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Digital Twin-assisted Blockchain-inspired irregular event analysis for eldercare

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Content

Abstract

- Digital Twin (DT) is considered one of the most promising technologies and a game changer in the field of healthcare. DT is generating a virtual imitation of a physical object that mimics the status of an event by changing the information in real time.

- In this article, a smart context-aware physical activity monitoring framework is developed by combining different advanced techniques such as loT, DT, FoT, CoT, and Blockchain to maintain the sensitiveness of the healthcare domain.

- In the proposed study, the physical movements of an elder are analyzed by utilizing the sequential data processing capability of deep learning to detect irregular physical events.

- The proposed framework can keep the data of an individual secured by applying progressed security highlights of blockchain.

- The proposed solution effectively analyzed an irregular event of an individual with considerable accuracy in real time.

- The performance of the proposed solution is measured with respect to irregular event recognition, model training and testing, rate of latency, and data processing cost. In this manner, a case study defines the effectiveness of the proposed methodology in the smart healthcare industry.

1. Introduction

- Introduction Continuous advancements in technology all through the ages have prompted the development of new techniques, tools, and machines
- Internet of Things (I0T) is considered one of the most revolutionized technologies that act as the backbone of all these advancements
- IoT is having the capability to connect to almost every smart device.
- IoT-enabled devices have contributed toward the considerable improvement of the healthcare domain by acquiring the correct information in real-time, processing and generating more accurate results, increasing the accessibility of medical records, as well as battling pandemics [1,2]
- Hence, IoT is playing an imperative role in the domain of healthcare by connecting almost every smart health monitoring device at the user's end
- In this manner, the improved working process of IoT assisted healthcare frameworks helps to expand health support and reduce the rate of morality [3,4]

1. Introduction

1.1 Problem identification

- Physical inactivity and irregularity have been realized very common in elders that lead to serious health conditions like diabetes, lipid issues, osteoporosis, heart related sicknesses, and colon disease [5]

- The majority of the current medical assets are following the conventional monitoring methodologies that represent a significant limitation in the distribution of medical assets in real-time [6,7]

- Apart from this, the report published by the U.S. Institute of Medicine defines that clinical mistakes such as failure to get to a patient's clinical history missed and deferred analysis, or tainted information also becoming one of the primary reasons behind the deaths of ~400 000 individuals every year [8]

- Additionally, contrasted with young individuals, an elder individual needs more care and that should be in a continuous manner

- Therefore, monitoring the scale of physical inactivity and predicting irregular physical events has become one of the primary research topics in the domain of smart healthcare

1. Introduction

1.1 Problem identification

- In addition, it has been determined that the utilization of smart sensors and the internet facilitates interoperability in the domain of healthcare [5]

- Despite the advancement in smart healthcare services, some limitations have been observed in the existing healthcare solutions as follows:

    1. A very limited regular interaction between the individual and medical institution has been observed
    2. The integration of smart medical systems and physical systems has not been fully implemented
    3. A lack in the observation of elderly patients, including information management and security with real-time alert deliverance is observed
    4. Moreover, the current platforms are not providing personal health management services to elders throughout their lifecycles

1. Introduction

1.2 Motivation

- Motivation To address the above discussed limitations, a proper interaction between physical and virtual space needs to be maintained and that can be achieved with the help of Digital Twin (DT)

- The concept DT defines the technology that refers to the digital replication of the actual object [10-12].

- DT has the capability to combine physical objects and their digital replica with different modern techniques such as IoT, Artificial Intelligence (Al), virtual reality, and many others to increase its utility in different domains.

- In this manner, digital twin could be used to design the smart physical systems. In the smart healthcare domain, a virtual object or replica of an individual can be an optimal solution to improvise health operations, control, and promotion [13].

- The simulation can help medical representatives to monitor the current physical status of an individual. Moreover, it can be feasible to analyze the future pattern by utilizing clinical event monitoring framework to predict any physical irregularity of an elder in real time. Moreover, blockchain technology can be utilized to maintain the record of history.

- By coordinating DT with medical care, the motivation of the proposed study is to develop a more intelligent and accurate loT assisted patients with a higher assurance of security and privacy.

2. Related work

1.3 State-of-the-art contribution

- The article proposes a framework to analyze the physical activities of an elder by following the principles of smart healthcare and by utilizing the capabilities of DT and blockchain.

