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Importance of Sensor Technology in Evaluation of Smart Monitoring System of Nursing Home

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In the era of informatization and population aging with rapidly advancing technology, nursing homes also pursue ‘smart systems’ to provide better care for elderly people. Although several smart systems have been implemented in care services for elderly people, there has not been an appropriate evaluation method for smart monitoring systems that can be used for nursing homes. Therefore, we developed an evaluation system considering recent technologies such as the Internet of Things, artificial intelligence, and sensor technology. Using the decision experiment and evaluation laboratory (DEMATEL) method and the analytical network process (ANP), the indicators for the evaluation of the smart monitoring system were defined by invited experts from diverse industries. As a result, four Level 1 indicators (system equipment capability, system stability, sensor configuration, and data processing) and 12 Level 2 indicators [sensing device frequency, life monitoring assistance, emergency response capabilities (system equipment capability), system running efficiency, system failure rate, system durability (system stability), assisted living device coverage, safety protection, emergency detection and alert (sensor configuration), and health data monitoring accuracy, health data acquisition speed, and health data analysis ability (data processing)] were determined. For the operation of the smart monitoring system, data processing capability and system stability were important, while system running efficiency, safety protection, emergency detection alert, and health data monitoring accuracy were important indicators for the evaluation of the system. The importance of the indicators was confirmed by the results of the evaluation of pension institutions in Suzhou City, China, which were selected by the constructed evaluation method and ArcGIS, a geographic information system (GIS) software. The results of this study indicate that the importance of sensor technology must be considered in the establishment and evaluation of smart monitoring systems for nursing homes. The results also provide a reference for the development of other smart systems for diverse purposes.

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1. Introduction

Amid the increase in the global population, population aging has become prominent in most countries.[1–3] It is predicted that the proportion of the population over 65 years old in Europe and North America will increase from 18.7 to 26.9% of their total population, and that in East Asia and Southeast Asia will increase from 12.7 to 25.7%, according to the projection of the age structure of the global population from 2022 to 2050.[4,5] Therefore, aging will inevitably cause social problems and challenges,[6] while traditional ways of caring for elderly people will fail to meet their needs. Smart information-based elderly care services can be a solution to fulfill the requirement of society as well as of elderly people. However, how to apply such advanced technology to satisfy their diverse needs, including even emotional and physiological needs, is an urgent problem that must be solved.

Recently, with the development of "Internet +", artificial intelligence (AI), and big data technologies, the so-called silver industry has adopted smart technology in various products and services including a real-time health monitoring system. The monitoring system largely depends on the development of smart sensors (sensors 4.0) that are used in various industries such as medicine, transportation, and education.[7–10] For example, Honeywell's Independent LifeStyle Assistant™ (*ILSA*) adopts various wireless sensor technologies to assist elderly people in their daily life.[11] A smart system with sensor technology helps elderly people maintain safe lives and prevent unexpected injuries and diseases. In such a system, data required for monitoring is collected from the sensor network and transmitted to the cloud server for processing and analysis and to execute necessary commands through the wireless sensor network.[12] Such a process can be used to monitor the health status of elderly people and prevent emergencies in nursing homes. However, at present, the use of smart monitoring systems is still in the exploratory stage as comprehensive evaluation and relevant research are necessary before they can be adopted in real life.

The application of smart elderly care services in nursing homes is mainly based on the Internet of Things, Internet, mobile Internet technology, and cloud computing technology. Through various sensors and wireless communication networks, information of elderly people at home is collected and transmitted in real time. The Wechat public platform and other channels enable elderly people to access services such as emergency rescue, daily care, active care, making appointments, shopping, and payment of fees. Considering the characteristics of sensor technology and the demands of elderly people, we developed an evaluation system for the smart monitoring system of a nursing home. We used the decision experiment and evaluation laboratory-analytic network process (DEMATEL-ANP) to define evaluation indices and determine their weights in order to understand the importance of the indices in the evaluation system. The research result is expected to provide a reference for the development and application of smart monitoring systems to provide more effective care for elderly people at nursing homes, as well as for other diverse purposes.

