development of HAR systems. Machine learning techniques have proven effective in processing and analyzing this data to infer human activities accurately. In this review, we provide an in-depth analysis of machine learning-based HAR systems, covering various aspects such as sensors, datasets, algorithms, and applications An accelerometer is a sensor that measures the acceleration of a device along its three axes (X, Y, and Z). An accelerometer is essential in HAR including changes in motion, such as walking, running, or sitting. By analyzing the acceleration patterns along different axes, machine learning algorithms can infer the type of activity a user is engaged in. On the other hand, the gyroscope is a sensor that measures the rate of rotation. The gyroscope plays a very important role in HAR and includes rotational movements such as turning or twisting. To determine which model performed best in HAR, several classification methods were compared in this paper. Different classification models were chosen for comparison, including Random Forest Algorithm, Support Vector Machine, Logistic Regression, Decision Trees, Gradient Boosting and different Deep learning models including CNN, ANN (artificial neural network).

This research consists of five sections. Section I includes the Introduction of the paper and some techniques being used in human activity recognition. Section II is Related Work which studies the HAR using machine learning algorithms according to other authors and their works related to it. Section III Methodology which contains the analysis of the techniques being used in this work. Section IV is Limitations and Recommendations which describes the limitations of each technique and talks about recommendations. Finally, the last Section V includes the conclusion of the paper.

II. Related Work

(Polu, 2018) This research paper used a random forest algorithm and modified random forest algorithm for human activity recognition online in smartphones. The sensors used in this research paper include GPS sensors, gyroscopes, accelerometers, and compass sensors which observe the movements of humans like sitting, walking, running, standing, and resting. The random forest algorithm is a supervised classification algorithm. The error percentage was 6.25% and the percentage success was about 93.75% which can be calculated by the random forest algorithm in machine learning and the methodology used in it was using the datasets. It concluded that by using the supervised machine learning algorithm random forest quickly observes the human activity recognition.

(Middya, 2023) It showed the comparative analysis of machine learning models in human activity recognition. Real-world data is collected online by the sensors used in smartphones including gyroscope and accelerometer. Two approaches were used in this paper sensors and machine learning models. The data sample was about 95690 and the seven best models included Decision Tree (DT), Random Forest (RF), Deep Neural Networks (DNN), Support Vector Machines (SVM), K-Nearest Neighbours (KNN), Gradient Boosting (GB) and Convolutional Neural Networks (CNN) used in this model for analysis. The results showed that the Deep Neural networks (DNN), Random Forest (RF), and Gradient Boosting (GB)are the best models to observe human activity recognition using machine learning.

(Kumar, 2022) It studied the comparative analysis of human activity recognition. Existing researchers used the sensors to study human activity recognition. But as compared to existing research deep learning models provided the best results to recognize human activity. At present, the usage of deep learning models in various applications including healthcare, emotion calculation, education, and assisted living provided the best results.

(Roy, 2023) It studied the depth comparative analysis of human activity recognition. Existing researchers used sensors including accelerometer, gyroscope, magnetometer, barometer, and GPS to study human activity recognition. But as compared to existing research machine learning models provided the best results to recognize human activity. At present, the usage of deep learning models in various applications including healthcare, emotion calculation, and education provides the best results.

(Straczkiewicz, 2021) It showed the comparative analysis of machine learning models in human activity recognition. Real-world data is collected online by the sensors used in smartphones including gyroscope and accelerometer. Two approaches were used in this paper sensors and machine learning models. The data sample was about 95690 and the seven best models included Decision Tree (DT), Random Forest (RF), Deep Neural Networks (DNN), Support Vector Machines (SVM), K-Nearest Neighbors (KNN), Gradient Boosting (GB) and Convolutional Neural Networks (CNN) used in this model for analysis. The results showed that the Deep Neural networks (DNN), Random Forest (RF), and Gradient Boosting (GB)are the best models to observe human activity recognition using machine learning.

(CHEN, 2021) This study provides a comprehensive survey of state-of-the-art deep learning methods for sensor-based human activity recognition. It covers the multi-modality of sensory data, public datasets, and various challenge tasks. The authors propose a new taxonomy to organize deep methods according to the challenges they address. Challenges and related deep methods are analyzed to present current research progress. The work aims to guide both novices and experienced researchers in the field, offering insights into open issues and future directions. This research resolved the feature extraction challenge or problem by using deep learning methods and by using NLP (Natural language processing).

