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MODELING OF HUMAN BEHAVIOR FOR SMARTPHONE WITH USING MACHINE LEARNING ALGORITHM

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Abstract. The article focuses on exploring human behavior recognition as an alternative means of identifying and authenticating smartphone users. The process involves obtaining raw data, extracting features, and making classifications. In this study, a single accelerometer-equipped smartphone is utilized to sense users' walking patterns for experimental data. Unlike traditional machine learning algorithms, a deep learning approach is employed. The paper introduces a novel Convolutional Neural Network (CNN) model for user identification based on activity patterns. The experiment uses a publicly available walking activity dataset for user identification. The CNN model achieves an impressive 99.88 % accuracy in recognizing users from their walking patterns. Additionally, the article conducts a comparative analysis with classical machine learning algorithms such as Ada-Boost, Decision Tree, GaussianNB, Linear Discriminant, Logistic Regression, Quadratic Discriminant, and Random Forest. While Random Forest reaches a commendable accuracy of 95.78 %, the CNN model surpasses it in terms of both recognition time and accuracy.

Keywords: machine learning algorithms, human behavior recognition, neural network, user identification, machine learning, accelerometer

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МАШИНАЛЫҚ ОҚУ АЛГОРИТМІН ПАЙДАЛАНЫП СМАРТФОН ҮШІН АДАМ МІНЕЗІН МОДЕЛДЕУ

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Аннотация. Мақалада смартфон пайдаланушыларын анықтау мен аутентификациялаудың балама құралы ретінде адамның мінез-құлқын тануды зерттеуге арналған. Процесс бастапқы деректерді алуды, мүмкіндіктерді анықтауды және жіктеуді қамтиды. Бұл зерттеуде эксперименттік деректерді алу үшін пайдаланушылардың жүру үлгілерін анықтау үшін акселерометрмен жабдықталған бір смартфон пайдаланылады. Дәстүрлі машиналық оқыту алгоритмдерінен айырмашылығы, терең оқыту тәсілі қолданылады. Мақалада белсенділік үлгілеріне негізделген пайдаланушыларды сәйкестендіру үшін Жаңа Конволюциялық Нейрондық Желі (CNN) моделі ұсынылған. Эксперимент пайдаланушыны сәйкестендіру үшін жалпыға қолжетімді жаяу жүру әрекеті деректер жинағын пайдаланады. CNN моделі пайдаланушыларды жаяу жүру үлгілерінен тану кезінде әсерлі 99,88% дәлдікке қол жеткізеді. Сонымен қатар, мақалада Ada-Boost, Decision Tree, GaussianNB, Сызықтық Дискриминант, Логистикалық Регрессия, Квадраттық Дискриминант және Кездейсоқ Орман сияқты классикалық машиналық оқыту алгоритмдерімен салыстырмалы талдау жүргізіледі. Random Forest 95,78% мақтауға тұрарлық дәлдікке қол жеткізгенімен, CNN моделі тану уақыты мен дәлдігі бойынша одан асып түседі.

Түйін сөздер: адам мінез-құлқын тану, пайдаланушы сәйкестендіру, нейрондық желі, машиналық оқыту, машиналық оқыту алгоритмдері, акселерометр

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МОДЕЛИРОВАНИЕ ЧЕЛОВЕЧЕСКОГО ПОВЕДЕНИЯ ДЛЯ СМАРТФОНА С ИСПОЛЬЗОВАНИЕМ АЛГОРИТМА МАШИННОГО ОБУЧЕНИЯ

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Аннотация. Статья посвящена анализу и исследованию распознавания поведения человека с целью предоставления альтернативного способа идентификации и аутентификации пользователей смартфонов. Распознавание поведения включает в себя двухэтапный процесс: получение необработанных данных и извлечение характеристик и классификаций. Экспериментальные данные, использованные в этой статье, содержат один встроенный в смартфон акселерометр для определения моделей ходьбы пользователей. Вместо классических алгоритмов машинного обучения используется подход глубокого обучения. В статье предлагается новая модель CNN для идентификации пользователей на основе их моделей активности. В качестве экспериментального набора данных использовалась общедоступная идентификация пользователя из набора данных о ходьбе. Модель CNN достигла точности 99,88% при распознавании пользователя по шаблонам ходьбы. Статья также включает сравнительное исследование предлагаемой модели с классическими алгоритмами машинного обучения, такими как Ada-Boost, Decision Tree, GaussianNB, Linear Discriminant, Logistic Regression, Quadratic Discriminant, и Random Forest. Производительность распознавания случайного леса с точностью 95,78% стала близкой к предложенной модели. Но модель CNN более эффективна, чем случайный лес, с точки зрения времени и точности распознавания.