The concept of the smart monitoring system is referred to as gerontechnology and is based on smart home technology. Gerontechnology is the technology for aiding independent living and social participation of elderly people and integrates sensors, monitoring equipment, robotics, and environment control technology with residential infrastructure. It aims to create a safe and reliable living environment that meets the needs of elderly people to realize a safe, independent, and healthy life. On the basis of the concept of gerontechnology, the British Life Trust proposed 'smart retirement' for which a "fully intelligent apartment for elderly people" equipped with a full set of electronic chip equipment would be built.(13) Equipment incorporating computer technology, wireless sensor technology, and others are used for "smart elderly care". As one of the important technologies, the Internet of Things (IoT) is used for the interconnection of sensors, transmission, storage, and processing of information (data), and control of the entire network. This network enables telemedicine, nursing services, communication, community activities, and the control of assistance robots through the local area network (LAN).(14) As an attempt to realize the smart monitoring system, the Internet of Medical Things (IMT) was developed in the USA, while Germany's Ambient Assisted Living system (AAL) has been used for the rehabilitation and prevention of disease of elderly people. Japan's robotics technology also has been used for smart care of elderly people.(15) There exist a number of ethical conflicts in the application of smart home technologies for elderly care. Therefore, it is necessary to further investigate the ethical issues with regard to the decision-making process of weighing the advantages and disadvantages of these technologies.(16, 17) Nurses may be essential to promote ethical awareness and practice in designing and implementing these technologies.

2. Methods

2.1 Architecture of smart monitoring system

The architecture of the smart monitoring system for nursing homes is presented in Fig. 1. The smart device of the all-in-one health machine collects and uploads data to the server through the

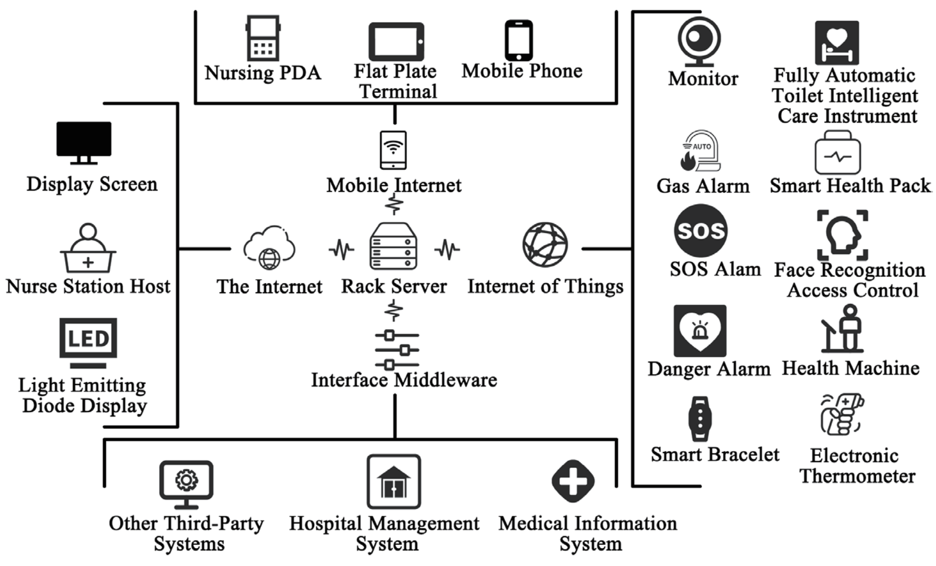

Fig. 1. Architecture of smart monitoring system for nursing home.

IoT. Then, the management system in the server processes the data and uses the processed data for various purposes such as preemptive warning of emergencies through mobile networks and decision-making for the improvement or addition of the necessary services and care. The smart monitoring system comprises the front end of the World Wide Web (WWW), a server-side module, and a mobile terminal. The system in the nursing home consists of five components: a management platform for radio-frequency identification, a video surveillance linkage module, a service platform, a cloud computing platform, and a platform for a short message service (SMS). The system in the nursing home also gathers data on environmental parameters, the exercise status of elderly people, and other control parameters. The users of the smart monitoring system include managers of the nursing home and family members. The smart monitoring system is designed to have appropriate system functions for user needs and virtual services.

2.2 Evaluation indicator

The evaluation system of the smart monitoring system is developed considering the needs of elderly people and the results of relevant research (Table 1). System software is critical for realizing the system management capability and system stability, and hardware is significant in data processing and the device configuration as the system's efficiency relies on the integrity, efficiency, and stability of the multiple devices used in the system. To define the indicators of the evaluation system, we invited nine experts, three in architectural design and two each in urban planning, information engineering, and medicine and health management, to participate in a questionnaire survey as they have an understanding of the research on the care of elderly people. By consistency and verification tests, the responses of all nine experts were validated. The evaluation indicators (Level 1) were defined as system equipment capability (D_1), system stability (D_2), sensor configuration (D_3), and data processing (D_4).

