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Modeling and Analysis of First Aid Command and Dispatching System of Cloud Medical System

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ABSTRACT Nowadays, with the phenomenon of the world ageing getting serious, the demand for intelligent medical treatment becomes higher than past. A series of smart bracelets have been launched for the health of the elderly, which can detect the health condition of the elderly in real-time. When an abnormal phenomenon occurs and the rescue will be needed, it can transmit the signal to the medical platform of the hospital or the mobile phone of its guardian, and then the hospital would send an ambulance and relevant doctors to rescue the patient. This paper mainly studies the starting bracelet sensors to collect data to rescue behavior of the entire process, proposes a Petri net model of distributed resource allocation based on cloud medical system. Through the structural analysis of the model and the construction of the algorithm, the rationality and efficiency of the whole system model are verified, and the case study shows that the model can effectively find the optimal scheduling path and each part of the system can respond well.

INDEX TERMS Cloud medical system, emergency scheduling, Petri net.

I. INTRODUCTION

With population aging problem, medical and health services are facing great challenges. For the elderly people, the vast majority suffer from potentially sudden illnesses, such as heart attack or cerebral hemorrhage. If he/she had a sudden illness without anyone presenting or treated in time, his/her life would be in great danger. Therefore, with the development of the Internet of Things (IoT) [1]–[4], various products are emerging to monitoring the human body, among which the most representative product is wearable devices [5]–[9].

Smart bracelet could be an interesting representation of wearable intelligent device. Through the bracelet, the user can record real-time data while he/she carries out regular activities like exercise, sleep, diet in daily life. These captured data will be further synchronized with their phone to guide healthy life. At present, many smart bracelets capture exercise and step counting as the main application scenarios, but they are not able to make accurate positioning. Some of them are related to health fields, such as monitoring sleep and exercise reminder [5]–[7]. However, bracelets which are specifically designed to help users to assist their regular activities are rare. Data collected by the existing bracelets cannot be used as a real basis, and most of them are used for monitoring of the body [8], [9].

Therefore, this paper proposes a danger alarm intelligent system model based on the medical cloud platform, which combines the monitoring and first aid through the smart bracelet to realize the intelligent alarm system and cloud medical first aid dispatch [10]–[12]. The traditional medical emergency dispatch system is mainly composed of computer network platform system, wired voice communication system, acceptance system, information management system and vehicle-mounted positioning system [13]. In case of emergencies, such as the old aged person, who suffers from a heart attack or cerebral hemorrhage while walking, if there is no one around to call 120 in time, the precious time to save life will be lost. This is one of the major drawbacks of the traditional medical emergency dispatch system.

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Compared with the traditional system, our smart bracelet system can realize remote alarm and timely notify the hospital or relevant guardian for emergency treatment after detecting abnormalities.

In this work, the smart bracelet system is modeled by Petri nets and the function of each part is analyzed. Further, the interaction is carried out to predict the task completion time in case of emergency. Through analysis of the model, the response scheduling algorithm is provided to realize the seamless connection between the bracelet and the hospitals. This mechanism renders a reduction in the rescue time. Intelligent bracelet cloud medical system is a distributed system, so Petri net is selected for modeling and analysis [14]. It is an effective modeling tool, which can dynamically reflect the running state of resources and the relationship between various parts.

The main contributions of this article are as follows:

1) Petri net is employed to the intelligent bracelet cloud medical system, and the whole process of the system is modeled through the Extension Petri net (EPN).

2) By analyzing the model structure, the whole process is optimized, and then the whole process is simulated with an algorithm simulated to depth-first traversal [15], [16] to analyze the running state of the whole system.

3) The applicability and effectiveness of the optimized model are analyzed by a case study.

The rest of this paper is organized as follows: Section 2 presents an overview of the current research status of cloud medical device. Section 3 provides the definition of the Extension Petri net and the model diagram of the whole system. Section 4 depicts the detailed discussion of the proposed algorithm. Section 5 elucidates the proposed strategy through the case study. Finally, the paper concludes in section 6.

II. RELATED WORK

Recent era has witnessed sufficient numbers of researches on the direction of integrating the IoTs with healthcare [17]–[23] system. Life sense Health Watch [17] is one of the latest developments. In the latest research trend, literature [18] proposed a cloud medical system framework based on digital twins healthcare, which realized more accurate and rapid medical services for the elderly by combining digital twins with medical treatment. The patient health monitoring system in [19] integrated cloud computing with the IoT and demonstrated the flexibility of this system using an electrocardiogram in a study of patient real-time monitoring of congestive heart failure. An mPHASiS system based on the requirements of vital signs monitoring solution space is developed in [20]. This system provides an end-to-end solution to enhance the functions of hospital information system and realize the loose combination of web services and hospital information system. Articles [21]–[23] discuss the combination of the IoT and medical care, and make a series of analysis on the problems and challenges it may face.