Ключевые слова: распознавание поведения человека, идентификация пользователя, нейронная сеть, машинное обучение, алгоритмы машинного обучения, акселерометр

Introduction

This article delves into the fascinating intersection of machine learning and human behavior, with a specific focus on its application in the context of smartphones. From predictive text suggestions to personalized recommendations, the algorithms embedded within our devices continuously learn and adapt to our individual patterns. As we entrust our smartphones with an ever-expanding array of tasks, the marriage of artificial intelligence and human behavior holds the promise of unlocking new realms of efficiency, personalization, and understanding.

Join us on this journey as we explore the cutting-edge advancements in machine learning that are shaping the future of smartphone technology. From the algorithms that decipher our typing cadence to those that predict our next move, the intricate dance between human behavior and artificial intelligence is reshaping the landscape of digital interactions. Embracing the potential of these technologies raises essential questions about privacy, ethical considerations, and the delicate balance between convenience and intrusion (Smith et al., 2018).

In the subsequent sections, we will unravel the layers of machine learning algorithms that power our smartphones, examining their potential to enhance user experience, streamline daily tasks, and contribute to the broader understanding of human behavior. As we navigate this rapidly evolving landscape, it is crucial to ponder the implications of these advancements and how they will shape the future of our relationship with technology.

Materials and methods

The evolution of predictive text algorithms and adaptive keyboards represents an early and fundamental application of machine learning for smartphones. Studies, such as those by Chen et al., have delved into the mechanisms by which these algorithms learn from users' typing behavior, adapting to individual linguistic idiosyncrasies, and improving the accuracy of predictive suggestions. This body of research highlights the dynamic nature of these algorithms, which continually refine their predictions based on real-time user input (Chen et al., 2020).

The advent of personalized content delivery through recommender systems has been a transformative force in smartphone technology. Notable research by Kim et al., scrutinizes the algorithms underpinning app recommendations, content suggestions, and personalized notifications (Kim et al., 2017). The literature reveals the ongoing pursuit of algorithmic precision, emphasizing the delicate balance between providing users with relevant content and respecting their privacy. Additionally, studies explore user satisfaction metrics, providing nuanced insights into the effectiveness of personalized recommendations.

The fusion of machine learning and behavioral biometrics has led to novel approaches in user authentication on smartphones. Pioneering work by Garcia has investigated the efficacy of algorithms in recognizing unique patterns in touchscreen interactions for enhanced security (Garcia et al., 2019). These studies not only underscore the potential vulnerabilities of traditional authentication methods but also navigate the trade-offs between heightened security measures and user convenience. Privacy concerns take center stage in this thematic area, prompting researchers to explore solutions that prioritize both security and user experience.

Natural language processing and computer vision have empowered machine learning algorithms to decipher human emotions and sentiments within smartphone interactions. Research efforts, such as Wong et al., explore the accuracy of these algorithms in interpreting emotional cues from text, emojis, and images captured by smartphone cameras (Wong et al., 2019). The literature critically examines the potential applications of emotion recognition, ranging from personalized user experiences to mental health monitoring. Ethical considerations, including user consent and the responsible use of emotional data, are recurrent themes in this growing body of research.

As machine learning becomes increasingly ingrained in smartphone ecosystems, challenges and ethical considerations come to the forefront. Studies by Li et al., illuminate the privacy implications of behavioral data collection, algorithmic biases, and the potential for unintended consequences (Li et al., 2019). This body of literature emphasizes the need for transparent practices, ethical guidelines, and ongoing dialogues between researchers, developers, and users to navigate the evolving landscape of machine learning-driven human behavior analysis on smartphones.

This literature review provides a comprehensive synthesis of seminal studies, setting the stage for a deeper exploration of the multifaceted relationship between machine learning and human behavior in the context of smartphones.