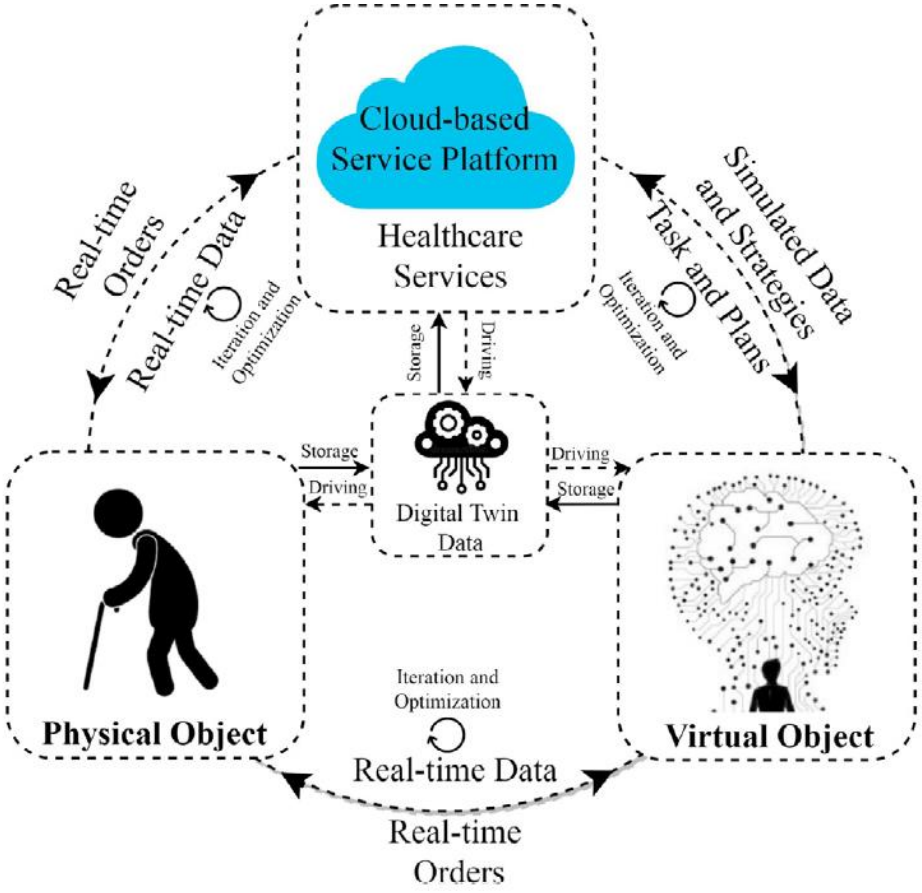

Fig. 1. The conceptual framework of the proposed solution.

2. Related work

1.3 State-of-the-art contribution

- The objectives of the proposed study are listed as follows:

1. Data acquisition related to physical events of the individual under observation.

2. Data preprocessing with pattern unification at the digital twin layer of the system architecture

3. Physical inactivity and irregularity analysis by utilizing deep learning algorithms at the cloud layer

4. Continuous health monitoring with record maintenance by following the concept of blockchain

2. Related work

1.4 Article structure

- The rest of this article is organized as follows.
- Some imperative studies related to the proposed work are discussed in Section 2.
- The parametric detail of the proposed architecture is explained in Section 3.
- In Section 4, the implementation detail and the calculated outcomes are discussed.
- At last, Section 5 concludes the article with the difficulties that face DT technology in the field of healthcare and depicts future work likewise.

2. Related work

2.1 DT-inspired smart solutions

- Rivera et al. [14] proposed a reference healthcare framework by following the capabilities of DT. Authors have focused on consistent observation and prediction by following the standards of self-adaption and autonomic computation to estimate the health of the patient

- Liu et al. [15] proposed a digital twin inspired reference framework for elder patients. They have followed the principles of cloud computing and the digital twin model to perform data analysis and effectively manage medical services

- Karakra et al. [16] proposed a DT based solution is proposed to deal with the clinical emergency. The authors have followed a discrete event based simulation framework to deal with an emergency. The healthcare process has been upgraded by utilizing a machine learning based predictive modal by continuously utilizing data without interrupting everyday exercises. The FlexSim HC programming has been utilized to test the practicality of the proposed solution in different situations.

- Leng et al. [17] proposed a semi-physical commissioning approach by utilizing the concept of the digital twin in the domain of smart manufacturing. The authors have proposed a new paradigm by combining the proposed digital twin approach and the open architecture approach in smart manufacturing systems to achieve sustainability

2. Related work

2.1 DT-inspired smart solutions

- Leng et al. [18] proposed a digital twin driven approach for the rapid reconfiguration of automated manufacturing systems. The process of data mapping was carried out by the digital twin. For verification, the optimized results were sent back to the data mapping module. A physical implementation was conducted to verify the effectiveness of the proposed approach

- In article [19], a product-service strategy for warehouses based on digital twins was proposed by the authors. Real-time data from the physical warehouse is aggregated and mapped to the cyber model using a digital twin

2. Related work

2.1 DT-inspired smart solutions

Table 1
Comparative analysis based on the specific parameters (Internet of Things (IoT), Digital Twin (DT), Fog Platform (FP), Cloud Platform (CP), Deep Learning (DL), and Blockchain (BC)).

Authors	Domain of the study	IoT	DT	FP	CP	DL	BC
Rivera et al. [14]	Healthcare: Prediction of irregular health events caused by diabetes	✓	✓	×	✓	×	×
Liu et al. [15]	Healthcare: Digital twin inspired elder patient monitoring	✓	✓	×	✓	×	×
Karakra et al. [16]	Healthcare: a DT-based smart solution to deal with the clinical emergency	✓	✓	×	✓	×	×
Leng et al. [17]	Manufacturing: DT-inspired semi-physical commissioning approach for smart manufacturing	×	✓	×	✓	×	×
Leng et al. [18]	Manufacturing: A DT-driven approach for reconfiguration of manufacturing system	×	✓	×	✓	×	×
Leng et al. [19]	Manufacturing: DT-inspired product-service strategy for warehouses	×	✓	×	✓	×	×
Guo et al. [20]	Healthcare: IoT-cloud-assisted smart health monitoring framework	✓	×	×	✓	×	×

2. Related work

2.2 IoT-cloud-inspired smart solution

- In article [20], an IoT cloud assisted intelligent management framework is proposed to maintain an effective environment for smart healthcare. Moreover, the authors have focused on the concept of optimization and redistribution of medical assets.

- in article [21], an loT cloud based smart health framework was proposed to maintain personal health records by following the concept of virtualization. In the proposed solution patients were using virtual technology to maintain their PHR records which can be shared with the stakeholder when it is required.

- In article [22], the proposed solution was having the facility to deal with unstructured and semi-structured heterogeneous information related to the physical parameters of the patient to deal with the issue of concurrency with considerable outcomes.