However, there are few studies on the modeling and preliminary analysis of the whole system, most of which are on the scheduling of medical resources [24]–[28], without considering the combination of equipment and cloud system, or the mechanism of processing of the IoT [29]–[32]. For example, Mahulea *et al.* [24], [25] proposes a Petri net-based modular modeling of medical system, which can reasonably divide resources through the construction of medical protocols. Also in [27], Petri net was used to describe the relationship between medical process and resources, and the bottleneck medical resources of the system were effectively allocated by studying the patient scheduling problem.

These studies focus on the modeling and analysis of resources and protocols in the parts of medical process, while our work is modeling and analysis of the entire system of the intelligent monitoring and alarm system. Based on various factors and emergencies in real life, this paper adopts formal methods to conduct real-time analysis and research on the optimal scheduling scheme, and completes the first-aid measures of the whole process through the combination of wearable devices, cloud computing and system server. The hospital dispatching responds to the system and its model is Petri net.

III. PROCESS MODELING

This paper mainly focusses on the whole procedure from the bracelet detection to the hospital dispatch for rescuing the people who are in danger. By modeling and analyzing the system, the optimal scheduling scheme is obtained, to rescue *emergencies* faster. The smart bracelet cloud medical emergency system not only integrates cloud computing, IoTs and sensors [33], [34], but also considers the various needs between patients and hospitals and medical emergency system. It is capable to identify the gap and solutions when the needs are integrated with new technologies.

Fig.1 is the overall framework of our work, which is divided into four parts: process flow, application layer, modular implementation layer and module integration. Here, we mainly focus on the research of the first part – process modeling and analysis. Through the modeling and resource scheduling of the intelligent bracelet danger alarm system, the shortest time and the best path selection can be realized.

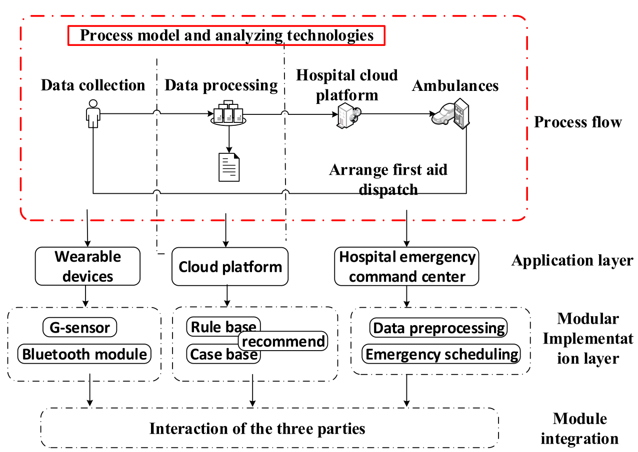

FIGURE 1. The overall framework.

Generally, before the implementation of the system, we need to conduct dynamic simulation and analysis of the whole process, which is a key step in the system implementation process and lays a solid theoretical foundation for the realization of the system.

In this section, we mainly introduce the formal modeling - Extension Petri net. Through definition and modular modeling of the intelligent first aid system, we can better understand the components and main functions of the system.

A. MODELING APPROACH

Petri net is chosen for a formal modeling of the system, which can be extended to depict more complex processes, such as Logical Petri net, Time Petri net and so on [35], [36]. In the process of operation of the system, there are several different types of resources, including the information of the wearer of the bracelet, the hospital, nurses and vehicles. In order to depict them effectively, we describe them by extending the type set of the place. The following is a formal definition of extension petri net.

Definition 1: An *Extension Petri net* is a five-tuple, *EPN*= (P, T, F, M_0, R), where

1) $P = P_C \bigcup P_S$ is a finite set of places, where $P_S = \{P_j|$ j=1, 2, 3... } is the set of task store place and $P_C = \{H_i|$i=1, 2, 3...)} is the set of control places.

2) $T = T_C \bigcup T_U$ is a finite set of transitions, $T \bigcap P = \emptyset$, $T_C \bigcap T_U = \emptyset$, in which

a) T_C denotes a set of controllable transitions;

b) T_U denotes a set of uncontrollable transitions;

3) $A = (P \times T) \bigcup (T \times P)$ is a set of directed arcs.