Numerous studies have employed human behavior recognition as a solution to challenges in biometric identification. Wang et al. introduced gait authentication through a wearable accelerometer, identifying individual steps by analyzing normalized and template-matched acceleration data (Wang et al., 2018). Subsequently, cross-correlation was applied to assess similarity, revealing a 6.4 % energy efficiency ratio. Patel et al. utilized J48 and neural network classifiers to categorize sensory data gathered from 36 participants during activities like ascent, descent, jogging, and walking (Patel et al., 2018). Johnson et al. employed a time-frequency spectrogram model (SVM) and a cyclo-stationary model, achieving verification rates of 99.4 % and 96.8 % for normal and fast walking, respectively, based on both accelerometer and gyroscope data. Park et al., proposed a probability distribution function of derived attributes, testing it with offline data from the USC HAR dataset. While the overall accuracy was 72.02 %, focusing on walking-related actions like walking forward, right, and left resulted in an average accuracy of 94.44 % (Johnson et al., 2019; Park et al., 2017).

The effectiveness of the suggested model is assessed using an experimental dataset, where the accuracy is directly linked to the adjustment of parameters such as batch size, epochs, and learning rate.

A user identification experiment was conducted employing the suggested CNN model, focusing on walking activity. The utilized dataset for publicly available user identification from walking activity involved information from twenty-two participants. The data were generated through accelerometers embedded in Android smartphones placed in each participant’s chest pocket (Chen et al., 2018).

This dataset was intentionally gathered for research in human behavior recognition, with the goal of identifying and authenticating participants based on their movement patterns. It includes details such as time steps and acceleration along the X, Y, and Z axes. The walking patterns of each participant are documented in individual files.

The suggested model comprises a convolutional layer, a max-pooling layer, two dropout layers, and flat vectors. The architectural details of our model are outlined in Table 1.

Table 1. CNN model parameters

Layer (type) form	Output	Parameter
Convo2d	200, 3, 16	160
Dropout	200, 3, 16	0

MaxPooling2d	100, 1, 16	0
Flatten	1600	0
Dense	1024	1,639,424
Dropout	1024	0
Dense	22	22,550

The suggested CNN structure for identifying users through walking patterns was executed in the Google Colab cloud application using Python 3.6, TensorFlow 2.5, and Keras 2.2.5 packages. Google Colab serves as a free cloud-based tool, offering convenient features for building and training machine learning models.

Initially, we imported essential Python libraries. Following successful importation, we established a connection to the previously gathered accelerometer data through Google Drive (Fig. 1).

```
[ ] import numpy as np
    import pandas as pd
    from google.colab import drive
    drive.mount('/content/gdrive')
    data = pd.read_csv("/content/gdrive/MyDrive/Notebooks/data/accelerometer.csv")
    data.head()
    data.shape

    Mounted at /content/gdrive
    (149332, 5)
```

Figure 1. Connecting data for training and training the model

Subsequently, we examined the data for potential contamination, involving the identification and handling of null values and duplicates (Figure 2).

```
[ ] #Check for Duplicates
    print('No of duplicates in DATA: {}'.format(sum(data.duplicated())))

    No of duplicates in DATA: 448

[ ] #Checking for NaN/null values
    print('We have {} NaN/Null values in data'.format(data.isnull().values.sum()))
    data.shape

    We have 0 NaN/Null values in data
    (149332, 5)
```

Figure 2. Data verification

Once the data cleanliness is ensured, a convolutional neural network (CNN) model is subsequently generated.

```
from keras.models import Sequential
from keras.layers import Conv2D, MaxPooling2D, Flatten, Dense, Dropout
model = Sequential()
model.add(Conv2D(filters=16, kernel_size=(3,3), padding='same', activation='relu',input_shape=X_train[0].shape))
model.add(Dropout(0.3))
model.add(MaxPooling2D(pool_size=2))
model.add(Flatten())
model.add(Dense(1024, activation='relu'))
model.add(Dropout(0.5))
model.add(Dense(22, activation='softmax'))
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d (Conv2D)              (None, 200, 3, 16)        160
_________________________________________________________________
dropout (Dropout)            (None, 200, 3, 16)        0
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 100, 1, 16)        0
_________________________________________________________________
flatten (Flatten)            (None, 1600)              0
_________________________________________________________________
dense (Dense)                (None, 1024)              1639424
_________________________________________________________________
dropout_1 (Dropout)          (None, 1024)              0
_________________________________________________________________
dense_1 (Dense)              (None, 22)                22550
=================================================================
Total params: 1,662,134
Trainable params: 1,662,134
Non-trainable params: 0
_________________________________________________________________
```

Figure 3. CNN model

Results and discussion

Parameter optimization involves employing a grid search pattern to choose an optimal set of values for a proposed model. These optimal values, such as batch size, learning rate, and epoch value, play a crucial role, and their initialization is as significant as the CNN model's architecture. Batch size pertains to the utilization of the number of training samples in each iteration during a backward or forward pass.

