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MOBILE SYSTEMS

A Context-Aware Interactive Health Care System Based on Ontology and Fuzzy Inference

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Abstract In the present society, most families are double-income families, and as the long-term care is seriously short of manpower, it contributes to the rapid development of tele-homecare equipment, and the smart home care system gradually emerges, which assists the elderly or patients with chronic diseases in daily life. This study aims at interaction between persons under care and the system in various living spaces, as based on motion-sensing interaction, and the context-aware smart home care system is proposed. The system stores the required contexts in knowledge ontology, including the physiological information and environmental information of the person under care, as the database of decision. The motion-sensing device enables the person under care to interact with the system through gestures. By the inference mechanism of fuzzy theory, the system can offer advice and rapidly execute service, thus, implementing the EHA. In addition, the system is integrated with the functions of smart phone, tablet PC, and PC, in order that users can implement remote operation and share information regarding the person under care. The health care system constructed in this study enables the decision making system to probe into the health risk of each person under care; then, from the view of preventive medicine, and through a composing system and simulation experimentation, tracks the physiological trend of the person under care, and provides early warning service, thus, promoting smart home care.

This article is part of the Topical Collection on *Mobile Systems*.

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Introduction

Research background and motives

With the advancement and application of calculator technology, pervasive computing is seen everywhere. At present, the computing hardware of embedded equipment, as well as increasingly intelligent software, are more inclined to interact with humans. However, before the interaction between machinery equipment and human, the hardware and software of pervasive computing shall cooperate with each other. This concept enhances the interaction of the human-machine interactive system.

Context awareness is a basic feature of pervasive computing that provides appropriate services for users, such as smart home, smart office, etc. Awareness varies with individual needs by providing matching services by collecting user information [1, 2]. Therefore, context awareness is very important in smart spaces. In order to create a personalized and intellectualized care decision support system, this study combined fuzzy inference with ontology to create an intelligent context-aware care system. This study aims at the method for implementing context-aware service [4, 8–10].

In addition to context-aware service, the support of the Internet of Things (IoT) is required for implementing the world of smart service. The IoT contains many applications, for example, a connected home and car can monitor individual behaviors, and use the sensors of collected data push service. The IoT is a universal "air global neural network", which touches upon all aspects of life. In terms of technology, the IoT is defined as an intelligent machine performing interaction and communication with other machines, objects, and environments, where mass data are generated, and these data are processed into useful behaviors that can command and control things, thus, rendering human life more convenient [5,7].

As the global aging population grew explosively in the past decade, living alone will be an inevitable life style of the elderly. However, the elderly who live alone are sometimes accompanied by many high risks. Therefore, the technology of the smart home has developed various sensors to sense, track, and monitor the elderly's activities at home, providing warning and assisting them in living alone. In Taiwan, the top 10 causes of death are mostly chronic diseases. The incidence of chronic diseases increases with age, and neglecting the risk factors in lifestyle is one of the causes [6, 11].

This study proposes a system architecture of context-aware space, which is combined with the IoT technology, in order to establish automatic care service for interaction between the person under care and the system in the various home spaces, thus, assisting the elderly and chronic-care persons to live alone, which could prevent the relapse of chronic diseases.

In order to attain the above goals, the sensors of the IoT, such as Kinect, THC blood pressure monitor, temperature and humidity sensors, are used to identify the person under care and capture physiological and environmental data. When the home environment data are obtained, the knowledge of various domains is stored by ontology, such as physiological data, environmental data, and space type, and the relationships of entity, category, attribute, and function are constructed, respectively. Afterwards, the system uses fuzzy theory to deduce personal advice or execute service, and respond to the activity or requirement of the person under care, thus, implementing human-centered, human-machine interactive health care to reduce the labor demand and implement the smart home. Finally, the proposed method can enhance the effect of the system in the aging family environment [3, 5, 7, 11].

Research purposes

The care of the elderly and chronic-care persons involves professional knowledge of different areas, and the conditions vary with the individuals. In order to implement the home care stated by the aforesaid background and motives, this study will integrate ontology, fuzzy inference, and a context-aware space interactive care system to improve the level of care and reduce the cost of labor.

The purposes of this study are described, as follows:

1) The relationship among service, space, and user shall be analyzed first, and then a knowledge ontology model, which can describe different contexts in the home care environment, is constructed, where different types of knowledge regarding the person under care at home are explained by ontology, the knowledge is integrated, and the service is automatically executed to attain the purpose.
2) In order to implement human-machine interaction, the sensors of the IoT are used to capture different environmental factors, and a perfect prototype of a home care system is created. The corresponding care service is offered by data collection and the fuzzy inference mechanism.
3) In the home environment, the elderly or chronic-care persons with unusual conditions, such as heart disease or high blood pressure, are inconvenient to move and cannot receive assistance, thus, the motion-sensing equipment is useful, as the system can instantly detect the gesture of the person under care to determine the required service. It is also applicable to spatial interaction to judge whether there is a person in the space.

Section 2 offers literature review of context awareness, ontology, fuzzy inference, and motion-sensing interaction. The categories of context-aware system research, as well as the topics researched in these categories, are found, and the results are compiled to determine areas for improvement and propose evaluation criteria. Section 3 proposes the research methods for the proposed evaluation criteria, and analyzes these research methods. Section 4 uses different contexts and problems in home environments to present and validate the results of this care system. The conclusion describes the results of this study and future research directions [7, 10, 12].

Literature review

This study proposes building a context-aware interactive home care system in the context awareness concept based on the IoT. Therefore, this chapter introduces the relevant concepts applied in this study, including the IoT, context awareness, fuzzy inference, and ontology.

IoT

The era of networking is a network environment where people are connected to each other and obtain the information of objects via the network, and such objects can be connected to each other. The era of the IoT represents the evolutionary trend of future information technology in operation and communication. The evolutionary process shall be driven by the technologies of various fields and technological innovation, from nano technology to the construction of municipal wireless networks, where the range of influence is extensive. The development of the IoT can be divided into three dimensions, including "time", "place", and "thing", as shown in Fig. 1. As the IoT becomes mature, an environment where all the things can communicate with each other anywhere and anytime will

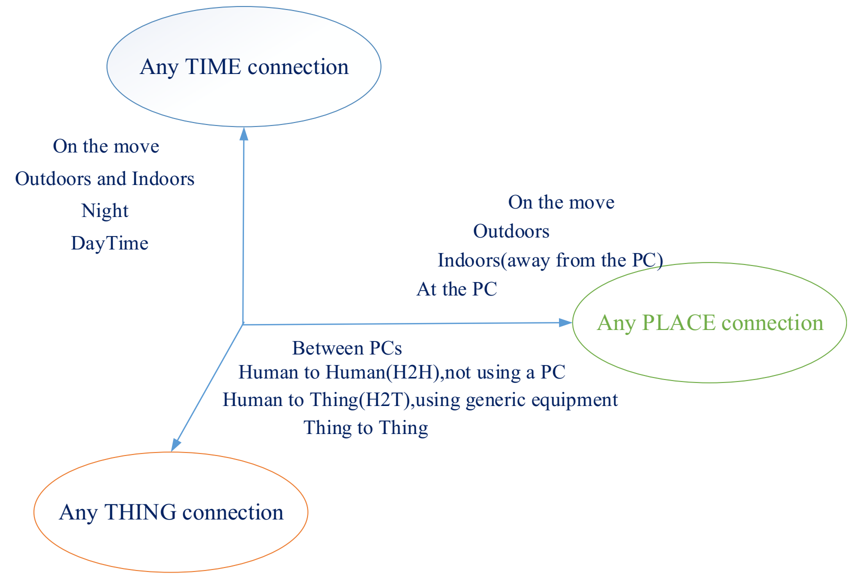


Fig. 1 The relevancy of time, place, and thing in the IOT

be created, and includes three major categories, "Human to Human", "Thing to Thing", and "Human to Thing".