- In article [23], another framework based on biosensors and cloud computing is proposed to collect and process the health parameters with respect to an individual in real-time.

2. Related work

2.2 IoT-cloud-inspired smart solution

- In the business and practical region, a smart personal healthcare framework named "HealthVault" was proposed by Microsoft [26].

- "Seoul National University Hospital" utilized a cloud based Virtual Desktop Framework (VDF) to design a private cloud database for the hospital [27].

- "Huawei eHealth" distributed the "Savvy Wellbeing Cloud Arrangement" to implement a platform to exchange information by covering multiple healthcare frameworks in China [28].

- Moreover, business cloud-oriented organizations, for example, "Ali Healthcare" [29] and "Baidu Clinical Cloud" [30] offered different solutions such as "Graded Diagnosis and Treatment Cloud", "Telemedicine Cloud", "Medical Image Cloud", and "Cloud Medicine" to provide medical services to individuals in real-time.

2. Related work

2.2 IoT-cloud-inspired smart solution

Table 1
Comparative analysis based on the specific parameters (Internet of Things (IoT), Digital Twin (DT), Fog Platform (FP), Cloud Platform (CP), Deep Learning (DL), and Blockchain (BC)).

Authors	Domain of the study	IoT	DT	FP	CP	DL	BC
Gorp and Comuzzi [21]	Healthcare: IoT-cloud-based smart solution for health records maintained by following the concept of virtualization	✓	×	×	✓	×	×
He et al. [22]	Healthcare: Cloud-based framework to provide pervasive medicinal services to patients in real-time	✓	×	✓	✓	×	×
Benharref and Serhani [23]	Healthcare: IoT-inspired smart monitoring framework by acquiring health parameters in real-time	✓	×	✓	✓	×	×
Leng et al. [24]	Manufacturing: Blockchain-inspired autonomous manufacturing process to improve the adaptability and timeliness of production control	×	×	×	✓	×	✓
Leng et al. [25]	Manufacturing: Blockchain-inspired multi-agent solution for effective task coordination under disturbing conditions	×	×	×	✓	×	✓
Proposed solution	Healthcare: a smart context-aware physical activity monitoring framework by combining data augmentation and data security features of digital twin and blockchain, respectively	✓	✓	✓	✓	✓	✓

2. Related work

2.3 Blockchain-inspired smart solution

- In article [24], authors proposed a blockchain-inspired autonomous process to improve the adaptability and timeliness of control in the direction of manufacturing. The multi-agent system is following the concept of smart contracts for task negotiation and coordination.

- A blockchain-based multi-agent solution is implemented in article [25] to ensure effective task coordination under disturbing conditions. A deep learning-driven prediction model is built in the cloud to support the rescheduling decisions, and it is based on the data about operation events and control decisions that were collected at the edge.

- **Limitation:** It has been realized that the research related to DT and blockchain has started to develop in the domain of healthcare. However, the current solutions are majorly discussed the theoretical solutions rather than implementation.

3. Digital Twin and Blockchain-inspired proposed solution

- The proposed solution utilizes the concept of a digital twin to make a virtual replica of the individual under observation that empowers medical experts to analyze every possible situation in real-time