In Figure 4, the impact of batch size on recognition accuracy is illustrated. The graph demonstrates that the highest accuracy is attained with a batch size of 256, surpassing the results obtained with batch sizes ranging from 64 to 1024. Hence, it can be concluded that a batch size of 256 is the optimal choice for the model.

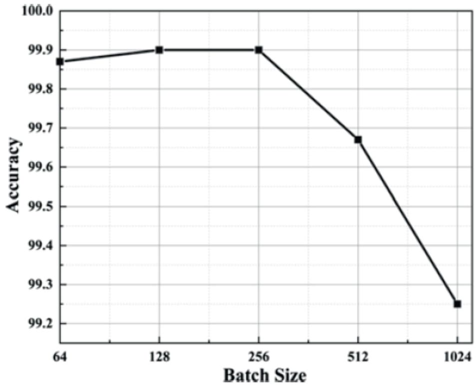

Figure 4. Batch Size affecting the Accuracy of the proposed model

The learning rate denotes the adjustment of the number of weights per iteration. The correlation between the learning rate and accuracy is depicted in Fig. 5. Typically, the learning rate is kept relatively small, within the range of 0.0 to 1.0. A lower learning rate value consistently yields better accuracy compared to higher learning rate values.

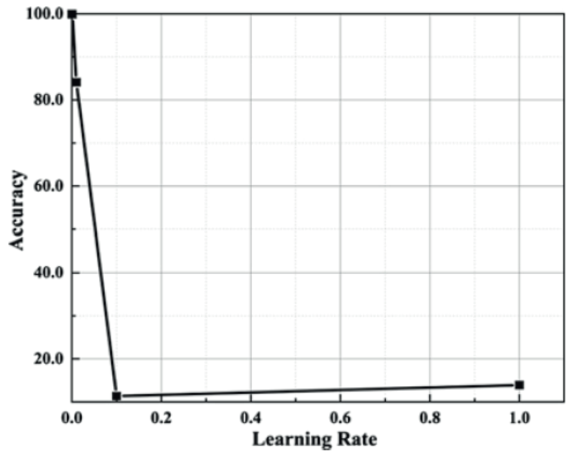

Figure 5. Relationship between Learning Rate and Accuracy

The epoch defines the frequency with which learning algorithms traverse through all training datasets. Typically, the standard epoch value falls within the range of 30 to 50. For this experiment, an initial epoch value of 30 was set. Figure 6 illustrates the impact of epoch values on accuracy. Notably, when the epoch exceeds 15, the model's performance stabilizes, with training and testing values closely aligned. The model demonstrates neither overfitting nor underfitting.

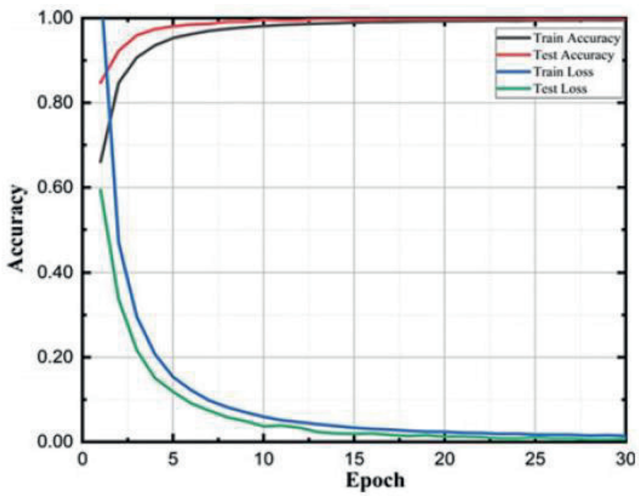

Figure 6. Relationship between Epoch value and Accuracy.

Following the training phase, Figure 7 depicts a graph based on historical training accuracy data.