4) $M: P \to Z$ (set of non-negative integers) is a marking function, where M_0 is the initial state, and $\forall p \in P$, $M(p)$ is the number of tokens in p;

5) R is a time interval function defined on the transition set, and is expressed as $T \to R_0 \times (R_0 \bigcup \{\infty\})$, where R_0 represents the set of nonnegative rational numbers.

Definition 2: The transition firing rules of *EPN*: $\forall t \in T$, $R(t) = (a, b)$, if $\forall p \in {}^{\cdot} t$: $M(p) \geq 1$, and t also satisfies the interval function $R(t)$, then t is enabled in M; if t is enabled, then it can be fire; and firing t in M generates a new marking M': $\forall p \in {}^{\cdot} t$: $M'(p) = M(p) - 1$, $\forall p \in t^{\cdot}$: $M'(p) = M(p) + 1$, $\forall p \notin {}^{\cdot} t \bigcap t^{\cdot}$: $M'(p) = M(p)$;

B. MODULAR MODELING

At the beginning of this section, the structure of the Extension Petri net is defined, and the following section is the detailed modeling of the system. As mentioned earlier we divided it into two parts, the first part is the smart bracelet medical system, as shown in Fig.2, and the second part is the model of the hospital cloud platform system, as shown in Fig.3.

Fig.2 depicts the operation process of the smart bracelet system, which is a simplified system model. Table-1 contains the representation of each symbol used in Fig.2

During the entire process, data collection and processing are performed in real-time. Hence, the immediate transitions are used in this model. On the cloud platform, multiple servers can be simultaneously accessed. In this paper, we only analyze the operating principle of the system and adopt the single-user mode.

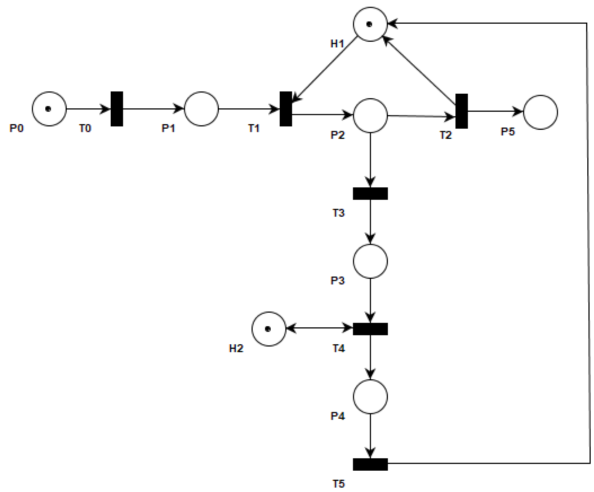

FIGURE 2. Bracelet modeling.

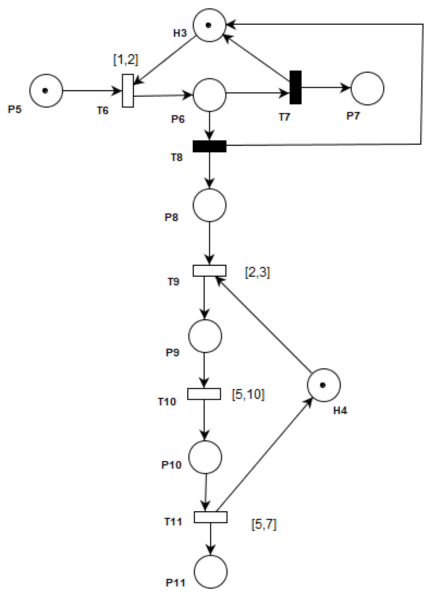

FIGURE 3. The model of hospital cloud platform.

TABLE 1. Graphic symbol.

place	Meaning	transition	Meaning
P_0	bracelet sensor	T_0	data collection
P_1	data memory	T_1	processing data
P_2	scratch pad memory	T_2	upload hospital system
P_3	bracelet cloud system	T_3	upload bracelet system
P_4	bracelet client	T_4	intelligent recommendation
P_5	hospital cloud platform	T_5	complete recommended
H_1	bracelet processor		
H_2	bracelet database		

TABLE 2. Graphic symbol.

place	Meaning	transition	Meaning
P_5	hospital cloud platform	T_6	data analysis
P_6	scratch pad memory	T_7	confirm false positives
P_7	list of unprocessed	T_8	confirm correct positives
P_8	first aid dispatch system	T_9	first aid resource scheduling
P_9	first aid resources ready	T_{10}	ambulance departure
P_{10}	arrive the rescue site	T_{11}	rescue and return to hospital
P_{11}	end of the rescue		
H_3	system administrator		
H_4	emergency resources		

Fig.3 mainly focusses on the hospital scheduling system. First, the cloud platform of the hospital receives the signal of danger, and then the administrator checks the information to determine whether it is a false alarm or not. Based upon the certainty, emergency resource scheduling will be conducted. Each process has a time interval to ensure that it occurs within the stipulated time period and thus the message should be processed as quickly as possible. The specific representation of each symbol of the model is shown in Table 2.