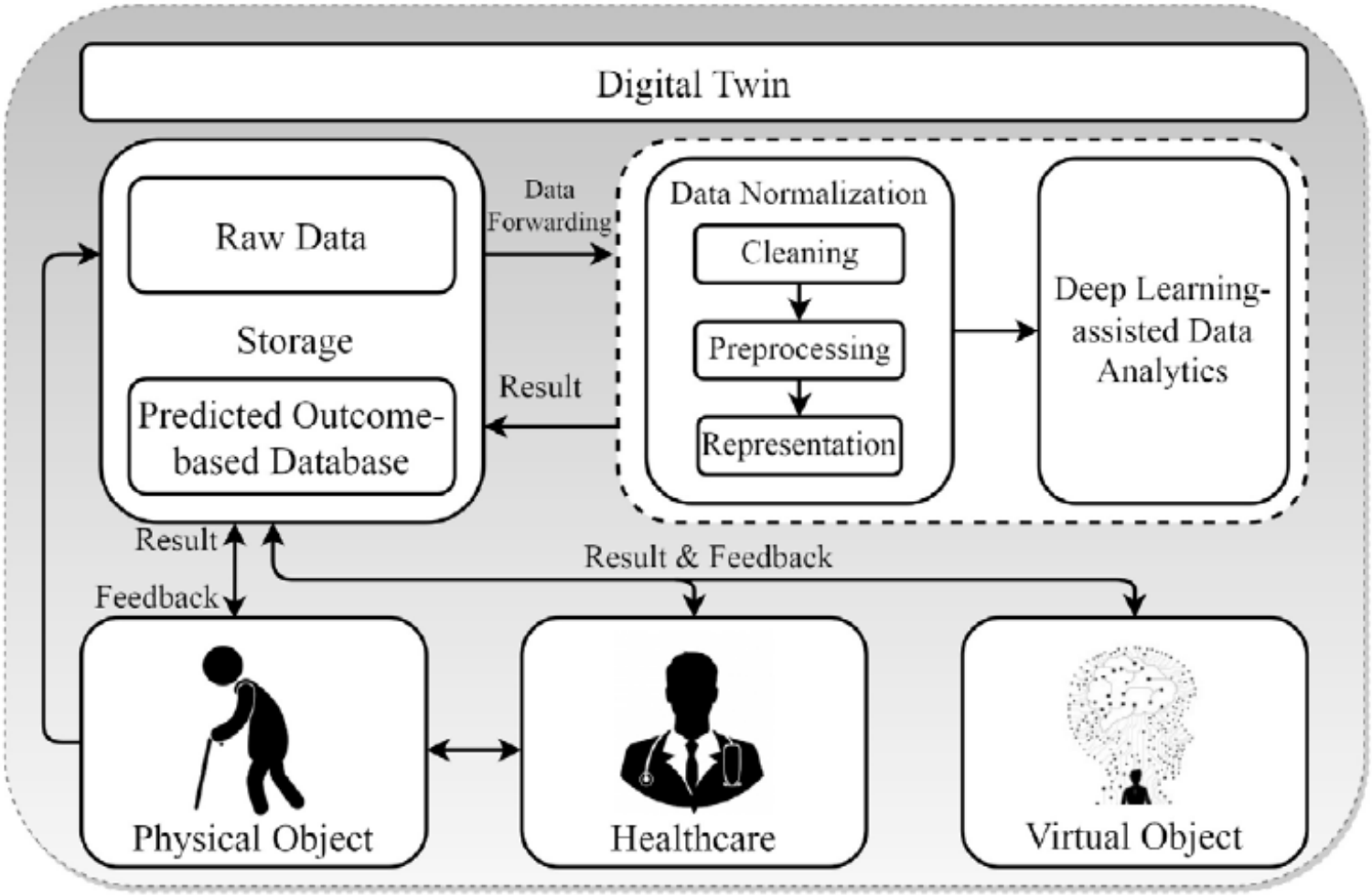

Fig. 2. The detailed overview of the proposed framework.

3. Digital Twin and Blockchain-inspired proposed solution

- The hardware and software requirements with respect to the framework in explained in Table 2

Table 2
System hardware and proposed solution's specifications.

System hardware specifications	Central Processing Unit	Core i5, 8th Generation
	Random Access Memory	16 GB
	Read Only Memory	2 TB
	Operating System	Ubuntu Linux 14.04 LPS (64-bit)
	Version of Docker Engine	17.03
	Version of Docker Compose	1.8
	Version of Nodejs	8.9
	Version of Node Package Manager	v5.x
	Version of Git	2.9.x or higher
	Version of Programming Language	2.7.x
Proposed solution specifications	Protocol for consensus	Customized RBFT
	Distribution of nodes	Ethereum network
	Hardware specification	3.6 GHz, 16 GB RAM, Octa-core, 2 TB HDD
	Blockchain environment	1 server as CoVEn, 10 peers, Peer2Peer network
	Perception nodes category 1	activPAL and ActiGraph
	Perception nodes category 2	Smartphones
	Test tool	Hyperledger Caliper
	Type of database	CouchDB