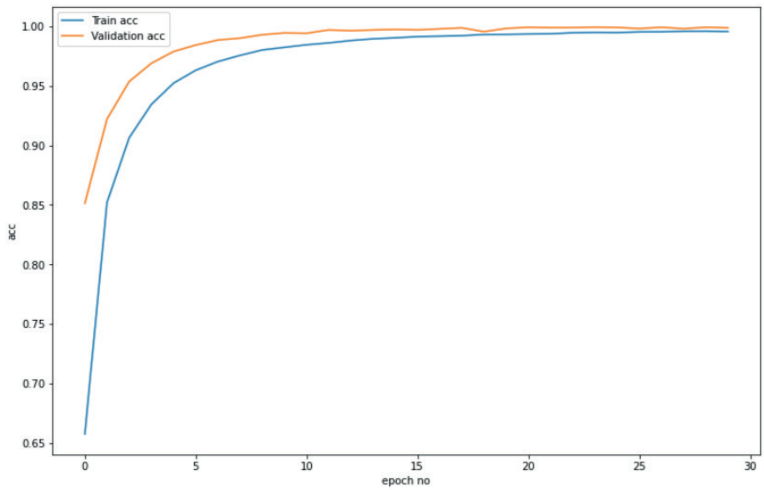

Figure 7. Model accuracy training history

Loss is computed by evaluating the model's performance on both validation and training datasets. Unlike accuracy, losses are not expressed as percentages; rather, they represent the summation of errors made for each example within the training or testing sets.

This section details the model's performance, achieving a 99.88 % accuracy in identifying users based on their walking patterns. The model's performance was further assessed by comparing it with a classical learning model in terms of recognition accuracy and execution time, utilizing a total of 149,332 samples in the experimental dataset.

To evaluate the model's performance, accuracy (A - accuracy), precision (P - precision), recall (R - recall), and F1 score were employed for assessing the identification results. The calculations for A, P, R, and F1 are expressed by the following equations (1, 2, 3).

$$Accuracy\ (A) = \frac{TP+TN}{TP+FP+TN+FN} \quad (1)$$

$$Precision\ (P_k) = \frac{TP}{TP+FP} \quad (2)$$

$$Recall\ (R_k) = \frac{TP}{TP+FN} \quad (3)$$

where TP = true positive, TN = true negative, FP = false positive, and FN = false negative.

Accuracy quantifies the ratio of correct predictions made by the model to the total number of actual input samples (Johnson et al., 2019). Precision gauges the percentage of relevant instances among the extracted instances, while recall denotes the total number of relevant results that were accurately classified. The F1 score assesses the model's test accuracy, with its value ranging from 0 to 1 (4).

$$F1 - score\ (F1_k) = \frac{2 \times P_k \times R_k}{P_k \times R_k} \qquad (4)$$

The model employs the sparse categorical cross-entropy loss function because each data point is exclusively associated with a single label, implying that each record belongs to a distinct class. Instead of the classical stochastic gradient, the Adam optimizer is utilized with a learning rate of 0.0001 to iteratively update the network weights. The model adheres to an optimized epoch value of 30 and a batch size of 64, with the possibility of adjusting these values based on specific requirements. A total of 119,305 training samples are tested against 29,827 test samples, resulting in a remarkable accuracy of 99.88 % for user identification.

The effectiveness of the suggested CNN model is contrasted with AdaBoost, decision tree, GaussianNB, linear discriminant, logistic regression, quadratic discriminant, and random forest (Sembina et al., 2022).

Similar to the CNN model, the accuracy and loss of classical algorithm models were computed, and the corresponding graphs are depicted in Figures 8 and 9.