Table 1
Evaluation system of smart monitoring system.

Target layer	Level 1 indicators	Level 2 indicators
Evaluation system of smart monitoring system	System equipment capability (D_1)	Sensing device frequency (C_1)
		Life monitoring assistance (C_2)
		Emergency response capabilities (C_3)
	System stability (D_2)	System running efficiency (C_4)
		System failure rate (C_5)
		System durability (C_6)
	Sensor configuration (D_3)	Assisted living device coverage (C_7)
		Safety protection (C_8)
		Emergency detection and alert (C_9)
	*D*ata processing (D_4)	Health data monitoring accuracy (C_{10})
		Health data acquisition speed (C_{11})
		Health data analysis ability (C_{12})

2.3 Decision experiment and evaluation laboratory (DEMATEL)

2.3.1 Concept and application

The evaluation of the smart monitoring system relies on many factors, and the relationship between factors may be complex. Thus, a systematic structural system is required. The hierarchical structure of the smart monitoring system needs to be established focusing on key links and nodes in the system. The development of big data and AI algorithms enables new ideas to be integrated into the DEMATEL method,[18] such as adopting the graph theory and matrix tools to analyze the relationship between various factors.[19] Then, the complexity of the evaluation system can be simplified to effectively analyze the logical function and causal relationship between each index and determine the relationship and the importance of the indexes.

2.3.2 Calculation

2.3.2.1 Step 1

A direct impact matrix is created. The direct influence matrix M is established on the basis of the mutual influence relationship of factors and is normalized to obtain the normalized direct relationship matrix D:

$$D = M / K \ , \tag{1}$$

$$K = \max\left\{ \max \sum_{i=1}^{n} \left| a_{ij} \right|, \max \sum_{i=1}^{n} \left| a_{ij} \right| \right\}, \tag{2}$$

where a_{ij} is the degree of influence of the ith row index on the jth column index.

2.3.2.2 Step 2

The combined impact matrix is created. Using D, the comprehensive influence matrix T is constructed as Eq. (3).

$$T = D\left(I - D\right)^{-1} \tag{3}$$

2.3.2.3 Step 3

The centrality is calculated to find the degree of risk evaluation indicators:

$$c_i = \sum_{j=1}^{n} t_{ij} \ , \tag{4}$$

$$r_j = \sum_{i=1}^{n} t_{ij} \ , \tag{5}$$

where t_{ij} is the degree of influence of the ith row index on the jth column index. The centrality is defined as $c + r$, and the cause degree is $c - r$. If the cause degree is greater than 0, the factor has a greater probability of being a cause element; otherwise, it becomes a result element.

2.3.2.4 Step 4

The model threshold λ is determined. The threshold is set as the mean value, as the mean value is more in line with the comprehensive thinking of human beings. To determine the dependence and feedback relationship between risk evaluation indicators and to construct the network relation model (NRM) and causality charts, the following equation is used.

$$\lambda = \mu_T \tag{6}$$

Here, μ_T represents the average of each value in the comprehensive influence matrix T.

2.4 Analytic network process (ANP)

2.4.1 Concept and application

ANP is a multicriteria decision-making method for adapting to an irrelevant hierarchy.[20] The decision-making process is represented by a network composed of clusters and nodes, which is a generalized form of the analytic hierarchy process (AHP). ANP is based on AHP but emphasizes the interaction between different indicators at the same level and combines qualitative and quantitative analysis. Its decision-making process is similar to the human thought process. On the basis of the organization and analysis of mathematics and psychology, the smart monitoring system is decomposed into system stability, hardware configuration, and software processing by ANP to conduct qualitative and quantitative analysis and decision-making. Currently, the ANP method is widely used in government, business, industry, and healthcare.[20]

2.4.2 Calculation

2.4.2.1 Step 1

A network structure is established. The ANP network structure of the monitoring system is generated in accordance with the mutual influence relationship between the index factors of the same and different target layers.

