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LIGHTWEIGHT ARTIFICIAL INTELLIGENCE FOR PHYSICAL ACTIVITY RECOGNITION BASED ON WEARABLE DEVICES: A SYSTEMATIC LITERATURE REVIEW

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Abstract. With the development of artificial intelligence, physical activity recognition has begun to play an important role for healthcare, sports, safety, and improving user interaction in intelligent environments. The active proliferation of wearable devices with multimodal sensors provides data collection, which can be used to improve the quality of life. Conventional AI models require large computing resources, so they are not suitable for devices with low performance. The study of lightweight AI, combined with the optimization of machine learning models, is gaining relevance. Such models work in conditions of limited memory and energy resources. Given the rapid technological progress and the latest relevant research, it is important to examine the current state of the physical activity recognition system, highlighting its strengths, as well as the challenges that this area continues to face. This study provides a systematic review of the literature on lightweight artificial intelligence for recognizing physical activity based on wearable devices, based on an analysis of articles published from 2010 to 2025.

Keywords: lightweight artificial intelligence, wearable devices, physical activity recognition, machine learning, systematic review, PRISMA.

Introduction. In present days, the use of wearable devices is increasing in the world. These include smart watches, fitness bracelets, smart sensors embedded in clothing that support the monitoring of human physical activity. The devices collect data on movement, heart rate, body position and other information, representing significant potential for the use of artificial intelligence (AI) to analyze and recognize various types of activity.

However, traditional AI models are often computationally intensive, limiting their use on low-performance devices. In this regard, the research of lightweight AI is developing. Lightweight AI is a yet efficient compact version of AI systems. It requires less memory, processing power, and power consumption to run it. In this regard, in resource-constrained environments, lightweight AI has an advantage in optimizing the machine learning model for work.

While there has been an increase in research in this area, there has been no attempt to combine existing approaches achieved using lightweight AI to recognize activity on wearables into a systematic review. In this study, the authors attempted to fill the gap using the PRISMA methodology.

Methods. Lightweight artificial intelligence for detecting physical activity based on wearable devices is an area of active growth in production and research. It includes various types of sensors, as well as built-in sensors for wearable electronic devices, mobile devices, and IoT platforms [1]. Today, there is an active spread of wearable gadgets, while their computing capabilities are increasing along with the growing adoption of compact machine learning models. This study is limited to considering only wearable devices and lightweight training models that are used to integrate into such systems. The study was conducted using the PRISMA 2020 methodology [2]. The study is aimed at analyzing the effectiveness of lightweight artificial intelligence models for recognizing physical activity based on wearable devices on open data sets, as well as identifying existing limitations, key problems and promising areas for the development of this area.

The search was carried out in the databases of Scopus, Google Scholar, PubMed using the following combination of keywords:

(«lightweight AI» OR «artificial intelligence») AND («physical activity recognition» OR «HAR») AND («wearable» OR «smartwatch» OR «fitness tracker») AND «machine learning»

The selection of sources and the search process included the formulation of research questions, the definition of the problem, the refinement of the search string using Boolean operators, and the development of selection criteria to identify articles to be used in the study.

Research Questions

This systematic review aims to examine the latest advances in lightweight AI techniques for wearable-based physical activity recognition. The authors studied effective models for devices with limited computing resources. In order to effectively analyze the sources, the authors posed the following questions for the study:

What lightweight AI architectures are used to recognize physical activity on wearable devices? What are the advantages and limitations of these models?

How do these models show accuracy and efficiency on wearable devices?

The selection and analysis of sources for the systematic review was carried out according to the inclusion criteria:

(1) Studies on the recognition of physical activity with wearable devices (smart watches, accelerometers, gyroscopes, etc.)
(2) Leverage lightweight AI models (optimized CNN, LSTM, SVM, and more)
(3) Publications in peer-reviewed journals, in English
(4) The period included 2010-2025.

Articles were not included in the sample according to the following criteria:

(1) Traditional AI models, no optimization for wearables
(2) Conference reports, reports
(3) Studies that did not draw conclusions about the recognition of physical activity.