Context awareness

Context awareness transmits the information required by the user to where the user can use it according to different geographic environments. With the assistance of sensors to judge the situational factors of the time, and provide appropriate information, is implemented by the wireless network environment. The context-aware device can forecast the user requirement, thus, providing advice and guidance throughout daylong activities. Its role has changed from the positioning of traditional computers into user's personal assistant, thus, changing the interactive mode between the user and the information device, and between the user and the device provided service [17, 21].

According to the study of Guanling and David, there are four categories of the factors of context awareness:

1) Computing context: Quality of Service, bandwidth, communication expenses.
2) User context: user's location, record files, preference settings, adjacent user.
3) Time context: times of the day, week, month, and season.
4) Physical context: temperature, brightness, sound volume.

Context awareness is divided into active context awareness and passive context awareness, and classified into direct apparent awareness (input) and implied awareness (input), where the former includes location information, time information, and equipment environment information, while the latter includes user's features, habits, knowledge level, and preference. Schmidt defined context awareness as knowledge regarding user and IT equipment status, including ambient environment, form, and position. The hierarchy chart of context awareness categories is as shown in Fig. 2.

Fuzzy inference

Fuzzy inference is also known as approximate inference, where a reasonable result is obtained by inference of anthropomorphic thinking from known truth. The major functions of fuzzy inference include variable input, fuzzy set (fuzzy interface), inference engine, inference rule, defuzzification, and variable output, as shown in Fig. 3.

An example of fuzzy inference is given, as follows:

Precondition 1	The person under care has high blood sugar.
Precondition 2	High blood sugar may be accompanied by diabetes.
Inference result	The person under care has high blood sugar, and thus, has suffered from diabetes [14, 15]. As traditional explicit logic cannot explain the descriptions of "high", "may", and "suffer from", fuzzy logic can use fuzzy quantifiers to represent the degree values of such descriptions.

Fuzzy inference is based on the conclusion deduced from fuzzy rule base and truth in real life. For example, variable X of probability distribution and an X-Y fuzzy rule are given, and the probability distribution of variable Y can be inferred. The fuzzy rule is represented in the form of If–Then, the If is called an antecedent in fuzzy logic, i.e., precondition; the Then is called the consequent in fuzzy logic, i.e., conclusion.

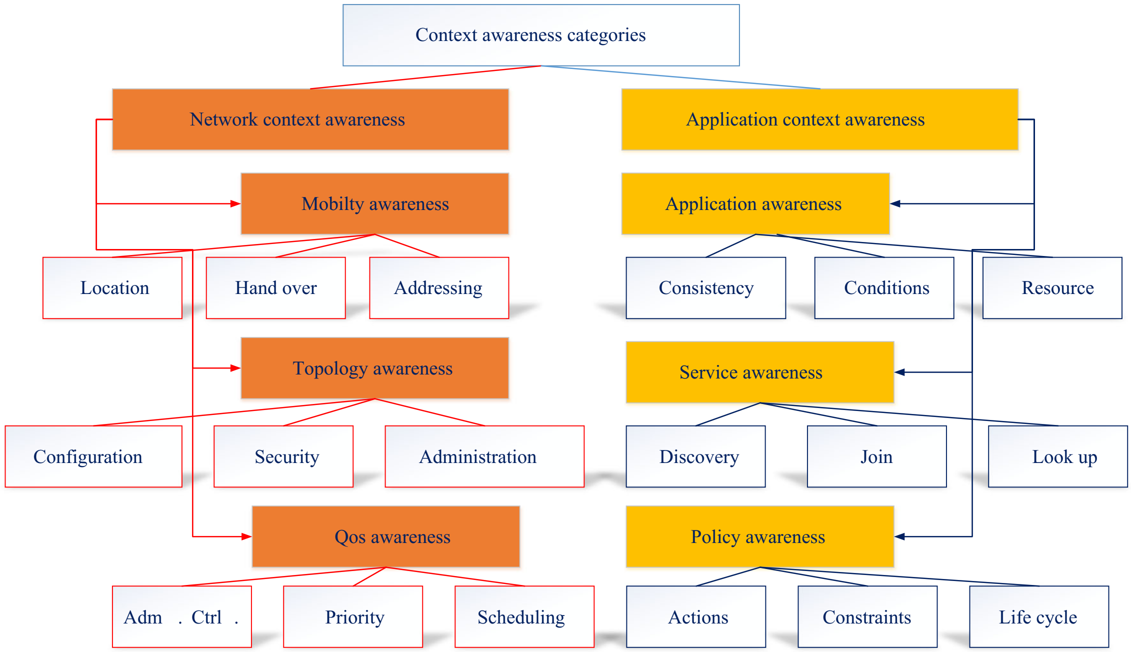


Fig. 2 Hierarchy chart of context awareness categories

The most used fuzzy rule base is the linguistic fuzzy rule, also known as the Mamdani fuzzy rule. The typical semantic fuzzy rule is expressed, as follows:

$$R^j : \ If\ X_1\ is\ A_1^j\ and\ \ldots and\ X_p\ is\ A_p^j,\ then\ y\ is\ B^j$$

Where A_1^j and B^j are linguistic fuzzy variables, $x=(x_1,x_2,\ldots x_p)^T \in U \subset R^p$ and $y \in V \subset R$ are defined by membership functions $\mu_{A_1^j}$ and μ_{B^j}, respectively.

Ontology

According to the systematology of Gruber, the cognition of things of the real world is conceptualized, and this concept is defined and specified to assist the program and human to share knowledge. To sum up, ontology defines the knowledge, terms, and concepts of a specialized field to specify a formalized expression, in order that the calculator system can analyze the data content and provide the accumulated knowledge base for the human to inquire and share.

There are two common classification criteria for the expression of a concept, which are "topic meaning" and "use". The topic meaning is divided into the following three categories according to the concept structure of Ontology topic or meaning: (1) term ontology: like words for expressing the knowledge of specialized fields, for example, the printer fault diagnosis manual is a sort of term ontology;(2) information ontology: record database architecture in detail, for example, the schema in the database is a sort of information ontology;(3) knowledge modeling ontology: for knowledge modeling, create a complete expression of conceptual knowledge.

Uschold proposed an ontology combined with systematology, regarded the opinions of the real world as a set of concepts, and proposed a concept set composed of entity, attribute, and correlation factors.

1) Entity: tangible or intangible important things of a specific domain, e.g., person, matter, object.
2) Attribute: conceptual characteristics of entity, e.g., exterior, weight.

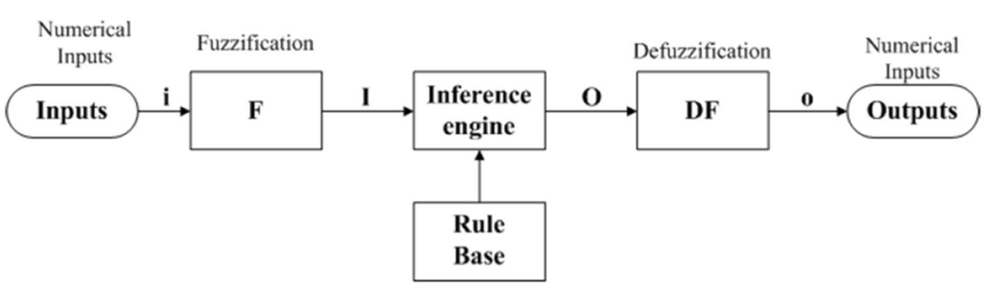


Fig. 3 Architecture of fuzzy inference system

3) Correlation: description of the rule and relationship between entities, and between entity and attribute. The correlation between entities is defined as “relationship”; while the correlation between entity and attribute is defined as “belong to”.

The entity in this study refers to a category, such as physiological status of a fall or qualm, or chronic disease, such as diabetes and high blood pressure, where each one is an entity. The attribute describes the condition of the category, such as the time attributes of daily application time and weekly exercise frequency. Correlation refers to the relationship between entities or between entity and attribute. The correlation will inherit all attributes or their class relations, for example, regular drug administration, exercise, and blood pressure measurement of the patient with high blood pressure prevent qualm [12, 13, 16, 18, 20].