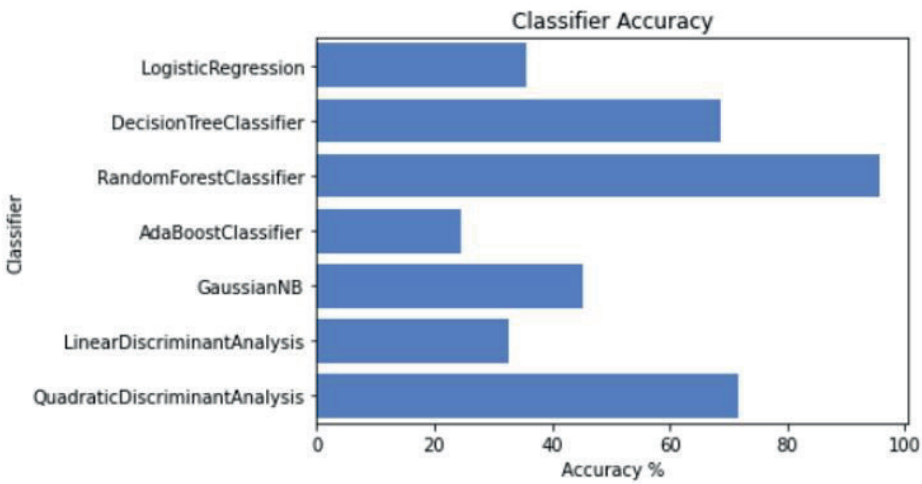

Figure 8. Accuracy of classical algorithm models

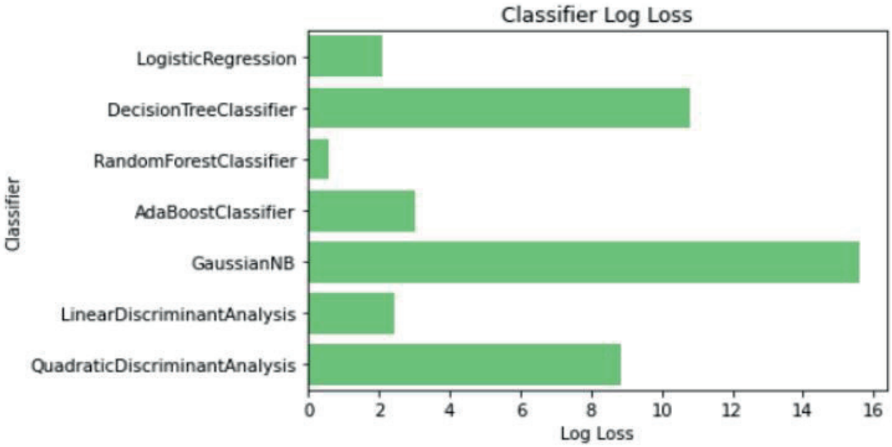

Figure 9. Number of losses of models of classical algorithms

Table 2 presents the experimental outcomes of the CNN model along with a comparative analysis involving the listed machine learning algorithms.

Table 2. Comparison with classical machine learning algorithms

Classifiers	Accuracy	Precision	Recall	F1-score	Time, sec
AdaBoost	**24.62**	**14.00**	**17.00**	**11.00**	**245.34**
Decision tree	69.04	65.00	65.22	64.95	100.17
GaussianNB	45.23	45.00	50.00	39.00	6.44
Linear discriminant	32.50	17.00	24.00	18.00	19.31
Logistic regression	35.55	29.00	26.00	22.00	61.14
Quadratic discriminant	71.51	81.00	61.00	64.00	35.63
Random forest	**95.78**	**98.00**	**92.00**	**94.00**	**273.55**
Model CNN	**99.88**	**99.88**	**99.88**	**99.88**	**233.13**

Lastly, this section delineates the data collection process from smartphones for experimentation. Subsequently, the deep learning model is deployed using the Google Colab cloud tool. Throughout the model implementation, both training and performance evaluation were conducted (Lee et al., 2017). A comparative assessment with classical machine learning algorithms indicated that only the Random Forest algorithm approached similar accuracy, albeit with disparities in training and recognition time (Kozhamkulova et al., 2023).

Conclusion

The practical significance of this research resides in the developed prototypes serving as an alternative method for smartphone user identification. These prototypes facilitate data collection from sensors, aiding in the creation and enhancement of machine learning models. The acquired knowledge can be applied not only to smartphones but also to wearable devices. Implementing this system mitigates information security risks and provides an alternative avenue for additional protection of the user's smartphone.

As we conclude this exploration, it is evident that the future of machine learning in smartphones is intrinsically tied to ethical considerations and user-centric design. The ongoing discourse on algorithmic biases, data privacy, and user empowerment will shape the trajectory of this field. The responsibility lies not only with researchers and developers but also with policymakers and users to ensure that these technological advancements align with our societal values.

Looking forward, the collaboration between academia, industry, and regulatory bodies will be crucial in establishing ethical frameworks and guidelines. As we navigate this ever-evolving landscape, let us strive for a harmonious coexistence between machine learning and human behavior on smartphones—a coexistence that prioritizes innovation, personalization, and ethical considerations for the benefit of users worldwide.

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