2.4.2.2 Step 2

The judgment matrix is calculated. A 5-level Likert scale is used in this study with a scale of 9, resembling human thinking, which has become possible with the advance of computing power. A pairwise comparison of the factors of the index layer is made, and the index elements of the criterion layer i are called subcriteria. The degrees of influence of the indicators in criterion layer j are compared with those in criterion layer i, and the judgment matrix is created; then the normalized eigenvector matrix w is constructed.

$$w = \left[W_{i1}^{(j)} \ W_{i2}^{(j)} \ \cdots \ W_{in_i}^{(j)} \right]^T \tag{7}$$

2.4.2.3 Step 3

The unweighted supermatrix is calculated. ANP expresses the degrees of influence of elements through a supermatrix as a result of comparison between elements using a judgment matrix. When there is no mutual influence among the elements, W_{ij}=0 and the unweighted supermatrix W is obtained as Eq. (8).

$$W = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix} \tag{8}$$

2.4.2.4 Step 4

The weighted supermatrix is calculated. When the unweighted supermatrix does not satisfy the normalization, it is necessary to normalize each column of the weighted matrix. When all sample inputs are positive, the weights connected to the neurons in the first hidden layer increase or decrease at the same time, resulting in a slow learning speed. Therefore, when scoring the elements of the smart monitoring system, it is necessary to summarize the statistical distribution of uniform samples. The weighted calculation of the degrees of influence of different index layers is carried out to obtain the weighted matrix A.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ a_{21} & a_{22} & \cdots & a_{2N} \\ \vdots & \vdots & & \vdots \\ a_{N1} & a_{N2} & \cdots & a_{NN} \end{bmatrix} \tag{9}$$

The unweighted supermatrix W is weighted to obtain the weighted supermatrix $\bar{W} = a_{ij}W_{ij}$ (I = 1, 2, …, N; j = 1, 2, …, N. Among them, $N \leq 5$).

2.4.2.5 Step 5

The limit matrix is computed and stabilized by a weighted supermatrix. The final weight of the selected factor is deduced to obtain the limit matrix W^∞. The infinite limit is adopted for the k power of the supermatrix, and the index weight is calculated.[21] The limit matrix W^∞ is

$$W^\infty = \lim_{k\to\infty} \bar{W}_{ij}^k . \tag{10}$$

In this study, the decision-making software Super Decisions (SD)[20] is used to perform the complex operation of ANP.

3. Results and Discussion

3.1 Evaluation result

According to the results, a comprehensive impact matrix was constructed, and the results for the Level 1 indicators were obtained as presented in Table 2. The scatter diagram of centrality and causality, also known as the causality diagram, is shown in Fig. 2(a). The greater the

Table 2
Centrality and causality of Level 1 indicators.

Level 1 indicators	c_i	r_j	Centrality $c + r$	Causality $c - r$
System equipment capability (D_1)	−2.053	−1.947	−4.000	−0.105
System stability (D_2)	−1.842	−2.026	−3.868	0.184
Sensor configuration (D_3)	−1.737	−1.289	−3.026	−0.447
Data processing (D_4)	−1.895	−2.263	−4.158	0.368

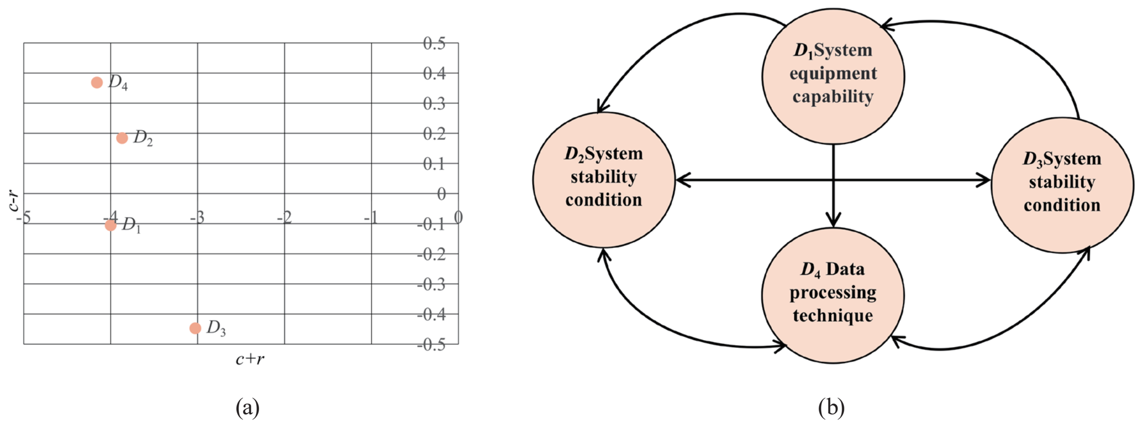

Fig. 2. (Color online) Causality diagram of Level 1 indicators.