3. Digital Twin and Blockchain-inspired proposed solution

3.1 Data sensing and transmission

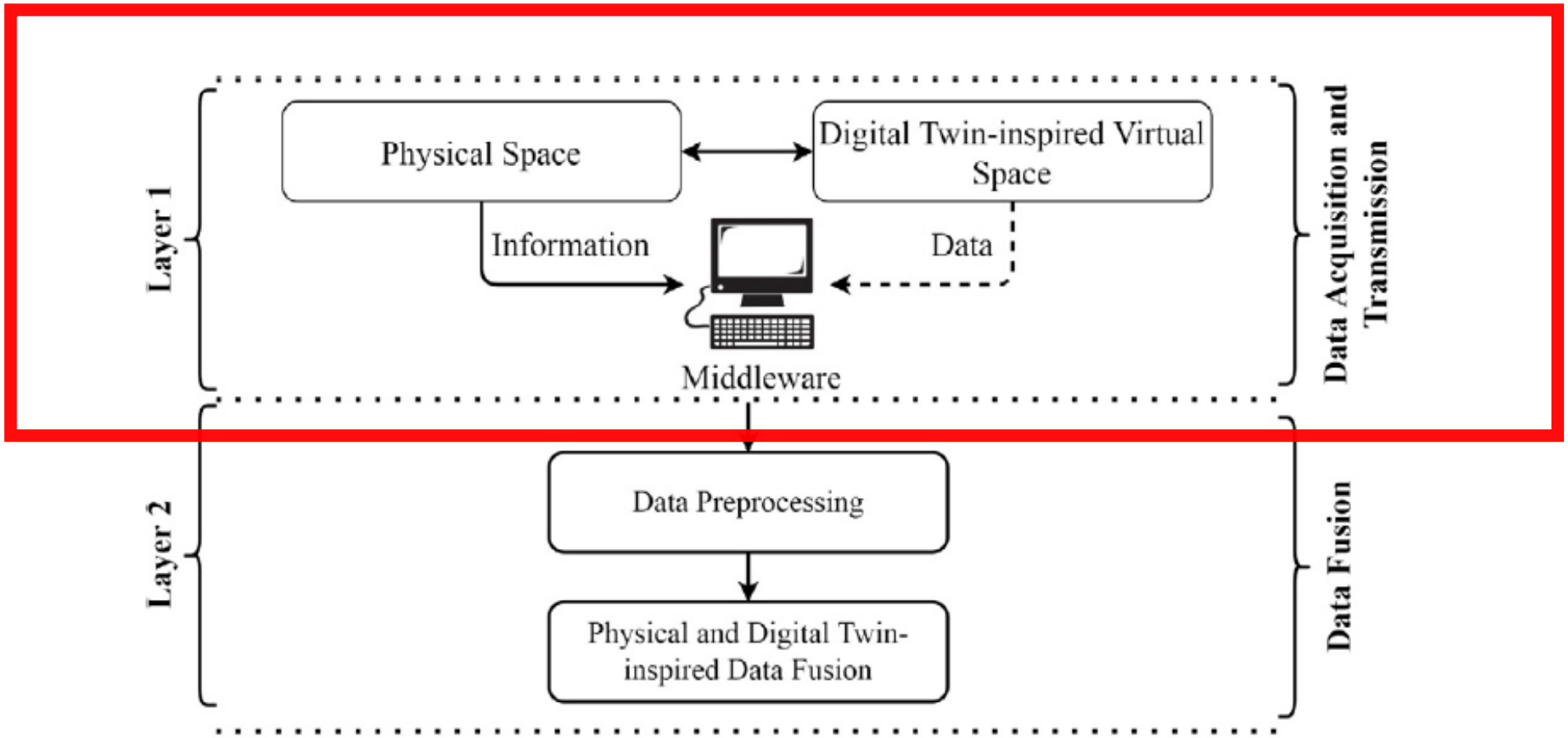

Fig. 3. The layered overview of the proposed framework.

3. Digital Twin and Blockchain-inspired proposed solution

3.1 Data sensing and transmission

Table 3
The detail of parameters of the DFS.

Dataset	Wearable sensors	Communication techniques	Activities
Multi-Sensors based event acquisition	activPAL [31], ActiGraph wGT3X-BT [31]	Rate of Bluetooth: 2.1 Mbps, Total value of bands: 2.4 GHz, Communication distance: 20–200 m, Network nodes: 8, Security approach: 128 bits AES, Required working power: 1–100 (mW)	Standing still, Sitting, Walking, Knees bending, Waist bends forward, Lying down, Jogging, Front arm elevation, Running, Falling

3. Digital Twin and Blockchain-inspired proposed solution

3.1 Data sensing and transmission

- **Definition 1 (Time Window-based Block Formation:)**
  - A block related to an event is containing four parameters listed as T_s, S_s, S_m, and T_e.
  - Here, Ss defines the type of sensor that captures the signal with respect to an event denoted as Sm.
  - The parameters T_s and T_e define the start and end point of the event related to a specific time instance denoted as ΔT .
  - The length of the signal related to a time instance is calculated **$\Delta T = |Ts - Te|$**

3. Digital Twin and Blockchain-inspired proposed solution

3.2 Data fusion

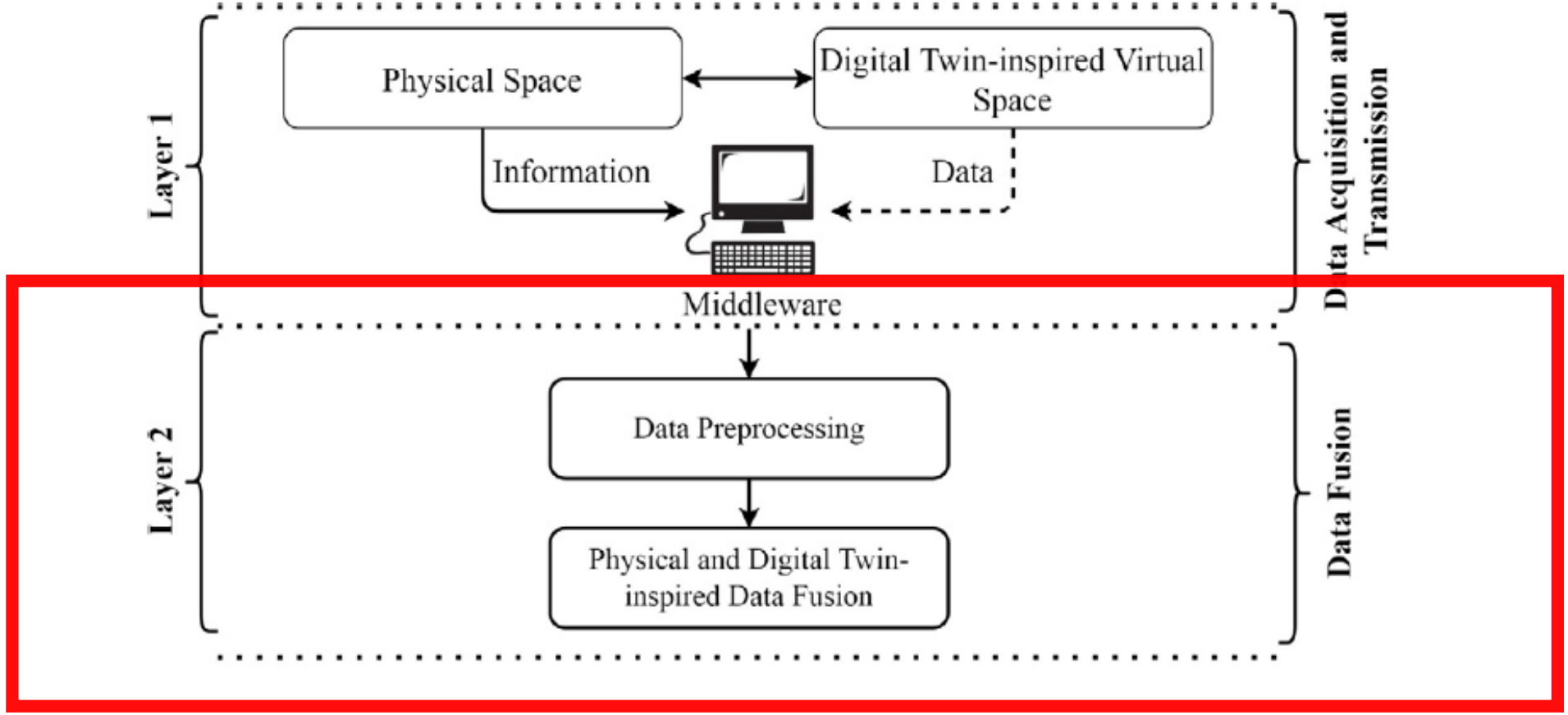

Fig. 3. The layered overview of the proposed framework.