The process of selecting articles included the following stages: removal of duplicates; primary screening by titles and annotations; analysis of the full text to assess compliance with the inclusion criteria; Data extraction by authors, years, sensor type, AI models, recognition accuracy (Figure1)

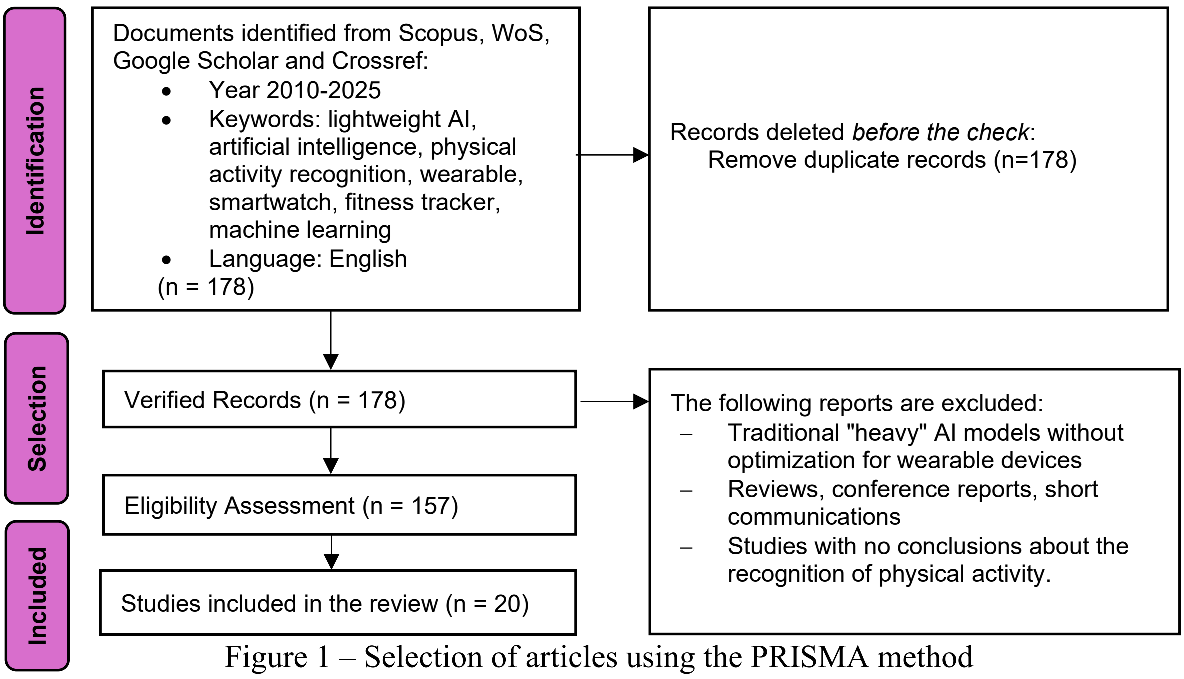

Figure 1 – Selection of articles using the PRISMA method

Results and discussion. An initial search in the database covered 178 sources. The next step was to check the articles for duplication and filter by year of publication, from 2010 to 2025, and in the end, all remained relevant. 21 studies were excluded by title and abstract. The remaining 157 sources were evaluated for relevance in the current study.

The sample was collated according to the following parameters: model architecture, sensor type, data set, recognition accuracy, device type. The content analysis of selected publications showed that the research can be grouped into three thematic scientific clusters.

The first cluster brings together research on Lightweight Deep Architectures. These include optimized CNNs (convolutional neural networks), TinyML models (ultra-compact machine learning models for microcontrollers), and networks built on the principle of MobileNet-like architectures [3-5]. These approaches are characterized by reducing computational complexity without significantly losing accuracy. Compactness also facilitates activity recognition on wearables with limited memory and power resources.

The second cluster includes research on Sensor-Efficient HAR (Resource-Efficient Recognition of Human Activity from Sensory Data). These include dimensionality reduction methods and energy-efficient signal processing algorithms [6-8]. The main idea of the research is to optimize the input data before the model training stage. This approach reduces the computational load. In addition, processing latency is reduced and the algorithms' immunity to sensor noise is increased, improving real-world operating conditions.

The third cluster is represented by research on Edge-AI Deployment. The articles reveal the implementation of models on wearable devices, embedded systems and microcontrollers [9-11]. These systems perform calculations locally, unlike cloud solutions. This results in faster response times and increased data privacy. All these conditions allow you to use activity recognition algorithms in real time even in the absence of a stable Internet connection.

An analysis of the selected 20 studies for 2021 - 2025 showed a steady increase in scientific interest in lightweight AI architectures for activity recognition. Noticeable dynamics have been observed since 2022. The growth of research during this period is associated with the spread of edge computing (local data processing on edge devices without contacting the cloud) and the development of TinyML ecosystems (an environment for implementing lightweight machine learning models on microcontrollers and low-power wearable devices).

In most studies, the models showed an accuracy of 87 to 96% [4, 12-14]. Based on the analysis of the algorithms, it was concluded that the best results are realized due to not the most complex architectures. Effective solutions are based on hybrid CNN-LSTM structures (combinations of convolutional neural networks (CNNs) for spatial feature extraction and long-term memory recurrent networks (LSTM) for modeling the temporal dynamics of signals. optimization than network depth.