The time interval shown in Fig.3 is dependent upon the time taken for the rescuer of a certain hospital. For different hospitals, these times should vary. For transition with time interval, its trigger is according to the certain principle, as shown in Definition 1. For example, T_6 has a time interval of [0, 1], which means its occurrence needs at least 0 unit time and at most 1 unit time.

By analyzing the time interval of the model of the hospital cloud platform, the shortest and longest time of the whole system can be obtained. In this particular case, the shortest time is 13 minutes and the longest time is 22 minutes.

For control place H_4, the token number represents the number of ambulances and medical staff available. Here, we assume that the medical staff and the ambulance are tied together, that is, an ambulance is equipped with a fixed number of people.

In order to facilitate the synthesis of the model, we simplified Fig.3 and deleted the unimportant branches, leaving only those areas which require further study. The simplified figure is shown in Fig.4.

The functions and properties of the simplified model are the same as those shown in Fig.3, still satisfies the characteristics of *Safety* and *Reachability* [35] of the Petri net. Fig.2 and Fig.4 are the *EPN* models of the two systems. In the next section, we will integrate them to analyze the interaction between the parts.

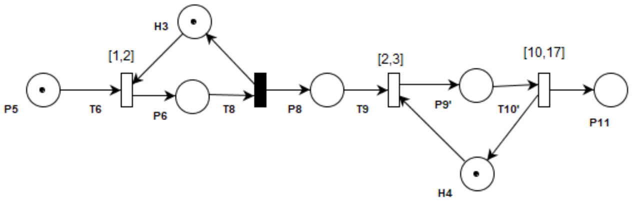

FIGURE 4. A simplified model.

C. MODEL INTEGRATION

Through the interaction between smart bracelet and hospital platform, the real-time monitoring and rescue of elderly people can be realized. Currently, this function has not been implemented in many ways, and there exists too many aspects [22]. Therefore, we model this process to judge the rationality and efficiency of the model.

First of all, we extracted a specific area and integrated the model for this region. In that particular area, three hospitals are cooperated with the smart bracelet. In case of a crisis, which hospital should give first aid is decided through the scheduling of the system. Its model for this specific purpose is shown in Fig.4.

Let us assume there is an old man in emergency in the denoted area and the cloud platform of the hospital receives the emergency information. The system then deploys aid, based on the distance between each hospital and the patient, and the amount of available resources. In the process of dispatching, distance should be the first consideration. This information is directly displayed on the cloud interface to denote the ordered list of hospitals which are near and far from the point of emergency. The system will select the nearest hospital for dispatch. If the emergency resources of the hospital are not enough, the second hospital from the ordered list is chosen. In a word, dispatch vehicles should be taken out as early as possible for rescue.

In Fig. 5, (T_9', P_9', T_{10}'), (T_9'', P_9'', T_{10}'') and $(T_9''', P_9''', T_{10}''')$ represent the three hospitals in the region. In terms of time budget, the middle hospital is the closest with relatively less resources, followed by the third one with the highest resources. The first one is with the longest time, but it resources are moderate among the available three hospitals. Although the *EPN* model in Fig.5 is simple, the principle is complex, and corresponding algorithm needs to be combined to realize the operation of the whole emergency treatment process of the smart bracelet system.

To ensure the proper functionality of the developed model, we need to analyze its structure. First, we have verified that there is no deadlock within the system, which eventually denotes that there should not be any dead transition. If there is a dead transition, the model will be appropriately modified in order to cope up with such a situation. Therefore, we use the special software *pipe* [37] to analyze the model and obtained a reachability state graph as shown in Fig.5. This result shows that in the whole process, all transitions are possible to occur, so for the model in Fig.4, it is safe without deadlock.