centrality $c + r$, the greater are the status and role of the indicator in the indicator system and the higher the correlation with other factors. When the causality $c - r$ is greater than 0, the indicator has a greater impact on others. The results show that the causalities of D_2 (0.184) and D_4 (0.368) are positive and D_4 has the highest degree. Thus, the data processing capability and system stability influence the smart monitoring system most significantly. Figure 2 verifies that the direct impact matrix selects indicators with large centrality and positive causality. The influence relationship among indicators is presented in Fig. 2(b).

ANP is normally used to analyze the relationship between indicators with SD,(21) which is used to establish the network structure diagram, judgment matrix, and limit supermatrix. For the weight calculation of Level 2 indicators in the evaluation system, a pairwise comparison was used. The calculation results were obtained using the geometric mean of the scores in the expert questionnaires (Table 3).

Among the first-level indicators, D_3 has the largest weight (0.353), meaning that sensor configuration is the most important indicator for the smart monitoring system. System stability (D_3, 0.316) and data processing (D_4, 0.294) are also found to be important for the system. In summary, it is found that indicators affecting the system configuration are important for the smart monitoring system. At present, the system configuration of the smart monitoring system is not standardized and differs considerably between different institutions. In configuring the smart monitoring system, the priority should be ensuring the coverage and functions of sensors. The stability of the system and the collection, processing, and analysis of data must also be considered seriously to ensure the appropriate operation of the smart monitoring system.

3.2 Empirical Research

3.2.1 Study area

China has been approaching an aging society at the fastest rate in history. Population aging in Jiangsu Province in China continues to be severe. In 2021, there were 2.16 million permanent

Table 3
Evaluation index of Level 2 indicators of smart monitoring system.

Level 1 indicators	Level 1 index weight	Level 2 indicators	Level 2 index weight	Rank
System equipment capability (D_1)	0.037	Sensing device frequency (C_1)	0.023	8
		Life monitoring assistance (C_2)	0.004	12
		Emergency response capabilities (C_3)	0.010	11
System stability (D_2)	0.316	System running efficiency (C_4)	0.229	2
		System failure rate (C_5)	0.026	7
		System durability (C_6)	0.061	6
Sensor configuration (D_3)	0.353	Assisted living device coverage (C_7)	0.020	10
		Safety protection (C_8)	0.104	4
		Emergency detection and alert (C_9)	0.229	1
Data processing (D_4)	0.294	Health data monitoring accuracy (C_{10})	0.189	3
		Health data acquisition speed (C_{11})	0.022	9
		Health data analysis ability (C_{12})	0.083	5

residents over the age of 60 in Suzhou, accounting for 16.96%. of the total population. We chose Suzhou City in Jiangsu Province as the study area to apply the evaluation system (Fig. 3). To respond to the challenges of urban population aging, the Suzhou Municipal Government has developed elderly care services. In 2007, the Gusu District of Suzhou implemented digital sensor equipment in nursing homes. In the urban area of Suzhou, there are a variety of elderly care services such as home-based chain services, day-care centers, and small and micro-apartments with embedded sensor equipment for elderly people.

3.2.2 Analysis of results

To verify the applicability of the constructed evaluation index system, we selected institutions for elderly care services in 10 districts and counties under the jurisdiction of Suzhou City for empirical evaluation. The selected areas are Suzhou Industrial Park (S_1), Huiqiu (S_2), Wujiang (S_3), Wuzhong (S_4), Xiangcheng (S_5), Kunshan (S_6), Gusu (S_7), Taicang (S_8), Changshu (S_9), and Zhangjiagang (S_{10}). Scoring was performed by the same group of experts in accordance with the study's assessment system.

On the basis of the weight of the second-level indicators in the evaluation index system and ArcGis, the geographic information system software, three institutions with high-quality facilities were selected in each district. ArcGIS was used because its natural discontinuity point method was effective in analyzing the plant information (*PI*) of each county, and it has been widely used in medical care, elderly care, and other industries. Jenks's natural discontinuity method of ArcGIS was used with the *PI* values for the selection of the institutions with the smallest intraclass difference and the largest interclass difference.[22] The combined analysis of spatial and nonspatial information provides better and more precise visual queries and selection of the institutions. In accordance with the natural discontinuity point method, the *PI* value was divided into five different grades from low to high.