Context-aware motion-sensing interactive health care design

This study proposes a home care system combined with a semantic web architecture, which has the following functions:

1) Signal detection: detect specific signal template of the signals received by sensors.
2) Context description: the fragment value of the detected specific signal template is obtained, and standardized words are used for context description. The sensors of a home environment provide the required information for context awareness operation.
3) Event inference: the environmental status, as presented by the context description, is represented by a description close to human logical inference, which is then converted by the inference algorithm to generate an event, meaning the system is forced to perform some actions, called service demand.
4) Service triggering event: the physiological or environmental parameters of the person under care are inferred and graded according to the risk level. In the case of a physiological variable, or a dangerous and abnormal environment, there is a mechanism to execute service.

This study is divided into three major parts, construction of ontology, inference mode of the fuzzy theory, and design of the interaction between motion-sensing and system in different spaces. When the person under care enters the space, the sensing end obtains the identity of the person under care and the environmental data, and the relationship between the person under care and environmental factors is obtained by ontology, which infers behavior. Finally, the appropriate service is proposed. The motion-sensing technology uses a motion detector to judge the home space environment and detect the body movements of the person under care.

Context-aware care system architecture

This study develops a context-aware care system module, which provides services for chronic-care persons or the elderly, as shown in Fig. 4. The physiological data of the person under care and the probable symptoms of chronic diseases are collected, and the inference model is constructed by the interactive relationship between user and system in different spaces. The system offers comfort, convenience, and safety, as based on EHA assisted service [19].

The context-aware system in this study consists of the following three components:

1) Context provider: sensors distributed in different spaces. The sensor devices are mounted in general home environments, for example, using Kinect to collect environmental information.
2) Context management middleware: management of context information collection in different spaces. This study uses J2EE to implement context management middleware. The ontology management is based on JENA, which is a JAVA framework for constructing semantic web applications; the inference mechanism uses fuzzy theory and relational database MySQL to store the inference results of the ontology model.
3) Context consumer: the application adjusts its instruction according to context.

   Application to home environment: (1) the context management middleware is mounted in the home, i.e., system host; (2) a Kinect sensor is mounted in each room for judging space type and capturing environmental information; the sensor nodes can be connected to each other; (3) the user wears a physiological information transceiver wirelessly connected to the context management middleware, which identifies the room the person under care is in, as known from the middleware, in order to locate the person and provide assistance.

Space design for motion-sensing interaction

There are two types of space design according to the interaction between space and user: B.Space and F. Space. The concepts of F. Space and B. Space are integrated into the context-aware care system in this study.

If a context-aware care system has been built into a home environment, as shown in Fig. 5; when a chronic disease patient enters the home, the system switches into B. Space mode for background detection, including the environmental data of light rays, temperature, and humidity. The data are transmitted

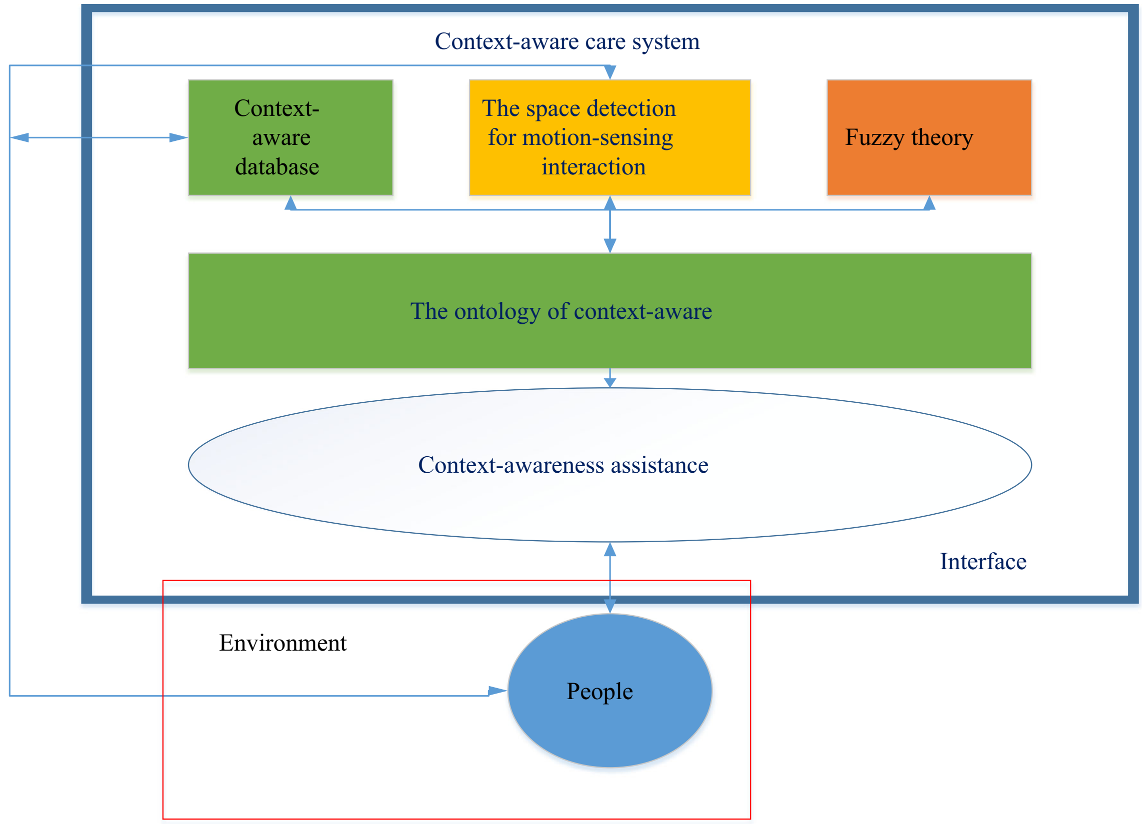
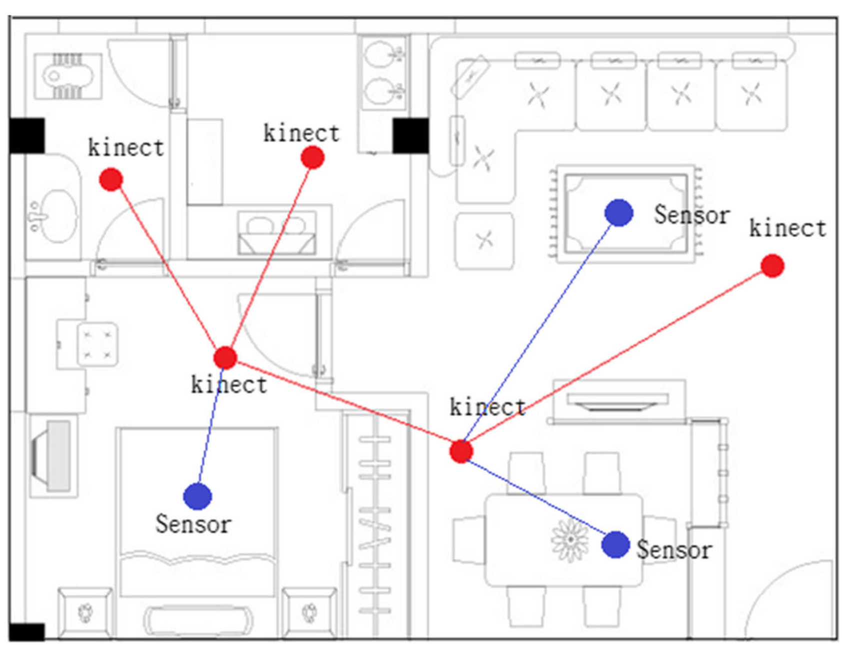


Fig. 4 Context-aware care system module

to the system to judge whether they meet user requirements. The lighting and air conditioning equipment are switched on and regulated to provide a comfortable environment. The system is logged in when the user waves a hand, and switches to F. Space mode; according to the preference settings, the system reminds the user of routine proceedings, such as taking medicine, measuring blood pressure, and exercise, in order to track the user's physiological status. However, the advice or service is stopped when the user raises up a hand.