3. Digital Twin and Blockchain-inspired proposed solution

3.2 Data fusion

- **Unification of activity patterns**
  - The data of physical activities captured from wearable sensors have continuous features and are typically collected at various frequencies based on their types as listed in Table 2
  - In order to achieve unification between data frequencies, features must be taken to lower frequencies either by expanding the indicators or to compress indicators with a higher frequency.
  - With the help of the deep learning approach, unification between the pattern of activities can be achieved as described in Definition 2.

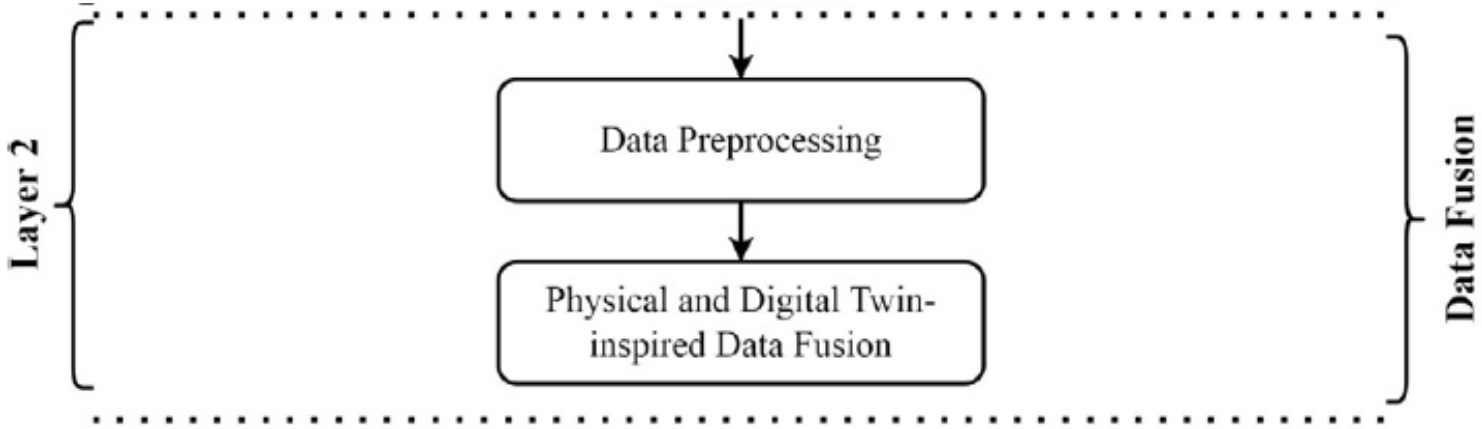

Fig. 3. The layered overview of the proposed framework.

3. Digital Twin and Blockchain-inspired proposed solution

3.2 Data fusion

- **Definition 2 (Pattern Unification).**

  - Let 2 sets of physical activity patterns denoted as X_1, and X_2 belonging to the same event be collected in different frequencies denoted as T_1 and T_2. Here, the dimension of the activity X_2 is considered the benchmark.

  - The new data dimension of X_1 will be generated based on X_2 and aligned with the data sampling frequency of X_2

$$X'_{1j} = X'_{1m} + (X_{1(m+1)} - X_{1m}) \frac{T_2 \times j - T_1 \times m}{T_1} \quad (1)$$

$$m = \lfloor \frac{T_2 \times j}{T_1} \rfloor \quad (2)$$

3. Digital Twin and Blockchain-inspired proposed solution

3.2 Data fusion

- **Definition 2 (Pattern Unification).**

Algorithm 1 The process of event pattern unification

Require: X_i and X_j two set of events, Event collection cycle T_i and T_j for X_i and X_j, respectively

Ensure: A new event pattern termed as X_i' correspond to X_i in database

for every X_{1j} in X_1 **do**

Corresponding Time Instance $t_{2j} = T_2 \times j$

Search for X_{1m} and X_{1n} in X_1

where $t_{1m} = \max(t_{1i} \mid t_{1i} < t_{1j})$

$t_{1n} = \min(t_{1i} \mid t_{1i} > t_{1j})$

end for

for every X_{1j}' in X_1' **do**

$X_{1j}' = \text{linear mean}(X_{1m}, X_{1n})$

end for

3. Digital Twin and Blockchain-inspired proposed solution

3.2 Data fusion

- After performing the operation of data fusion and unification the unified events are forwarded to the cloud layer to analyze the type of event and to perform the prediction of any physical irregularity.

- The process of prediction is utilized to provide healthcare services such as real-time monitoring medication-oriented services, data mining, and many others.