The largest number of studies were geographically conducted in China, South Korea, the United States and the EU countries. The predominance of these countries is due to the fact that these regions have the necessary infrastructure of data sets for experiments and laboratories for sensor technologies.

Table 1 - Lightweight Artificial Intelligence Models and Efficiency

№	Author, year	Model	Dataset	Device	Accuracy
1	Sun, 2024	Efficient CNN	UCI HAR	Smartwatch	94%
2	Choudhury, 2025	ConvLSTM	WISDM	Wearable node	95%
3	Deepan, 2022	1D-CNN	PAMAP2	Fitness band	91%
4	Krishnaleela, 2025	CNN-SLSTM	RealWorld HAR	Embedded device	96%
5	Allafi, 2025	Hybrid DL	Custom dataset	IoT wearable	89%
6	Zhang, 2023	TinyCNN	Opportunity	Microcontroller	92%
7	Kim, 2022	Pruned CNN	UCI HAR	Smartwatch	90%
8	Li, 2024	MobileNet-Lite	WISDM	Smartband	94%
9	Park, 2023	Quantized CNN	RealWorld	Edge device	93%
10	Singh, 2021	SVM-Lite	PAMAP2	Wearable sensor	87%
11	Ignatov, 2018	CNN	WISDM	Smartphone	94%
12	Xia, 2020	LSTM	UCI HAR	Smartphone	95.8%
13	Agarwal, 2020	Lightweight RNN-LSTM	WISDM	Wearable device	95.8%
14	Akter, 2023	Attention DL	KU-HAR	Smartwatch	96.9%
15	Cheng, 2020	CondParam CNN	PAMAP2	Wearable device	95%
16	Tang, 2020	Lego-CNN	UCI HAR	Smartphone	94%
17	Li, 2024	HARMamba	WISDM	Wearable sensor	99.2%
18	Essam, 2024	HARCNN	UCI HAR	Smartwatch	97.9%
19	CNN-GRU, 2023	CNN-GRU	WISDM	Smartphone	97.2%
20	Kaya, 2024	1D-CNN	UCI-HAPT/WISDM	Smartband	97%

Lightweight Deep Architectures

Studies of this group show that the accuracy is practically not reduced by reducing the number of network parameters by 40-80%. At the same time, some studies noted an improvement in the generalizing ability of models due to the elimination of overfitting. Particularly effective are the methods of pruning and knowledge distillation [3, 4]. Sun in its study showed that an optimized CNN on a smartwatch is able to achieve 94% accuracy with a minimum number of parameters [3]. In a study of the TECA-HAR (Temporal Efficient Channel Attention for Human Activity Recognition) model, Li combined convolutional neural networks (CNNs), long-term memory recurrent networks (LSTM), and the Efficient Channel Attention (ECA) mechanism to achieve accuracy of up to 98% across multiple datasets, including UCI HAR and WISDM [4]. Deepan also studied the use of One-Dimensional Convolutional Neural Networks (1D-CNN, one-dimensional convolutional neural networks) in the analysis of sensory signals of fitness bands. The result showed that their use reduces computational costs while maintaining accuracy above 90% [15]. Research demonstrates that lightweight architectures not only save resources, but can also be more resilient to overfitting. Thus, reducing the parameters of networks leads to compact and efficient HAR models without compromising accuracy.

Energy-efficient Sensor-Efficient HAR

The work of the second cluster focuses on reducing the computational load by optimizing the input data. Feature selection, downsampling, and frequency-domain conversion methods are used [16-18]. In his study, Ignatov showed that CNN with abbreviated features reduces CPU load and maintains 94% accuracy on smartphones [6]. Researchers Agarwal and Alam have developed a lightweight recurrent neural network with long-term memory (RNN-LSTM) for the analysis of sensor data from the WISDM (Wireless Sensor Data Mining dataset) [7]. This model made it possible to reduce the computing load on wearable devices while maintaining high accuracy of activity recognition. Thus, the power consumption of devices was reduced by up to 35%, without losing recognition quality. Other researchers have used a deep learning method with an attention mechanism on smartwatches. This made it possible to optimize the processing of sensor data and increase immunity to noise [17]. These approaches show that good data processing and preprocessing help save energy and speed up algorithms.

Using AI at the Edge (Edge-AI Deployment)

The practical applicability of lightweight models on wearable devices and microcontrollers is considered in the third group of studies [11, 19, 20]. Researcher Zhang described the use of TinyCNN on a microcontroller in an article, and the results showed an accuracy of 92% with minimal resource consumption. Other authors, Kaya and Topuz [21] have shown that 1D-CNN can run on UCI-HAPT/WISDM with 97% accuracy. One of the studies on HARMamba showed that lightweight models can be used in Edge-AI for sports monitoring and real-time medical tasks [5]. As such, all of these studies highlight that local data processing speeds up system responsiveness and increases privacy.