Fig. 5 Sensing system of smart home, multiple space nodes formed



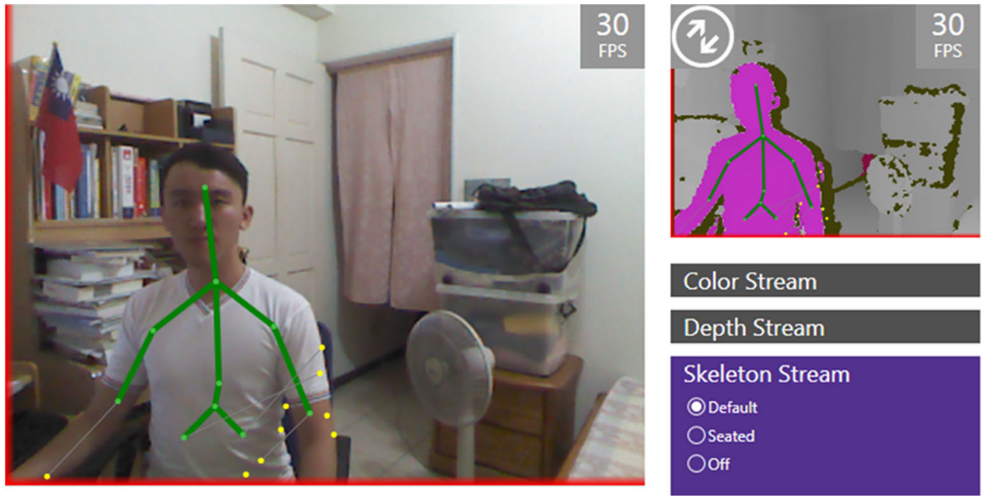


Fig. 6 Kinect Explorer example display

Implementation procedure of the motion-sensing interaction module: first, Kinect extracts color image, depth image, skeleton image, and skeleton coordinates, from the detection range, and the data are transferred via USB to the care system; secondly, this system uses the application developed by this study, in addition to Kinect SDK and the fuzzy inference mechanism for information integration; thirdly, the motion-sensing interaction mechanism uses the information of the depth image to obtain the human skeleton, and analyzes the wave according to the movement of the hand skeleton; fourthly, the external speaker gives audible warning to remind the elderly or the chronic-care person, thus, providing corresponding services.

The Kinect Explorer is an example program for testing all the functions of all Kinect sensors, as shown in Fig. 6. All the connected Kinect devices can be seen in the main window of Kinect Explorer, and the identification code of each device is displayed. In addition, the fed back color image, depth image, sound source, and skeleton information can be observed [18].

Design of context service

The generation of an event usually represents the generation of service demand. This study uses ontology as the information classification system, where the definitions of standard words are usually applied to describe the available "service support" of the system, and such service support is described by a lower level, in order to guarantee the authenticity of the description. For example, the air-conditioner provides the service support of temperature decrease. However, the description level of the "service demand" generated by context awareness is higher, thus, a mechanism for coordinating service support and service demand is required, called context service, is divided into the following three categories, as shown in Fig. 7.

1) Emergency treatment: the person under care is detected, protected, and assisted in an emergency. This service can monitor the health and environmental safety of the person under care, and gives a prompt warning or prevents injuries when an accident occurs.
2) Autonomy enhancement: very useful to persons under care or the elderly with physiological chronic diseases; the services include assistance for cooking, cleaning, dressing, shopping, eating, and taking medicine. The "smart pillbox", as proposed by Niemala, is a service mechanism that can actively remind the person under care to take medicine.
3) Comfort services: covering various fields, including the former two services. The comfort services includes the smart home and assistance to person under the care and safety of the home environment. For example, the temperature and humidity of home environment are sensed in order to adjust the level suitable for the person under care, providing a comfortable and safe service.

Fuzzy inference module

The care system of this study is based on the semantic web, divided into a context level, a link level, and an application level according to tasks, described as follows: the physiological data of the person under care and home environment data are imported into the context level to create the knowledge ontology of individual, environment, and the knowledge ontology of

Fig. 7 Classification chart of home care context service

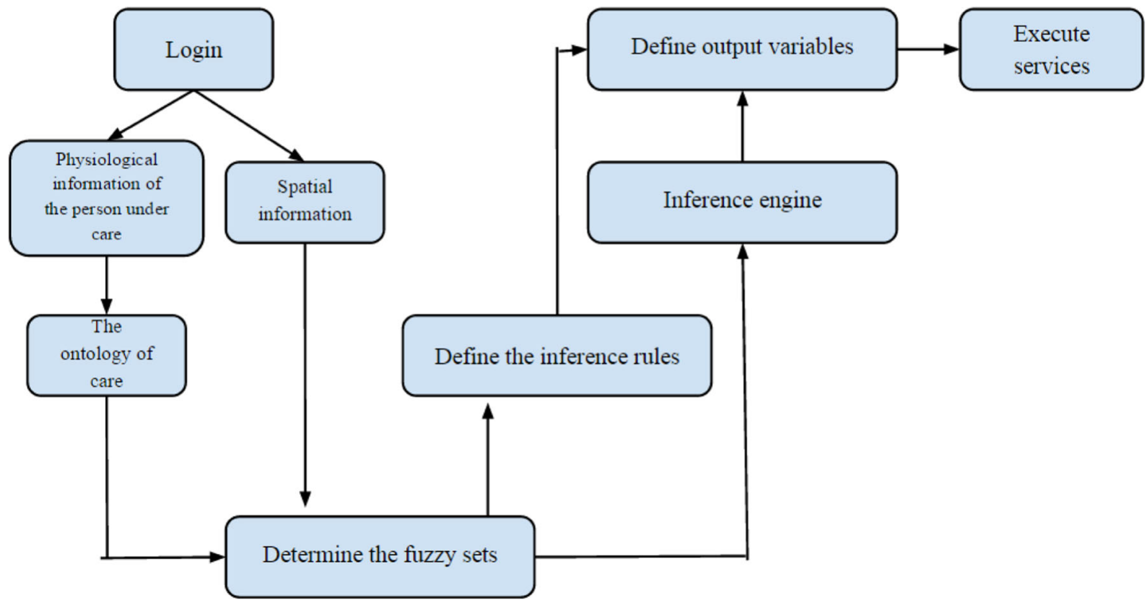


Fig. 8 Process of fuzzy inference system

the chronic disease, and ontology language is used for compilation. The link level links the data of the context level to the application level via the access interface. In terms of application level, the user can link hand-held devices, such as smart phone, tablet PC, or PC, to the context-aware care platform via the internet. This platform interface is constructed by JAVA and JENA, and the background database is built by MySQL.

However, the automatic service of care system must be implemented by the feedback of the inference mechanism. Therefore, this study uses the fuzzy inference system for context-aware inference. This system is formed of a fuzzy system and fuzzy inference, simulating the "fuzzy process, accurate result" inference of human thinking.

The fuzzy inference mechanism is the core of the overall context-aware care system, which compares various measured values in a range of parameters, in order to determine the health status of patients or the elderly. Therefore, each range of parameters shall specify the upper and lower thresholds and relative early warning conditions as the standards of judging low, medium, and high risk levels, thus, providing appropriate services for the users.