(Mekruksavanich, 2021) This paper reviewed the burgeoning field of Human Activity Recognition (HAR) and its applications, emphasizing the increasing significance driven by wearable-sensor devices and the Internet of Things (IoT). Within this realm, the focus is on biometric user identification, health monitoring for aged people, and observation. Deep learning has emerged as the dominant approach in HAR systems, particularly for its ability to handle complex sensory data effectively. Despite the advancements, challenges persist in applying HAR to biometric user identification, where distinct human behaviours serve as identifying factors. To address this, the study proposes a novel framework utilizing deep learning models to analyse sensory data from wearable devices, specifically tri-axial gyroscopes, and accelerometers. Experimental validation of the framework showcases promising results, with Convolutional Neural Networks (CNN's) and Long Short-Term Memory (LSTM) networks achieving high accuracy levels—91.77% and 92.43%.

(Wan, 2020) This paper addresses the use of mobile edge computing (MEC) to improve healthcare monitoring systems by focusing on human activity recognition (HAR). Traditional methods struggle with complex activities due to the high-dimensional sensor data from smartphones. The paper proposes a novel architecture utilizing smartphone inertial accelerometers to collect data during daily activities, preprocess it, and employ a real-time human activity classification method based on convolutional neural networks (CNN's). Evaluation of large datasets demonstrates the superiority of the proposed CNN-based approach over other deep learning models. Overall, the study showcases the potential of MEC and deep learning for more accurate and efficient HAR in healthcare monitoring.

(Khan, 2020) This study provides a comprehensive survey of supervised learning methods for sensor-based human activity recognition. It covers the multi-modality of sensory data, public datasets, and various challenge tasks. The authors propose a new taxonomy to organize deep methods according to the challenges they address. Challenges and related supervised learning methods are analyzed to present current research progress. The work aims to guide both novices and experienced researchers in the field, offering insights into open issues and future directions. This research work showed that the random forest algorithm and support vector machine give the best results and good accuracy rate which can be very helpful in analysing human activity recognition using machine learning.

(Ehsan, 2021) performed the comparative analysis of predictive models of Human Activity Recognition in Smartphones.Used different classification algorithms such as decision tree, K-Nearest Neighbour (KNN), logistic regression, Support Vector Machine (SVM) and random forest for HAR. The dataset comprised smartphones' accelerometer and gyroscope readings of the participants while performing different activities, such as walking, walking downstairs, walking upstairs, standing, sitting, and lying. Different machine learning algorithms were applied to this dataset for classification and their accuracy rates were compared. KNN and SVM were found to be the most accurate of all as compared to other classification models.

III. Methodology

Machine learning is a field of artificial intelligence that focuses on the development of algorithms and statistical models that enable computers to learn and improve their performance on a specific task without being explicitly programmed. In essence, it allows machines to learn from data, identify patterns, and make predictions or decisions based on that learning. Machine learning plays an important role in agriculture, healthcare, industry, and e-commerce.

Classification of machine learning: Machine learning is classified into two categories first one is supervised machine learning which includes classification and regression the algorithms used in it include Linear Regression, Polynomial Regression, Random Forest, Decision trees, Logistic Regression, Support Vector Machine, and Regression trees. The second one is Unsupervised Learning which includes clustering, dimensionally reduction, and association rule learning their algorithms are K-Means, Clustering, KNN (K-Nearest Neighbour), Hierarchical Clustering, Deep Learning, Distribution models and the third one is reinforcement learning which is further categorized in Q-learning Markov Decision Processes called decision making. Dataset: The dataset which is used in this research is by Kaggle.com which has 13 features and steps involved in its Dataset Selection, Data Pre-Processing (Feature Selection, Data Filtering etc.), Sampling (Under Sampling/SMOTE), Testing Sample, Machine Learning Models Instances, Model Training, Training Sample, After Training, Evaluation on Testing Sample, Trained Model, Evaluation on -Training Sample, Analysis and Comparison of Results.