The results of the evaluation of the institutions in the selected areas are shown in Table 4 and Fig. 4. The overall performance of the smart monitoring system is the best in the institutions in the Gusu District followed by Suzhou Industrial Park and Taicang pension institutions, which

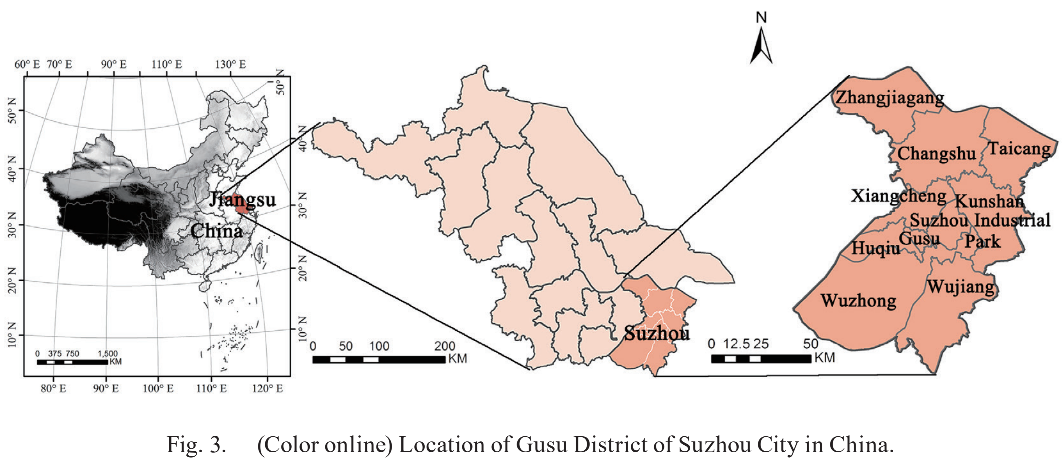

Fig. 3. (Color online) Location of Gusu District of Suzhou City in China.

Table 4
Empirical results of the evaluation of smart monitoring systems in Suzhou.

Level 1 indicators	Level 2 indicators	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
	C_1	1.79	1.79	1.62	1.45	1.11	1.28	1.62	1.11	1.62	1.11
D_1	C_2	0.37	0.28	0.25	0.25	0.16	0.19	0.28	0.16	0.31	0.22
	C_3	0.78	0.70	0.63	0.70	0.41	0.41	0.70	0.48	0.63	0.48
	C_4	17.81	16.11	12.72	12.72	9.33	9.33	11.03	7.63	11.03	12.72
D_2	C_5	2.25	1.21	1.91	1.56	1.56	1.56	1.56	1.56	1.91	1.91
	C_6	4.29	3.84	3.39	3.39	3.39	3.39	3.39	2.49	3.39	3.39
	C_7	1.85	1.56	1.56	1.70	1.11	1.26	2.00	1.11	1.70	1.11
D_3	C_8	8.09	6.55	8.09	8.86	5.78	5.78	9.63	5.01	8.86	6.55
	C_9	19.51	16.11	17.81	16.11	14.42	12.72	22.90	11.03	17.81	14.42
	C_{10}	11.90	13.30	10.50	9.10	10.50	9.10	16.10	7.70	11.90	10.50
D_4	C_{11}	1.06	0.90	0.90	0.73	0.73	0.73	1.71	0.73	1.39	0.73
	C_{12}	4.00	3.38	3.38	5.23	3.38	4.00	7.07	3.38	6.46	4.61
PI		73.70	65.74	62.75	61.81	51.88	49.75	77.99	42.39	67.00	57.75

S_1: Suzhou Industrial Park, S_2: Huiqiu, S_3: Wujiang, S_4: Wuzhong, S_5: Xiangcheng, S_6: Kunshan, S_7: Gusu, S_8: Taicang, S_9: Changshu, S_{10}: Zhangjiagang