Table 1 Age and corresponding membership function plots

Input variable	Range	Linguistic variable
Age	<=52	Young
	>52	Old

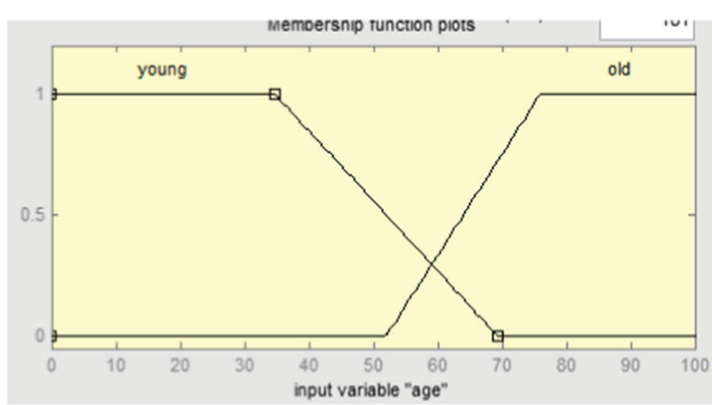
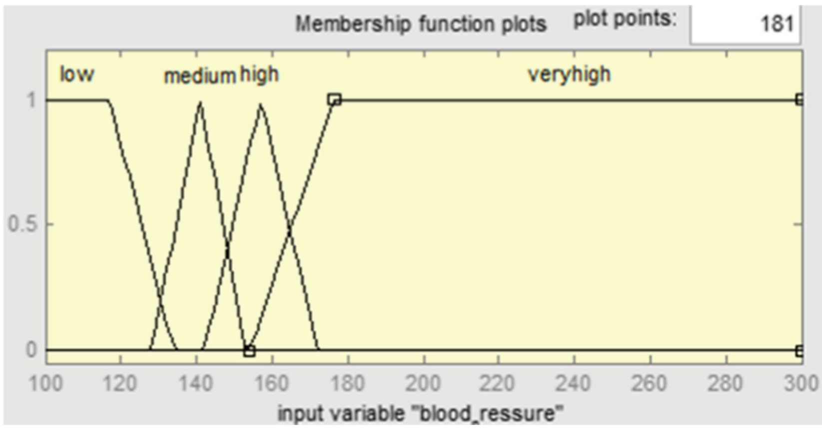


Table 2 Blood pressure and corresponding membership function plots

Input variable	Range	Linguistic variable
Blood pressure	<134	Low
	127-153	Medium
	142-172	High
	>154	Very High



The major functions of the fuzzy inference system include the input of variables, the fuzzy set (fuzzy interface), the inference engine, the inference knowledge base, defuzzification, and output of variables. The fuzzy knowledge base and fuzzy inference engine functions are the core, described as follows:

1) The fuzzy knowledge base stores the fuzzy concepts of human thinking, divided into (1) fuzzy rule base: to record expertise rules; (2) semantic database: to define fuzzy linguistic. The semantic words form the fuzzy set, the corresponding membership function shall be defined.
2) The fuzzy inference engine implements fuzzy inference for the knowledge in the knowledge base to obtain results.

The above theory is applied to this study, as follows: (1) different sensors are mounted on the person under care and in

Table 3 Blood sugar and corresponding membership function plots

Input variable	Range	Linguistic variable
Blood sugar	<66	Low
	63-150	Medium
	>140	High

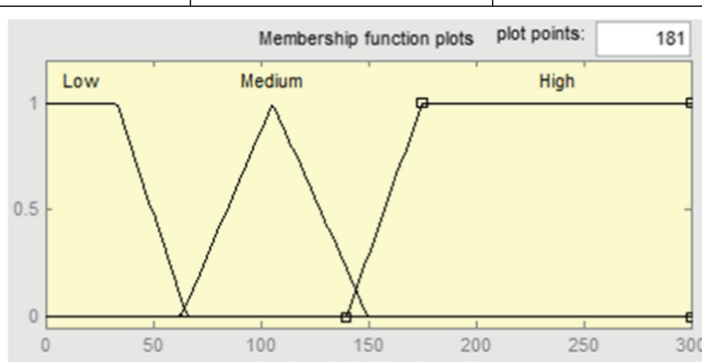
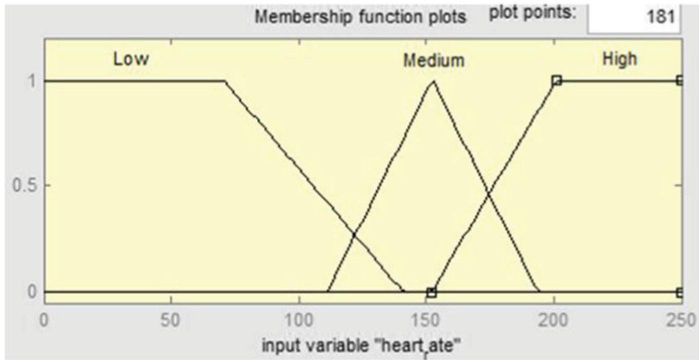


Table 4 Heart rate and membership function plots

Input variable	Range	Linguistic variable
Heart rate	<58	Low
	58-98	Medium
	>98	High



the living space for capturing data, and the physiological and environmental input variables are transferred to the system by radio; (2) the data are converted by the processing mechanism into a fuzzy set, and the fuzzy set is displayed on the principle of the ontology, different knowledge ontology categories are constructed, and the fuzzy knowledge base is formed; (3) the required knowledge ontology category is judged by the artificially set domain expertise according to the user requirement, as obtained from the fuzzy knowledge base by the capture mechanism, and sent to the fuzzy inference engine for inference; (4) finally, the inference variables are exported, providing services for the user, as shown in Fig. 8.

Table 5 Cholesterol and membership function plots

Input variable	Range	Linguistic variable
Cholesterol	<197	Low
	188-250	Medium
	217-307	High
	>281	Very High

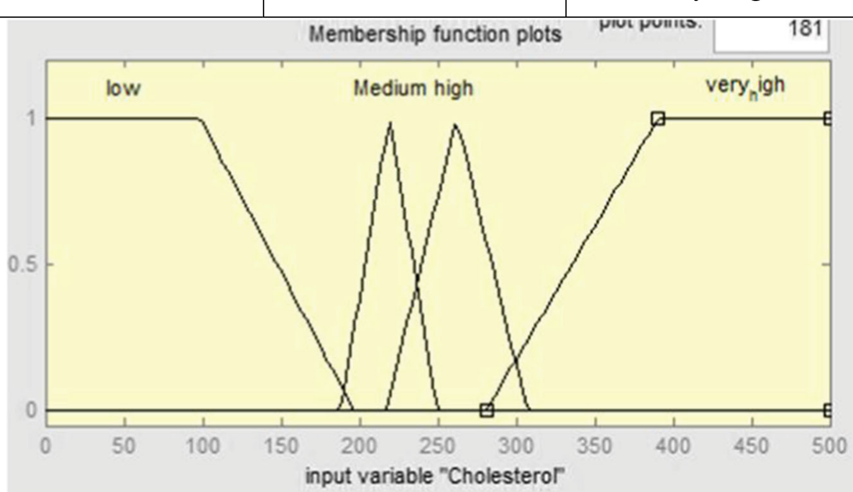


Table 6 Indoor-outdoor temperature difference and humidity

Environmental input variable	Range and linguistic variable
Temperature	>7°C: Level 5; 5–7°C: Level 4; 3–5°C: Level 3; 1–3°C: Level 2; <1°C: Level 1
Humidity	>85 %: Level 5; 80–85 %: Level 4; 75–80 %: Level 3; 70–75 %: Level 2; <70 %: Level 1

Semantic database in fuzzy knowledge base

The fuzzy inference system used in this study is the same as other inference systems, meaning the data must be imported first, then the inference result can be exported by the inference mechanism. This section discusses the design of the input data and output results, and these design results will be stored in the semantic database of the fuzzy knowledge base as the basis of system inference.

For the care system developed in this study, the sources of data input include the user's input and the input of sensor measured data. For the purpose of care, only the health of the person under care is considered. Therefore, these input sources are set as the input variables influencing the health of the person under care, and divided into physiological input variables and environmental input variables. There are five physiological input variables, such as age, blood pressure, blood sugar, heart rate, and cholesterol. The ranges are defined according to the data released by the World Health Organization (WHO), Ministry of Health and Welfare, and the A+ Medical Encyclopedia, where the values of the upper and lower standard deviations are deduced, as shown in Tables 1, 2, 3, 4 and 5. There are two environmental input variables, temperature and humidity. In addition, seven physiological and environmental input variables have related semantic words in the semantic database, forming the fuzzy set and the corresponding membership function [7, 22].