Secondly, we have verified that in any case, it is can reachable and is able to achieve the final result as expected. In exception, the bracelet can have two different results: one is to recommend a healthy lifestyle for the wearer and the other is to inform the hospital for emergency rescue in

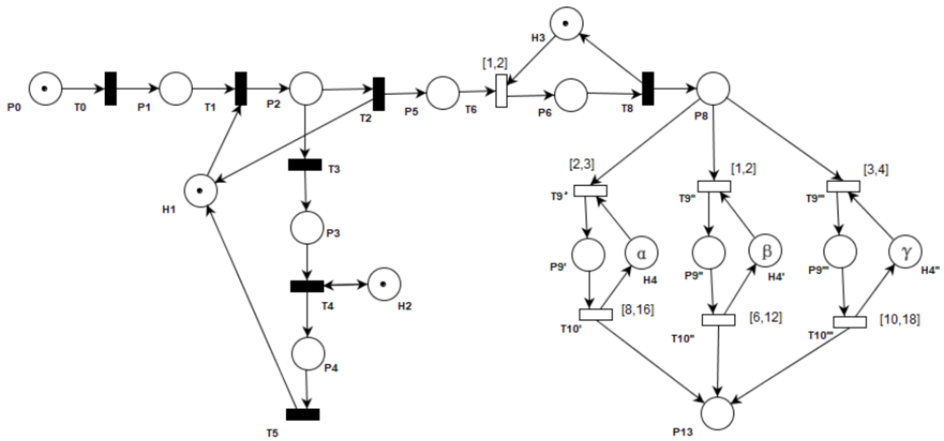

FIGURE 5. The *EPN* model for detection and rescue.

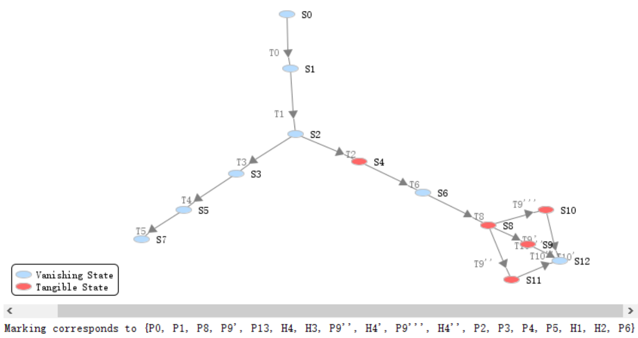

FIGURE 6. The reachability graph.

critical situation. It can be observed from the above figure that there are two optional paths, and the final result is consistent with the comparison of the model, that is, it meets our requirements and also confirms the design principles of the model.

Through the verification of the structure, the rationality and correctness of the model are obtained, which provides a theoretical basis for the work. In the next section, the algorithm for operating the system and the scheduling algorithm for first aid resource allocation are proposed.

IV. SCHEDULING ALGORITHM

Earlier, the model of first aid command and dispatch system of cloud medical system based on smart bracelet has been developed, but the details of its operation principle still require the algorithms to support. In this section, we will give the corresponding algorithm to find the optimal first aid scheduling scheme.

In the whole process, we need to establish two algorithms to complete, which is based on the Petri net we already built. The first one is used to analyze the collect data in the smart bracelet, so as to take different operations for the analysis results; the other one is to obtain an optimal scheme through a scheduling mechanism in the aspect of arranging hospital for emergency treatment. The following is a detailed introduction of these two algorithms.

The first algorithm is used in the process (P_2, T_2) and (P_2, T_3). By comparing the collected data with the original data, a value of similarity is obtained, and then the obtained value of similarity is utilized to carry out the next operation. The specific algorithm steps are as follows:

Algorithm 1 Analyze and Classify the Data

Input: the token vector s that transitions T_1 to pass, user initial data vector set s‘, $EPN = (P, T, F, M_0, R)$
Output: the path F_1 to be selected by the system
1. $F_1 = \emptyset$, $M =$sim(s, s');
2. Calculate the similarity between s and s' and store it in M:
3. **While** similarity M is obtained from formula (1) **do**
  the results are classified and a path is generated;
  3.1 **if** $M \leq 0.3$ **then**
    $F_1 = (P_2, T_2)$;
  end
  3.2 **else**
    $F_1 = (P_2, T_3)$;
  end
end

The similarity calculation method in algorithm 1 is as follows:

$$M = \text{sim}(s, s') = \frac{\sum_{i=1}^{n}(s_i \times s_i')}{\sqrt{\sum_{i=1}^{n}(s_i)^2}\sqrt{\sum_{i=1}^{n}(s_i')^2}} \tag{1}$$

The time complexity of Algorithm 1 is O (1), so it is not computationally expensive.

The second algorithm is applied to the process (P_8, T_9'), (P_8, T_9'') and (P_8, T_9'''), which is mainly used to dispatch hospital resources for emergency response. At this point, the identification set of the model is $M_5 = (0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 1, 1, \alpha, \beta, \gamma)$, which is used as part of the input of the algorithm. Therefore, there are three aspects that may affect the whole scheduling process i.e.

i. The response time of each hospital system;

ii. The distance from the hospital to the target location;

iii. Resource availability in the hospital that can be scheduled. These factors are taken into account while designing the algorithm. And the algorithm steps are as follows.