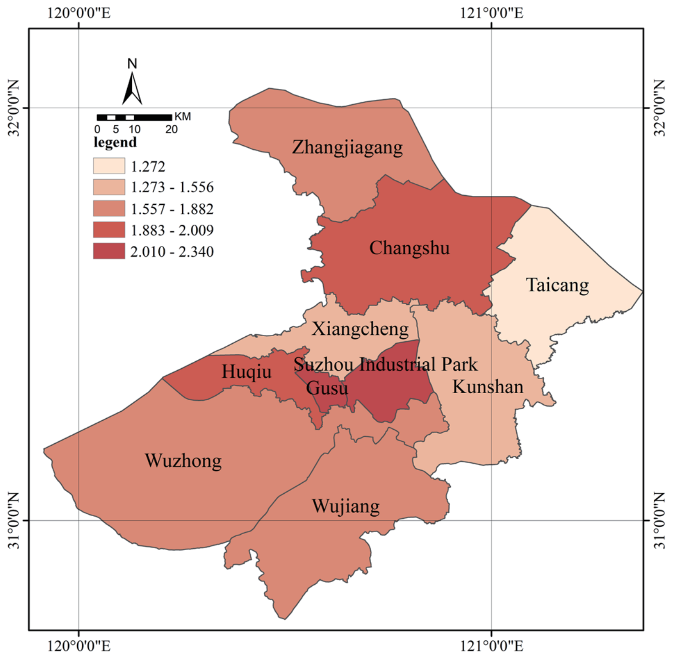

Fig. 4. (Color online) Scoring results (*PI* value) of smart monitoring systems in Suzhou.

need to invest more resources in the smart monitoring system. The evaluation shows that indicators such as system running efficiency (C_4) in system stability (D_2), safety protection (C_8) and emergency detection alert (C_9) in sensor configuration (D_3), and health data monitoring accuracy (C_{10}) in data processing (D_2) are important for evaluating the institutions. Among these indicators, emergency detection alert (C_9), system running efficiency (C_4), health data monitoring accuracy (C_{10}), and safety protection (C_8) are the most important with average indicator values of 16.28, 12.04, 11.06, and 7.32. These indicators largely depend on the performance of sensors for motion detection, fall detection, vital signal detection, and data transmission speed. Therefore, the importance of sensor technology is confirmed by the evaluation of the smart monitoring systems of the nursing homes. It is also found that the higher the values of C_9, C_4, C_{10}, and C_8, the higher the PI values.

4. Conclusions

Although technologies have been developing rapidly, the recent technology used in everyday life, such as big data, AI, and sensors, has not been considered in the evaluation of pension institutions. Recently, such institutions are adopting ‘smart technology’, which is used in various industries, and companies are introducing systems such as Honeywell’s ILSA as the smart system for pension institutions including nursing homes. The smart system is characterized by various sensors in a sensor network connected to a cloud server for detecting emergencies and alerting relevant personnel to execute the required actions.

This study was carried out to develop an evaluation system of smart monitoring systems for nursing homes and clarify how the sensor technology contributes to the establishment of the evaluation system and the smart monitoring system. DEMATEL and ANP were used for developing the evaluation system. We invited nine industrial experts to define 16 indicators for the evaluation system. Level 1 indicators were system equipment capability, system stability, sensor configuration, and data processing with level 2 indicators of sensing device frequency, life monitoring assistance, emergency response capabilities (in system equipment capability), system running efficiency, system failure rate, system durability (in system stability), assisted living device coverage, safety protection, emergency detection and alert (in sensor configuration), and health data monitoring accuracy, health data acquisition speed, and health data analysis ability (in data processing). Among Level 1 indicators, data processing capability and system stability were found to influence the operation of the smart monitoring system. The constructed evaluation system was applied to evaluate pension institutions in Suzhou City, China, as the city has implemented monitoring systems for various pension institutions. Ten areas in Suzhou City where multiple institutions are located were chosen in this study. Three institutions were selected in each area, for a total of 30 institutions evaluated for the capability of the smart monitoring system. For selecting appropriate institutions, ArcGIS was also adopted as it has been widely used in medical care service evaluations. The evaluation results show that the important Level 2 indicators for the evaluation are system running efficiency, safety protection, emergency detection alert, and health data monitoring accuracy as these have higher values than other indicators. Since these indicators are related to the performance of sensors, the importance of sensor technology is well revealed by the evaluation of the smart monitoring systems of nursing homes. These indicators also affect the selection of the institutions by the geographical information system.

Smart nursing homes with smart monitoring systems are based on the concept of a “combination of medical and living care”. To realize such care, cutting-edge sensor technology with AI, IoT, and network technology must be used in the system for collecting and transmitting various but essential signals related to motion detection, fall detection, vital signals, and environmental parameters.

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