The input variables and membership functions and output variables are described, as follows.

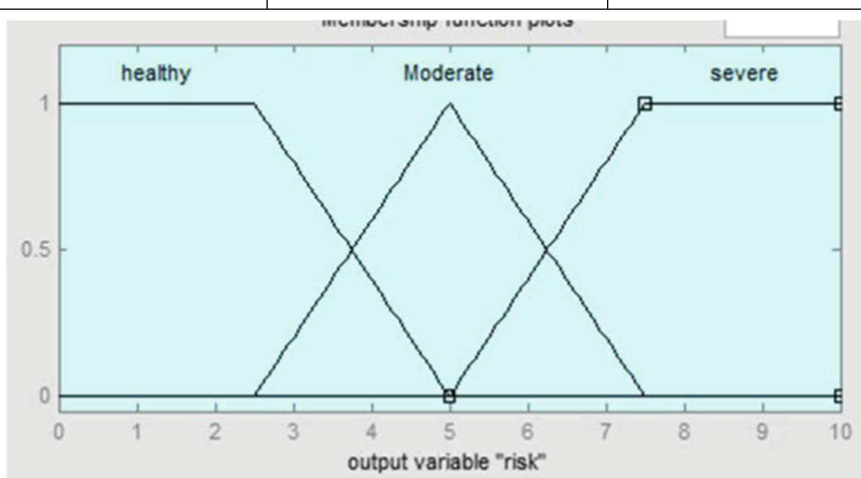
1) Physiological input variables

(1) Age: according to the study of Ali. Adeli, the fuzzy linguistic variables of age are divided into Young and Old fuzzy subsets, and the age brackets are as shown in Table 1. The membership function plots corresponding to the numerical ranges of age are represented by the two fuzzy subsets.

(2) Blood pressure: there are three types of blood pressure, systolic, diastolic, and mean. According to A Copetti, this study uses systolic as the basis. The fuzzy linguistic variables of blood pressure have Low, Medium, High, and Very High fuzzy subsets, and the blood pressure ranges are as shown in Table 2. The membership function plots corresponding to the numerical ranges of blood pressure are represented by the four fuzzy subsets.

Table 7 Risk level and membership function plots of risk level

Input variable	Range	Linguistic variable
Risk level	0~5	Healthy
	2.5~7.5	Moderate
	5~10	Severe



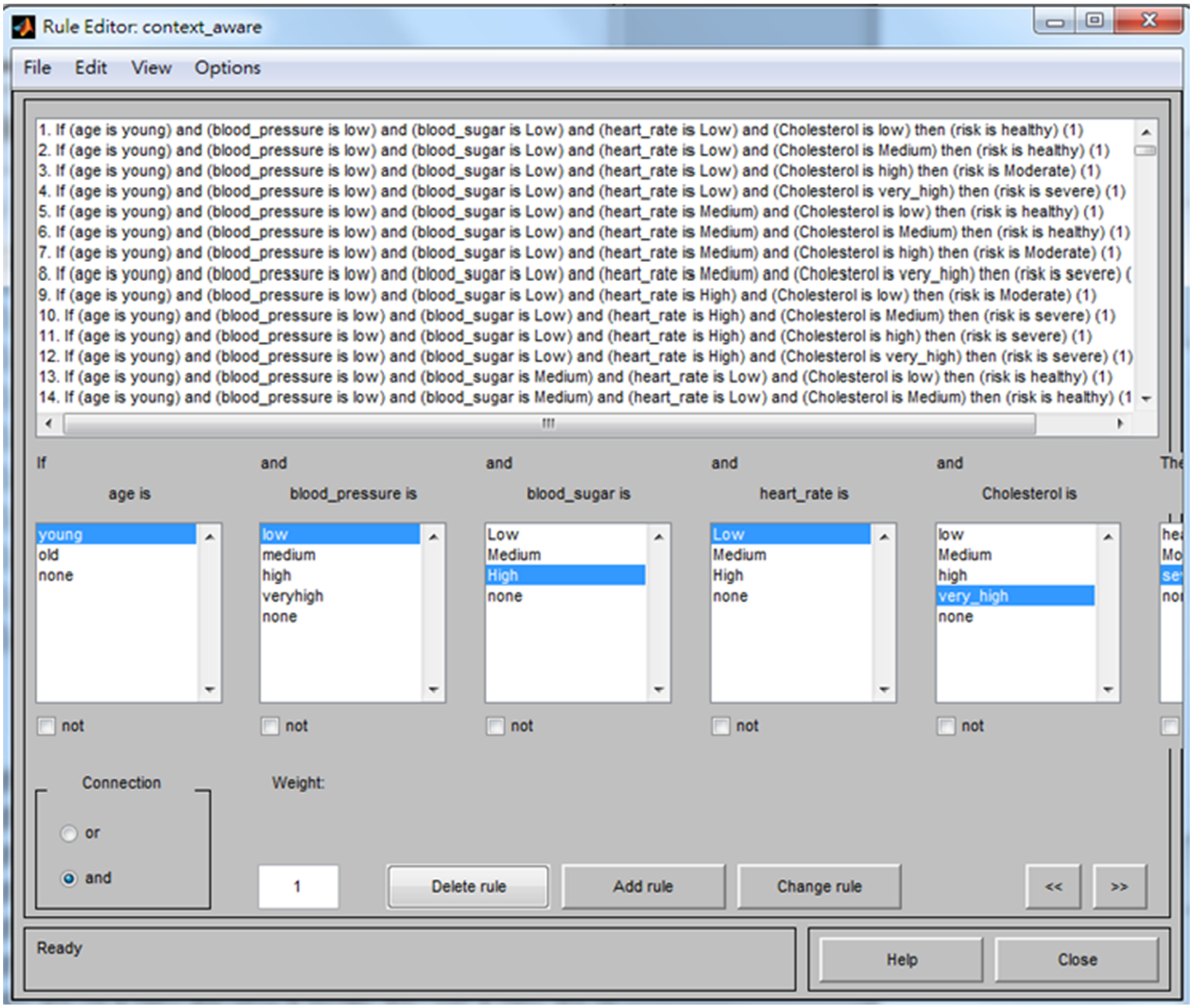


Fig. 9 Matlab fuzzy rules construction

(3) Blood sugar: the fuzzy linguistic variables of blood sugar have Low, Medium, and High fuzzy subsets. Referring to the data of the American Diabetes Association (2001) and the

Table 8 Examples in rule list

Code	Fuzzy rule
R1	If (age is old) and (pressure fuzzy is High) and (sugar fuzzy is High) and (hb fuzzy is High) and (c fuzzy is High) then (Risk us High)
R2	If (age is old) and (pressure fuzzy is High) and (sugar fuzzy is Medium) and (hb fuzzy is High) and (c fuzzy is High) then (Risk us High)
R3	If (age is old) and (pressure fuzzy is High) and (sugar fuzzy is High) and (hb fuzzy is High) and (c fuzzy is High) then (Risk us High)
R4	If (age is old) and (pressure fuzzy is Medium) and (sugar fuzzy is High) and (hb fuzzy is High) and (c fuzzy is High) then (Risk is High)
R5	If (age is old) and (pressure fuzzy is Low) and (sugar fuzzy is High) and (hb fuzzy is Low) and (c fuzzy is Medium) then (Risk is Medium)
R6	If (age is old) and (pressure fuzzy is Low) and (sugar fuzzy is Low) and (hb fuzzy is Low) and (c fuzzy is Medium) then (Risk is Medium)
R7	If (age is old) and (pressure fuzzy is High) and (sugar fuzzy is High) and (hb fuzzy is High) and (c fuzzy is High) then (Risk is Medium)
R8	If (age is young) and (pressure fuzzy is High) and (sugar fuzzy is High) and (hb fuzzy is Low) and (cfuzzy is Medium) then (Risk is High)
R9	If (age is young) and (pressure fuzzy is Medium) and (sugar fuzzy is Medium) and (hb fuzzy is Low) and (c fuzzy is Low) then (Risk is Low)
R10	If (age is young) and (pressure fuzzy is Low) and (sugar fuzzy is Low) and (hb fuzzy is Low) and (c fuzzy is Low) then (Risk is Low)