Algorithm 2 Hospital Emergency Dispatch

Input: $EPN = (P, T, F, M_0, R)$, initial marking M_5

Output: the optimal rescue scheduling path F_2, and the shortest and longest time periods S

1. $F_2 = \emptyset$, $\Gamma = \{M_5\}$, $S = [1, 2]$;
2. Let M_5 be the root node, and mark it as "enabled";
3. **while** "enabled" nodes exist **do**

 Choose the "enabled" node as M';

 3.1 **if** there is $\exists t \in T \rightarrow M'[t >$ **then**

 Select the transition t with the fastest and shortest occurrence interval R relative to other transitions;

 $F_2 = F_2 \bigcup \{t\}$;

 $S = S + R$;

 Go to 3;

 end

 3.2 **else**

 $T = T - F_2$; $F_2 = \emptyset$;

 $S = [1, 2]$;

 Go to 2;

 end

end

Theorem 1: Algorithm 2 can be terminated

Proof: Through the structural analysis of the model in section 3.3, we can observe that the input *EPN* of Algorithm 2 can reach the final state space under any identification. Algorithm 2 selects an enabling transition t under the marking M_5, and the transition response is the fastest and the time interval is the shortest. Meanwhile, the transition time interval is stored in S and the transition t is stored in F_2 by Step 3.1. If there is no enabled transition, the transition t in the current path is removed from the transition set T, and the path is maintained as empty, and the time interval is restored by Step 3.2. Then go back to Step 2 to re-select the other enabled transitions under identification M_5. This means that the marking set of "enabled" is continuously updated until it becomes empty, so it is limited. The above description proves that Algorithm 2 can be terminated. Through the depth traversal of the branch, the optimal path that can reach the final state is found.

V. ANALYSIS

The first aid command and dispatch system model ofthe intelligent bracelet cloud medical system designed insection 3, the optimal first aid dispatch is realizedby combining the algorithm given in section 4. Andin this section, the results are analyzed andverified.

In Fig. 4, we assume that its data similarityis less than 0.3, and then through analysis,three different paths and the corresponding shortest and longesttime S can be obtained, as shown below:

If $\beta \geq 1$,

$$F' = (T_0, T_1, T_2, T_6, T_8, T_{9'}, T_{10''}), \quad S_{'} = [8, 16];$$

If $\beta < 1$ and $\alpha \geq 1$,

$$F'' = (T_0, T_1, T_2, T_6, T_8, T_{9'}, T_{10''}), \quad S_{''} = [11, 21];$$

If $\alpha < 1$ $\beta < 1$ and $\gamma \geq 1$,

$$F''' = (T_0, T_1, T_2, T_6, T_8, T_{9'}, T_{10'''}), \quad S_{'''} = [14, 24];$$

Here, we assume that the resources of the threehospitals are α, β and γ , respectively, and then select an optimalscheduling strategy by analyzing the number of resources indifferent situations.

There is another situation in Fig.4, that is,the similarity value of the data is greater than0.3, in this case, only one path can occur,i.e. $F = (T_0, T_1, T_3, T_4, T_5)$, which means that there is no danger alarm, no needto dispatch, just recommendation.

The reason behind the occurrence of these fourdifferent paths is that at each time the emergencyresources of the hospital are uncertain then it should bejudged according to the specific actual situation. Theexperimental results showed that the closer the hospital wasto the location of the outbreak, the faster theresponses to the danger signal was, and the shorter therescue time was. Under the condition of insufficientresources, all the optimal conditions were successively traversedto find the most suitable path for the currentemergency. And according to the actual situation ofanalysis and investigation, the designed model can be verifiedto be reasonable.

VI. CONCLUSION

In this paper, the Extension Petri net was used to model the cloud medical emergency command and dispatch system of the smart bracelet, and the whole process was simulated dynamically. By incorporating the scheduling algorithm, the optimal scheduling path in different situations was obtained.

This content is an analysis and modeling of the operating principle. In the future work, we will continue to conduct in-depth studies to make further contributions to the better integration of smart bracelet and medical treatment.

REFERENCES

[1] B. R. Ray, M. U. Chowdhury, and J. H. Abawajy, "Secure object tracking protocol for the Internet of Things," *IEEE Internet Things J.*, vol. 3, no. 4, pp. 544–553, Aug. 2016.