3. Digital Twin and Blockchain-inspired proposed solution

3.3 Real-time data analysis

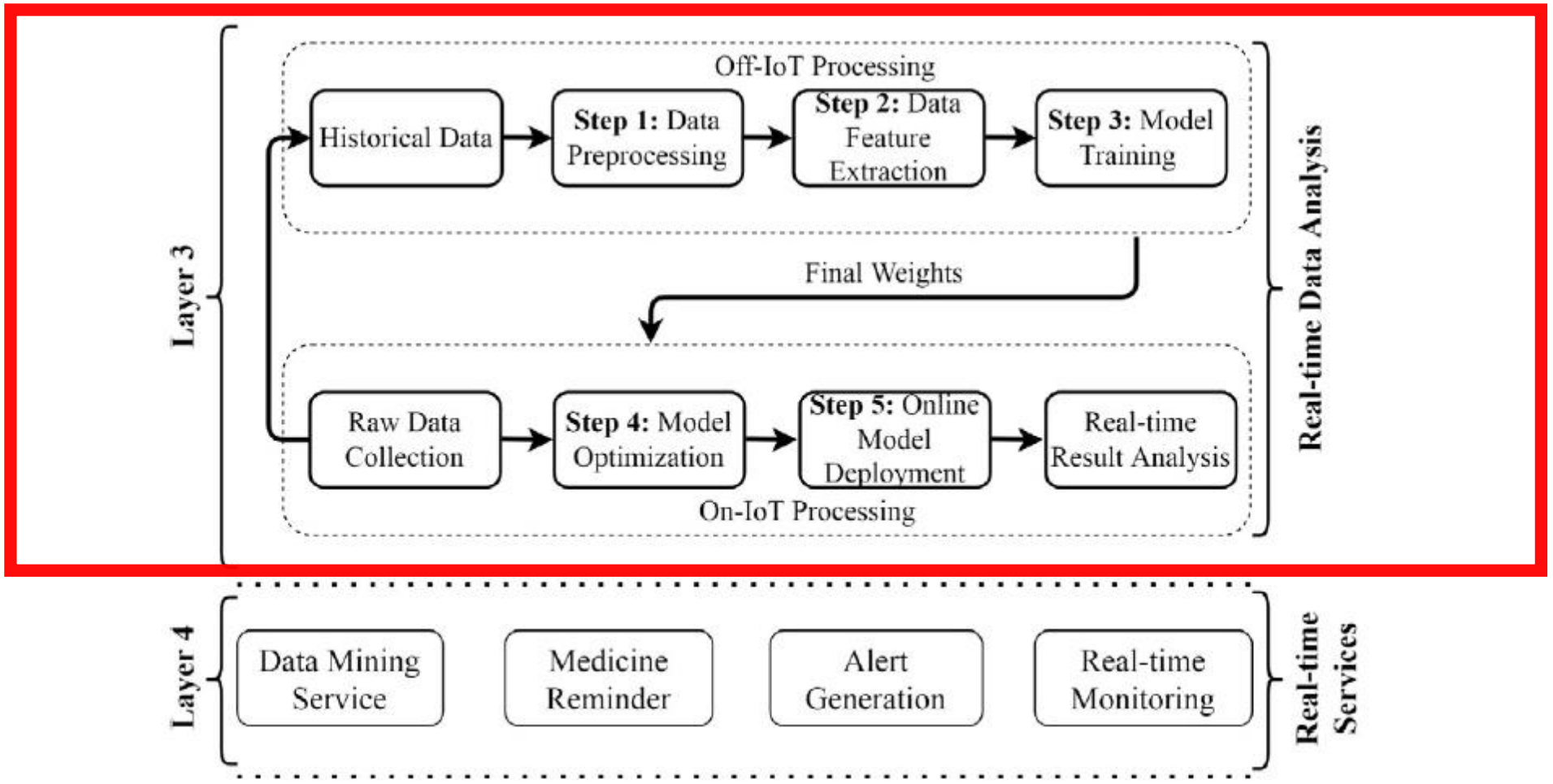

Fig. 3. The layered overview of the proposed framework.