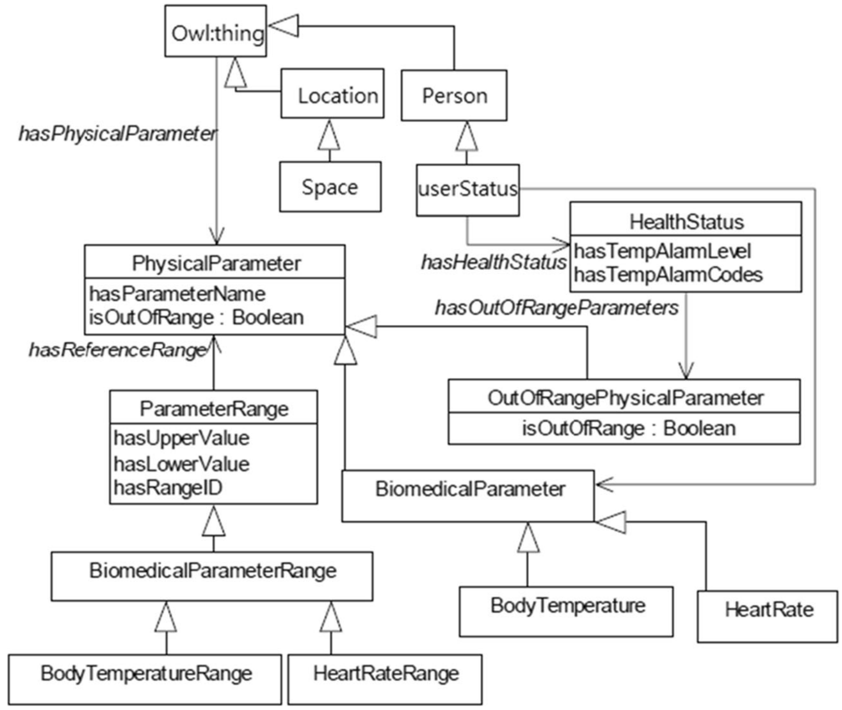


Fig. 10 Knowledge ontology architecture of context-aware health care

Diabetes Prevention Manual of Executive Yuan, Taiwan, the blood pressure ranges are specified, as shown in Table 3. The membership function plots corresponding to the numerical ranges of blood sugar are represented by the three fuzzy subsets.

(4) Heart rate: according to Chengyu Liu, the fuzzy linguistic variables of heart rate have Low, Medium, and High fuzzy subsets, the heart rate ranges are as shown in Table 4. The membership function plots corresponding to the numerical ranges of heart rate are represented by the three fuzzy subsets.

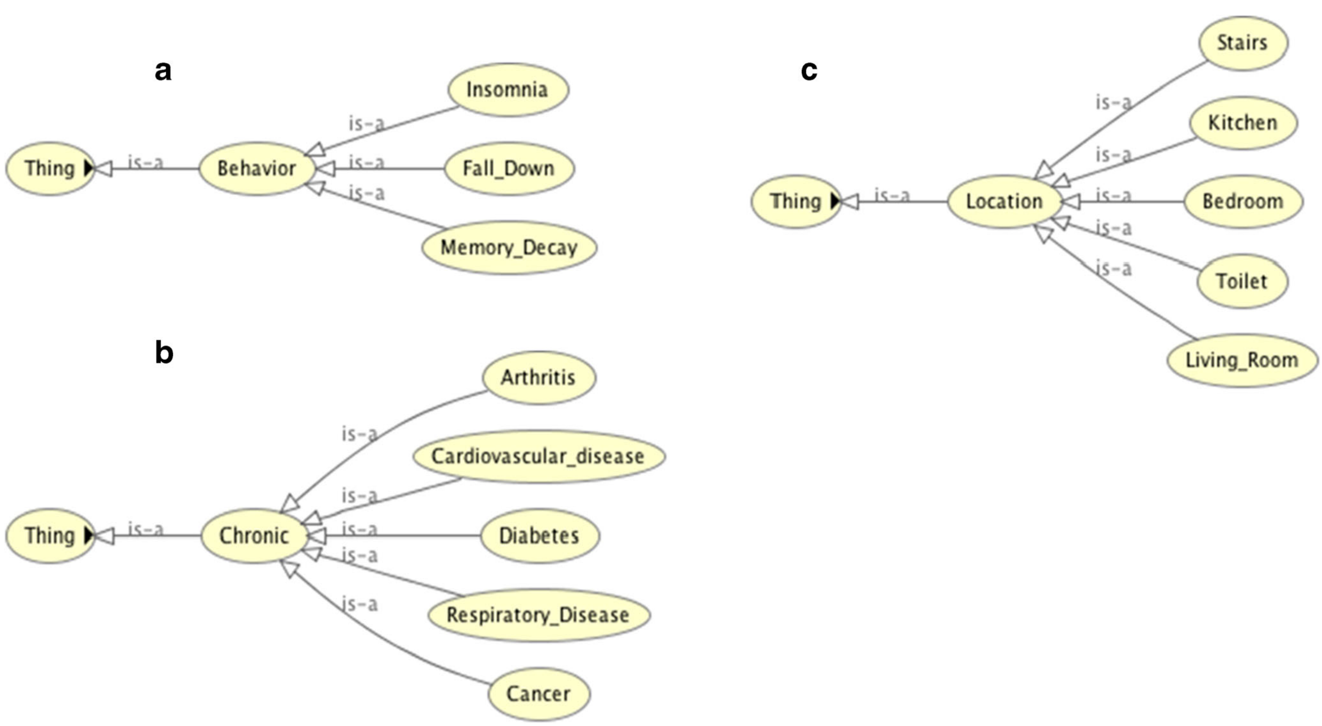


Fig. 11 **a** Categories of behavior ontology, **b** Categories of chronic disease ontology, **c** Categories of space ontology, **d** Categories of measure ontology, **e** Categories of context-aware service ontology

Fig. 11 (continued)

(5) Cholesterol: according to Ali Adeli, cholesterol is divided into LDL and HDL. This study uses LDL as the basis. The fuzzy linguistic variables of cholesterol have Low, Medium, High, and Very High fuzzy subsets. The cholesterol ranges are as shown in Table 5. The membership function plots corresponding to the numerical ranges of cholesterol are represented by the four fuzzy subsets.

2) Environmental input variables

This study uses temperature and humidity as two environmental input variables. The temperature is mainly the indoor-outdoor temperature difference. The fuzzy linguistic variables of indoor-outdoor temperature difference and humidity have five fuzzy subsets according to the level of influence on the person under care, including Level 5, Level 4, Level 3, Level 2, and Level 1, from