[2] Y. Yin, Y. Zeng, X. Chen, and Y. Fan, "The Internet of Things in healthcare: An overview," *J. Ind. Inf. Integr.*, vol. 1, pp. 3–13, Mar. 2016.

[3] F. H. Alqahtani, "The application of the Internet of Things in healthcare," *Int. J. Comput. Appl.*, vol. 180, no. 18, pp. 1–5, Feb. 2018.

[4] B. P. L. Lo, H. Ip, and G.-Z. Yang, "Transforming health care: Body sensor networks, wearables, and the Internet of Things," *IEEE Pulse*, vol. 7, no. 1, pp. 4–8, Jan./Feb. 2016.

[5] Y. Liu, B. Dong, B. Guo, J. Yang, and W. Peng, "Combination of cloud computing and Internet of Things (IoT) in medical monitoring systems," *Int. J. Hybrid Inf.*, vol. 8, pp. 367–376, Dec. 2015.

[6] H. Tian, P. Lei, L. Xingjuan, and X. Shusong, "Wearable activity recognition for automatic microblog updates," in *Proc. IEEE/ASME Int. Conf. Adv. Intell. Mechtron.*, Jul. 2009, pp. 1720–1723.

[7] *Limmex Emergency Watch*. Accessed: Nov. 22, 2019. [Online]. Available: http://stage.shop.limmex.com/en/products/emergency-watch