3. Digital Twin and Blockchain-inspired proposed solution

3.3 Real-time data analysis

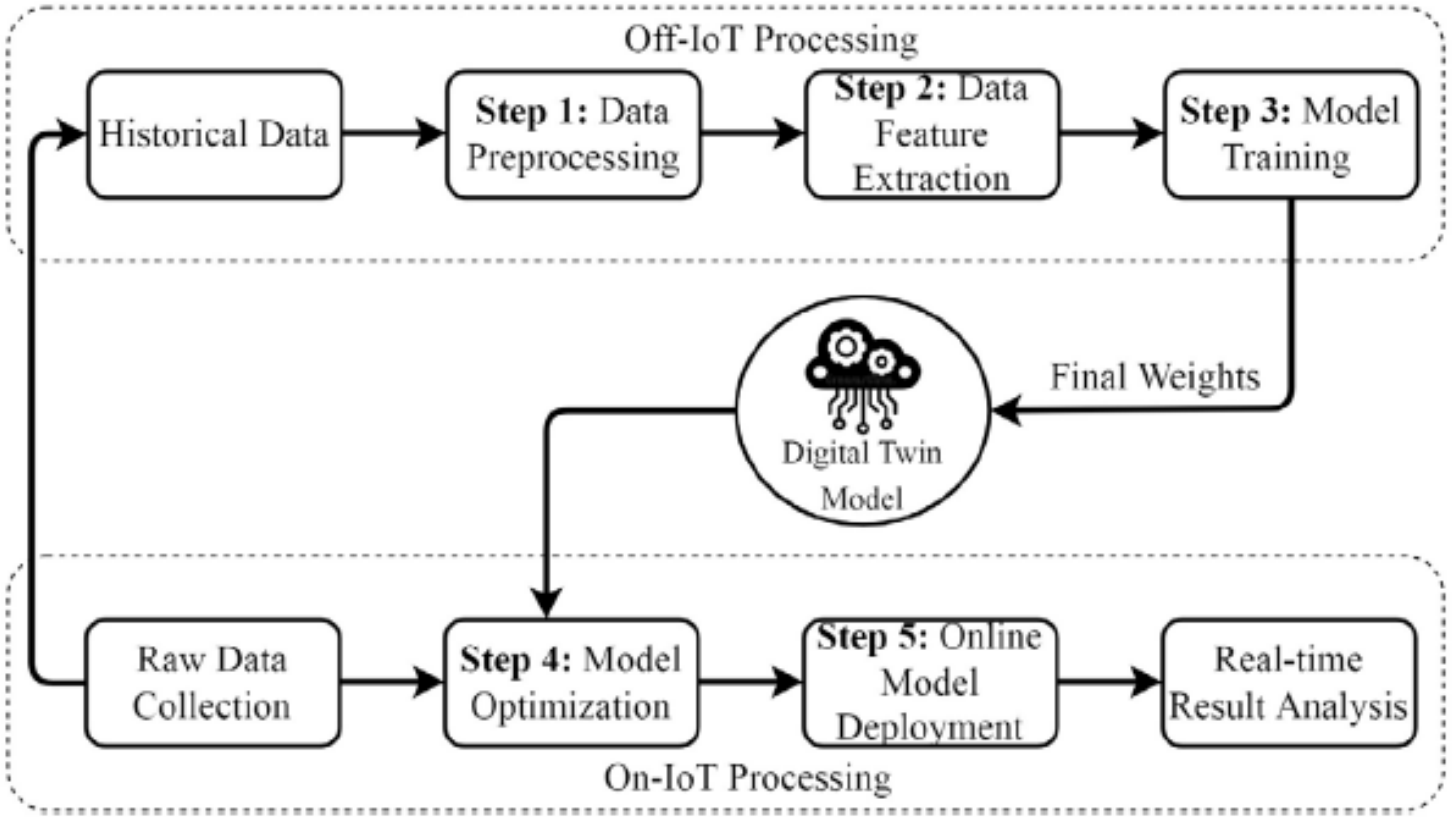

Fig. 4. The systematic flow of the proposed activity monitoring solution.

3. Digital Twin and Blockchain-inspired proposed solution

3.3 Real-time data analysis

Physical Event Representation

- Recognizing a singular physical event successfully is considered one of the primary components of the proposed methodology.
- For event prediction, 1 Dimensional (1D) Convolutional Neural Network (CNN) is considered the most suitable solution to process data signals by extracting features.
- To perform the operation of feature extraction, CNN is consisting several convolutional and pooling layers that learn the features according to their type of event [33].
- In this manner, the concept of feature extraction and learning provides another space for the proposed methodology that provides the capability of analyzing raw data signals in real time.
- The number of filters utilized in convolutional layers helps to evaluate local patterns from the captured signals and patterns of physical patterns are represented with the help of pooling layers.
- Traditional CNN-based solutions can separate the temporary patterns from the single or multi-channel-based data signals.
- **However, a limitation with respect to analyzing long temporal patterns related to different physical events such as running and climbing steps has been realized in 1D CNN.** To overcome the elimination of CNN Gated Recurrent Unit (GRU)-based hybrid approach is introduced in this proposed study

3. Digital Twin and Blockchain-inspired proposed solution

3.3 Real-time data analysis

Dynamic feature modeling

- As we have already discussed, CNN is recognizing the type of an event without analyzing the sensitivity of time.
- The supposition of time independency becomes invalid in the domain of healthcare as the physical events are highly dependent on the time factor.
- To deal with the above-discussed limitation, Gated Recurrent Unit (GRU) can be utilized to analyze the type of physical event by following the concept of sequential modeling [34].
- **The concept of GRU with CNN can provide more stability to the proposed model in terms of event analysis by taking a lesser amount of data for training.**
- Hence, we proposed a CNN-BiGRU-inspired hybrid solution to recognize a sequential physical event recognition by computing the successive connections between data samples.

3. Digital Twin and Blockchain-inspired proposed solution

3.3 Real-time data analysis

Dynamic feature modeling

- The concept of sequential feature modeling is achieved by providing the features extracted by the CNN model denoted as $X = [x_1, x_2, \ldots., x_n]$ as an input to the GRU network.
- Here, X represents the feature matrix and xi defines the current state of the event.
- In this manner, X_n feature matrices are provided as input to the GRU network at a specific time instance ti belongs to time module ΔT

$$r_t = \sigma(W_r x_n + U_r h_{t-1} + b_r) \tag{3}$$

$$\sigma(x) = \frac{1}{1 + e^{-x}} \tag{4}$$

$$c_t = tanh(W x_t + (U(r_t \circ h_{t-1}) + b)) \tag{5}$$

3. Digital Twin and Blockchain-inspired proposed solution

3.3 Real-time data analysis

Dynamic feature modeling

$$tanh = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}} \tag{6}$$

$$u_t = \sigma(W_u x_t + U_u h_{t-1} + b_u) \tag{7}$$

$$h_t = u_t \circ h_{t-1} + (1 - u_t) \circ c_t \tag{8}$$

$$O_t = softmax(W_o h_t) \tag{9}$$

$$L\langle O_t, P_t \rangle = -\sum_{i=1}^{m} O_t \log(P_t) \tag{10}$$

Opinion about the paper

- Digital Twin is a concept that models physical objects or processes in the real world in real time in a digital environment, and if applied to smart care for the elderly, it will be able to monitor and analyze the health status and movement of the elderly in real time to provide individual care.

- Digital twin solutions can provide a safe and comfortable environment for the elderly. For example, when an elderly person falls or is in an emergency at home, the digital twin can detect it and immediately notify the person involved. It seems to be meaningful in that it can receive prompt help and reduce the risk of accidents.

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Thank you

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