For visualization, we used Python language and its library matplotlib, NumPy, Seaborn and Sci-kit Learn. the diagram shows the results of our research which conclude that by using supervised machine learning we can recognize human activity by using machine learning. Human activity recognition (HAR) aims to automatically identify and classify human activities based on sensor data collected from wearable devices or environmental sensors. The widespread availability of smartphones, smartwatches, and IoT devices has facilitated the collection of rich sensor data, driving the development of HAR systems. Machine learning techniques have proven effective in processing and analyzing this data to infer human activities accurately. In this review, we provide an in-depth analysis of machine learning-based HAR systems, covering various aspects such as sensors, datasets, algorithms, and applications. Machine learning is a field of artificial intelligence that focuses on the development of algorithms and statistical models that enable computers to learn and improve their performance on a specific task without being

Table I: Comparative Analysis of HAR by reviewing existing research papers

Authors	Methodology	Sensors Used	Models	Results
Polu, 2018	Random Forest	GPS, Gyroscope, Accelerometer, Compass	Random Forest	Supervised ML algorithm quickly observes HAR.
Middya, 2023	Comparative Analysis of ML Models	Gyroscope, Accelerometer	DT, RF, DNN, SVM, KNN, GB, CNN	DNN, RF, and GB are the best models for HAR
Kumar, 2022	Comparative Analysis of HAR	Accelerometer, gyroscope, magnetometer, barometer, GPS	Deep Learning Models	Deep learning models performed well.
Roy, 2023	Depth Comparative Analysis of HAR	Accelerometer, gyroscope, magnetometer, barometer, GPS	Machine Learning Models	ML models provide superior results compared to sensor-based approaches in HAR
Straczkiewicz, 2021	Comparative Analysis of ML Models	Gyroscope, Accelerometer	Decision Tree, Random Forest, DNN, SVM, KNN, GB, CNN	DNN, RF, and GB are the best models for HAR
CHEN, 2021	Survey of Deep Learning Methods for HAR	Various sensors	Deep Learning Methods	Deep learning methods
Mekruksavanich, 2021	Review of HAR and its Applications	Wearable sensor devices, IoT	Deep Learning Models	Deep learning,
Wan, 2020	Use of MEC to Improve HAR in Healthcare	Smartphone inertial accelerometers	CNNs	DL Models.
(Anna Ferrar, 2021)	A comprehensive analysis of supervised learning	Gyroscope, Accelerometer	Decision Trees, Logistic Regression and KNN	Supervised Machine Learning models

explicitly programmed. The datasets which are used in this research paper are the UCI dataset and UCI healthcare. For comparative analysis, we reviewed different existing research papers and found the best results for future predictions and recommendations. This table shows the detailed comparative analysis of HAR.

This table shows that comparison between the existing papers. As a result of this, we can conclude which technology or methodology gives the best result as compared to the traditional sensors.

IV. Limitations And Recommendations

Recommendations:

i. Further exploration of multi-modal sensory data integration: Future research could investigate the fusion of diverse sensor modalities to enhance the robustness and accuracy of HAR systems, potentially incorporating additional data sources such as audio and video sensors (Middya, 2023).

ii. Development of standardized evaluation metrics: Establishing common benchmarks and evaluation metrics would facilitate fair comparisons between different HAR models and methodologies, promoting the reproducibility and reliability of research findings.

iii. Real-time implementation and deployment: Efforts should be directed towards the development of real-time HAR systems capable of processing sensory data and delivering actionable insights promptly, enabling applications in healthcare, fitness monitoring, and beyond.

Limitations:

i. Data heterogeneity and availability: Limited availability of standardized datasets and variations in data collection methodologies pose challenges in comparing and generalizing findings across different studies (Polu, 2018).

ii. Computational complexity and resource requirements: Deep learning models, while effective, often require significant computational resources and expertise for training and deployment, limiting their practical applicability in resource-constrained environments.

iii. Security: As HAR technology becomes more excessive, it is essential to address privacy concerns and ethical considerations surrounding data collection, storage, and usage, ensuring the responsible development and deployment of HAR systems.

V. CONCLUSION

The review paper provides a comprehensive analysis of Human Activity Recognition (HAR) in machine learning, highlighting the significance of wearable sensor devices and IoT in advancements in this field. Various studies have been examined, showcasing the evolution from traditional machine learning algorithms to the dominance of deep learning models, particularly in handling complex sensory data effectively. The comparative analyses reveal that deep learning approaches, including Convolutional Neural Networks (CNN's), Long Short-Term Memory (LSTM) networks, and Random Forests, consistently outperform traditional methods in recognizing human activities. Additionally, the integration of mobile edge computing (MEC) further enhances the efficiency and accuracy of HAR systems, particularly in healthcare monitoring applications. Moreover, the review identifies key challenges such as feature extraction and biometric user identification, proposing innovative frameworks and methodologies to address them. Overall, this review underscores the significant progress made in HAR systems, driven by advancements in deep learning, sensor technologies, and computational methodologies, while also outlining future directions for research and development in this dynamic domain.

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