Conclusion. The study found that approaches using lightweight artificial intelligence are enhancing the development of physical activity recognition systems on wearable devices. The high accuracy of models at low computational costs makes them a key component of future digital health systems.

There are several stable trends in the works. In general, we can note a gradual transition from «heavy» deep networks to compact lightweight architectures. There is also a trend of increasing integration of models into various devices. Research shows a significant increase in data optimization, not just model architecture improvements. Nevertheless, some of the problems remain unsolved. Topical issues include the need to standardize datasets, develop universal energy efficiency metrics, and create reproducible experimental protocols. As this study was limited to a sample of international source databases, further research in this area could be expanded and deepened.

Future research may include the development of unified platforms for testing lightweight AI models and the expansion of real-world data sets. A hot topic for research remains the creation of adaptive algorithms that can dynamically balance the accuracy and resources of the device. These areas will determine the next stage in the development of AI systems for recognizing physical activity.

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ЛЕГКОВЕСНЫЙ ИСКУССТВЕННЫЙ ИНТЕЛЛЕКТ ДЛЯ РАСПОЗНАВАНИЯ ФИЗИЧЕСКОЙ АКТИВНОСТИ НА ОСНОВЕ НОСИМЫХ УСТРОЙСТВ: СИСТЕМАТИЧЕСКИЙ ОБЗОР ЛИТЕРАТУРЫ

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Аннотация. С развитием искусственного интеллекта распознавание физической активности стало играть важную роль для здравоохранения, спорта, безопасности и улучшения взаимодействия с пользователями в интеллектуальных средах. Активное распространение носимых устройств с мультимодальными датчиками обеспечивают сбор данных, что может использоваться в целях улучшения качества жизни. Обычные ИИ-модели требуют больших вычислительных ресурсов, поэтому не подходят для устройств с низкой производительностью. Актуальность набирает изучение легковесного ИИ, в сочетании с оптимизацией моделей машинного обучения. Такие модели работают в условиях ограниченных ресурсов памяти и энергии. Учитывая стремительный технический прогресс и последние актуальные исследования, важно изучить текущее состояние системы распознавания физической активности, выделив сильные стороны, а также проблемы, с которыми продолжает сталкиваться эта сфера. Данное исследование представляет систематический обзор литературы по легковесному искусственному интеллекту для распознавания физической активности на основе носимых устройств, на основе анализа статей, опубликованных с 2010 по 2025 год.

Ключевые слова: легковесный искусственный интеллект, носимые устройства, распознавание физической активности, машинное обучение, систематический обзор, PRISMA.

КИІЛЕТІН ҚҰРЫЛҒЫЛАР НЕГІЗІНДЕ ДЕНЕ БЕЛСЕНДІЛІГІН ТАНУҒА АРНАЛҒАН ЫҚШАМ ЖАСАНДЫ ИНТЕЛЛЕКТ: ӘДЕБИЕТКЕ ЖҮЙЕЛІ ШОЛУ

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Андатпа. Жасанды интеллекттің дамуымен дене белсенділігін тану денсаулық сақтау, спорт және қауіпсіздік салаларында, сондай-ақ зияткерлік орталарда пайдаланушылармен өзара әрекеттесуді жетілдіруде маңызды рөл атқарады. Мультимодальды датчиктермен жабдықталған киілетін құрылғылардың кеңінен таралуы деректерді жинау үдерісін қамтамасыз етеді және алынған мәліметтерді өмір сапасын арттыруға бағытталған зерттеулерде қолдануға негіз болады. Дәстүрлі жасанды интеллект модельдері жоғары есептеу ресурстарын талап етеді, сондықтан өнімділігі төмен құрылғыларда қолдануға шектеулі. Машиналық оқыту модельдерін оңтайландырумен үйлестірілген ықшам жасанды интеллектті зерттеу қазіргі уақытта ерекше өзектілікке ие. Мұндай модельдер жады мен энергия ресурстары шектеулі ортада тиімді жұмыс істеуге мүмкіндік береді. Техникалық прогрестің қарқынды дамуын және соңғы ғылыми зерттеулерді ескере отырып, дене белсенділігін тану жүйелерінің қазіргі жағдайын зерделеу, олардың артықшылықтары мен осы салада сақталып отырған мәселелерді айқындау маңызды. Бұл зерттеу 2010-2025 жылдар аралығында жарияланған ғылыми мақалаларды талдау негізінде киілетін құрылғылар арқылы дене белсенділігін тануға арналған ықшам жасанды интеллект саласындағы әдебиеттерге жүйелі шолу ұсынады.

Түйін сөздер: ықшам жасанды интеллект, киілетін құрылғылар, дене белсенділігін тану, машиналық оқыту, жүйелі шолу, PRISMA.

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