[8] C. Zhu, W. Sheng, and M. Liu, "Wearable sensor-based behavioral anomaly detection in smart assisted living systems," *IEEE Trans. Autom. Sci. Eng.*, vol. 12, no. 4, pp. 1225–1234, Oct. 2015.
[9] V. M. Rohokale, N. R. Prasad, and R. Prasad, "A cooperative Internet of Things (IoT) for rural healthcare monitoring and control," in *Proc. Int. Conf. Wireless Commun., Veh. Technol., Inf. Theory Aerosp. Electron. Syst. Technol.*, Feb./Mar. 2011, pp. 1–6.
[10] L. Angelini, M. Caon, S. Carrino, L. Bergeron, N. Nyffeler, M. Jean-Mairet, and E. Mugellini, "Designing a desirable smart bracelet for older adults," in *Proc. ACM Conf. Pervasive Ubiquitous*, Zurich, Switzerland, Sep. 2013, pp. 425–434.
[11] M. Manimaraboopathy, S. Vijayalakshmi, and D. Hemavathy, "A wearable multiparameter medical monitoring and alert system with first aid," *Int. J. Smart Sens. Intell. Syst.*, vol. 10, no. 4, pp. 446–458, 2017.
[12] E.-S. Shanko and M. Papoutsidakis, "Real time health monitoring and wireless transmission: A μ controller application to improve human medical needs," in *Proc. E-Health Bioeng. Conf.*, 2014, pp. 1–4.
[13] M. Al-Khafajiy, H. Kolivand, T. Baker, D. Tully, and A. Waraich, "Smart hospital emergency system," *Multimedia Tools Appl.*, vol. 78, no. 14, pp. 20087–20111, Jul. 2019.
[14] Z. Wu, *Petri Net Principle*. Beijing, China: Electronic Industry Press, 1998.
[15] J. Hopcroft and R. Tarjan, "Algorithm 447: Efficient algorithms for graph manipulation," *Commun. ACM*, vol. 16, no. 6, pp. 372–378, 1973.
[16] R. Tarjan, "Depth-first search and linear graph algorithms," in *Proc. Annu. Symp. Switching Automat. Theory*, 1971, pp. 114–121.
[17] *Life Sense Health Watch*. Accessed: Oct. 26, 2019. [Online]. Available: http: //www.lifesense.com/ newsd/548
[18] Y. Liu, L. Zhang, Y. Yang, L. Zhou, L. Ren, F. Wang, R. Liu, Z. Pang, and M. J. Deen, "A novel cloud-based framework for the elderly healthcare services using digital twin," *IEEE Access*, vol. 7, pp. 49088–49101, 2019, doi: 10.1109/ACCESS.2019.2909828.
[19] J. H. Abawajy and M. M. Hassan, "Federated Internet of Things and cloud computing pervasive patient health monitoring system," *IEEE Commun. Mag.*, vol. 55, no. 1, pp. 48–53, Jan. 2017, doi: 10.1109/MCOM.2017.1600374CM.
[20] P. Kulkarni and Y. Ozturk, "mPHASiS: Mobile patient healthcare and sensor information system," *J. Netw. Comput. Appl.*, vol. 34, no. 1, pp. 402–417, Jan. 2011, doi: 10.1016/j.jnca.2010.03.030.
[21] N. Bui and M. Zorzi, "Health care applications: A solution based on the Internet of Things," in *Proc. 4th Int. Symp. Appl. Sci. Biomed. Commun. Technol.*, Oct. 2011, Art. no. 131.
[22] M. Hassanalieragh, A. Page, T. Soyata, G. Sharma, M. Aktas, G. Mateos, B. Kantarci, and S. Andreescu, "Health monitoring and management using Internet-of-Things (IoT) sensing with cloud-based processing: Opportunities and challenges," in *Proc. IEEE Int. Conf. Services Comput.*, Jun./Jul. 2015, pp. 285–292, doi: 10.1109/SCC.2015.47.
[23] M. B. Blake, "An Internet of Things for healthcare," *IEEE Internet Comput.*, vol. 19, pp. 4–6, Aug. 2015, doi: 10.1109/MIC.2015.89.
[24] C. Mahulea, L. Mahulea, J. M. G. Soriano, and J. M. Colom, "Modular Petri net modeling of healthcare systems," *Flexible Services Manuf. J.*, vol. 30, nos. 1–2, pp. 329–357, 2018, doi: 10.1007/s10696-017-9283-9.
[25] C. Mahulea, J.-M. García-Soriano, and J.-M. Colom, "Modular Petri net modeling of the Spanish health system," in *Proc. IEEE 17th Int. Conf. Emerg. Technol. Factory Automat.*, Sep. 2012, pp. 1–8, doi: 10.1109/ETFA.2012.6489599.
[26] C. Mahulea, L. Mahulea, J.-M. García-Soriano, and J. M. Colom, "Petri nets with resources for modeling primary healthcare systems," in *Proc. 18th Int. Conf. Syst. Theory, Control Comput.*, Oct. 2014, pp. 639–644.
[27] Y. Li, H. Wang, Y. Li, and L. Li, "Patient assignment scheduling in a cloud healthcare system based on Petri net and greedy-based heuristic," *Enterprise Inf. Syst.*, vol. 13, no. 4, pp. 515–533, 2019, doi: 10.1080/17517575.2018.1526323.
[28] Y. Li, Y. Li, N. Wang, and H. Wang, "A Petri net based model for a cloud healthcare system," in *Proc. 30th Chin. Control Decis. Conf. (CCDC)*, Jun. 2018, pp. 3928–3931.
[29] T. Pasquier, D. Eyers, and J. Bacon, "Viewpoint personal data and the Internet of Things: It is time to care about digital provenance," *Commun. ACM*, vol. 62, no. 6, pp. 32–34, 2019, doi: 10.1145/3322933.
[30] Z. Alansari, S. Soomro, M. R. Belgaum, and S. Shamshirband, "The rise of Internet of Things (IoT) in big healthcare data: Review and open research issues," in *Progress in Advanced Computing and Intelligent Engineering* (Advances in Intelligent Systems and Computing), vol. 564. Dec. 2017, doi: 10.1007/978-981-10-6875-1_66.
[31] C. Liu, C. Yang, X. Zhang, and J. Chen, "External integrity verification for outsourced big data in cloud and IoT: A big picture," *Future Gener. Comput. Syst.*, vol. 49, pp. 58–67, Aug. 2015.
[32] F. J. Riggins and S. F. Wamba, "Research directions on the adoption, usage, and impact of the Internet of Things through the use of big data analytics," in *Proc. 48th Hawaii Int. Conf. Syst. Sci.*, Kauai, HI, USA, Jan. 2015, pp. 1531–1540.
[33] H. Djelouat, X. Zhai, M. Al Disi, A. Amira, and F. Bensaali, "System-on-chip solution for patients biometric: A compressive sensing-based approach," *IEEE Sensors J.*, vol. 18, no. 23, pp. 9629–9639, Dec. 2018.
[34] X. Zhai, A. A. S. Ali, A. Amira, and F. Bensaali, "ECG encryption and identification based security solution on the Zynq SoC for connected health systems," *J. Parallel Distrib. Comput.*, vol. 106, pp. 143–152, Aug. 2017.
[35] J. C. Wang, *Timed Petri Nets: Theory and Application*. Norwell, MA, USA: Kluwer, 1998.
[36] C. Haoxun, "Net structure and control logic synthesis of controlled Petri nets," *IEEE Trans. Autom. Control*, vol. 43, no. 10, pp. 1446–1450, Oct. 1998.
[37] *Pipe*. Accessed: Oct. 29, 2019. [Online]. Available: http://sourceforge.net/projects/jfern

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