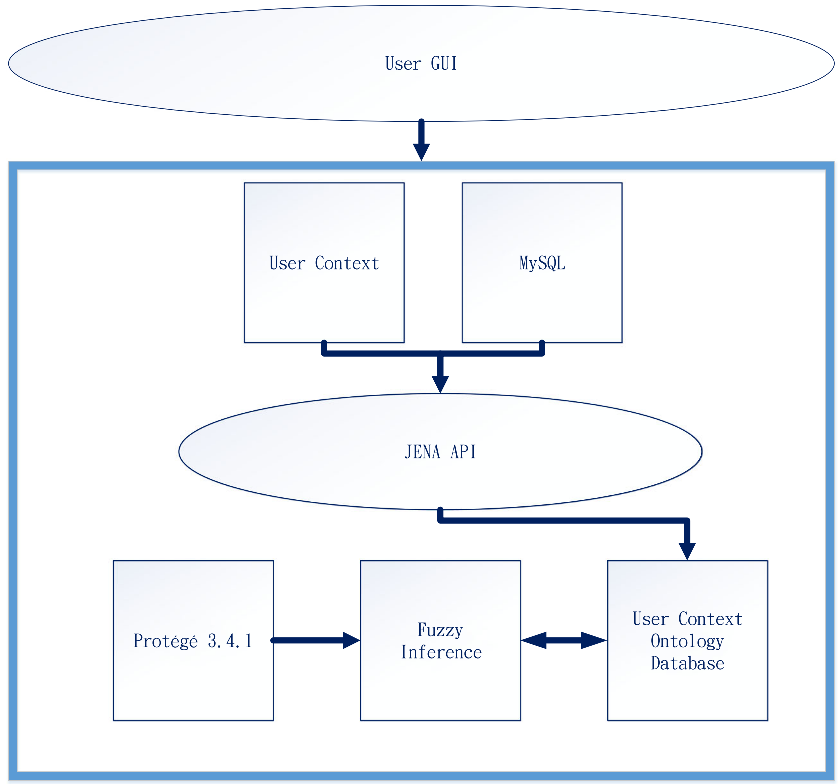


Fig. 12 Functional architecture of system

the riskiest to least risky. The ranges of indoor-outdoor temperature difference and humidity are as shown in Table 6.

3) Output variables

The output variables, as deduced by the fuzzy inference mechanism of the aforesaid input of seven physiological and environmental variables, are defined as risk levels. The fuzzy linguistic variables of risk levels are Healthy, Moderate, and Severe fuzzy subsets. The risk level ranges are as shown in Table 7.

The care system provides services corresponding to different risk levels, for example, in the Healthy state in the range 0~5, the system resumes comfortable service and recommended messages; in the Moderate state in the range 2.5~7.5, the system starts the service of autonomy enhancement and early warning message; in the Severe state in the range 5~10, the system executes emergency service, sending messages to family, neighbors, and rescue unit. The membership function plots corresponding to the numerical ranges of risk levels are represented by the three fuzzy subsets.

Fuzzy rule base in fuzzy knowledge base

The fuzzy rule base is of great importance to the fuzzy inference system, as the quality of inference results depend on the fuzzy rules. The care system developed in this study has 288 example rules, which cover all probable conditions, as shown in Fig. 9. The inference of rules refers to literature and personal judgment, while the example rules in the rule base are inferred according to the 10 Rules in Table 8.

Ontology module

This study uses ontology to describe knowledge. The knowledge represented by ontology is helpful to emphasizing the knowledge structure and expressing the lateral communication between things, thus, facilitating knowledge sharing and reuse.

Many scholars and experts used ontological subjects to propose different methods. Ontology development is based on Protégé ontology editing software with integrity and

Table 9 Environment and tools

Item	Version
Operating system	Windows7 enterprise edition
Program language	Java, C#
Java environment	Java JDK 1.8.0
Database	MySQL Server5.1
Open Source package	JENA2.1.2, mysql-connector-java-3.1.12
Fuzzy logic toolbox	MATLAB R2013a
Ontology module	Protégé 3.4.1

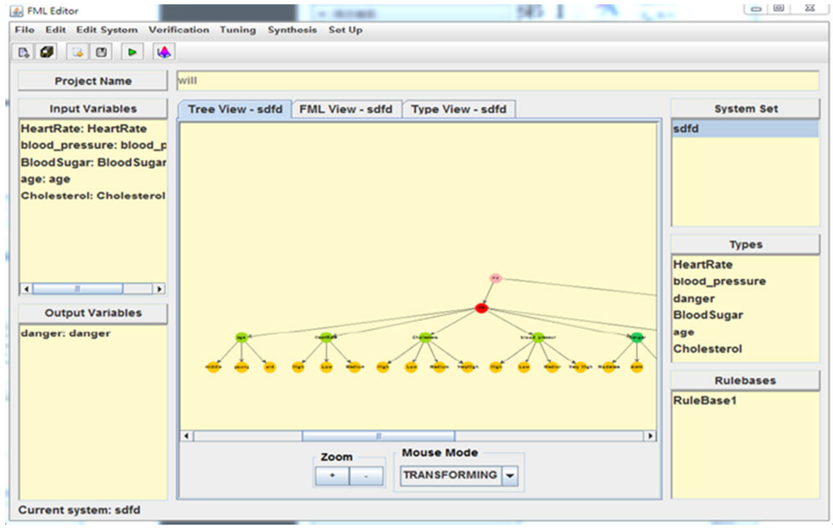


Fig. 13 Visual FML Tool interface

practicability. Therefore, this study uses Protege 3.4.1 as ontological module development and application platform. It not only provides an ontological application interface, but also provides the environment for composing the fuzzy inference engine.

The construction of Ontology has four key steps, determine the scope, define category, define relation (properties), and create example. Namely, the scope of research is determined, the categories are found, the relationship between categories is analyzed, and the example is given.

Determine ontology range

The context-aware space care system is based on the development of human-machine interaction; therefore, it covers how the elderly and chronic-care persons are taken care of and the services and devices that provide care. By monitoring the physiological and environmental input variables, and according to the physiological status of the person under care, the actual conditions are divided into three types: (1) care condition; (2) chronic disease condition; (3) emergency. The corresponding care services and devices are: (1) comfort services of care condition, for example, the indoor temperature data are sensed and transferred to the context management middleware for judgment, and the air conditioning is controlled by radio; (2) autonomy enhancement service of chronic disease condition, for example, the indoor humidity data are sensed and transferred to the context management middleware for judgment, and

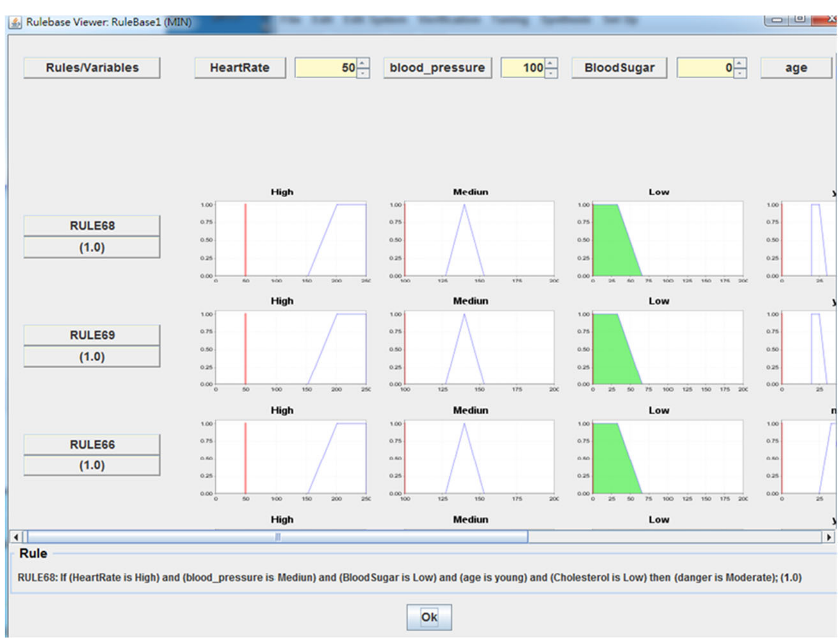


Fig. 14 Mamdani rules modeled with the Visual FML Tool

the dehumidification system is controlled by radio, thus, preventing relapse of arthritis; (3) report service of emergency, for example, if the person under care falls due to heart attack, it is immediately reported to the family and rescue unit.

The ontology range of this care system is deduced from the aforesaid conditions, including:

- Behavior Ontology: the content records human behavior, including the time, place, article, and sub-behavior related to human behavior. The human behavior can be inferred and judged according to these related clues.
- Environment Ontology: the content records the attributes of environment objects and the relationship between environment objects, e.g., the object drug, the drug is used by the person according to environment ontology, the time of taking medicine, applicability, and storage life. The major difference from "Behavior Ontology" is that the component records static information, and this information can be obtained without inference.

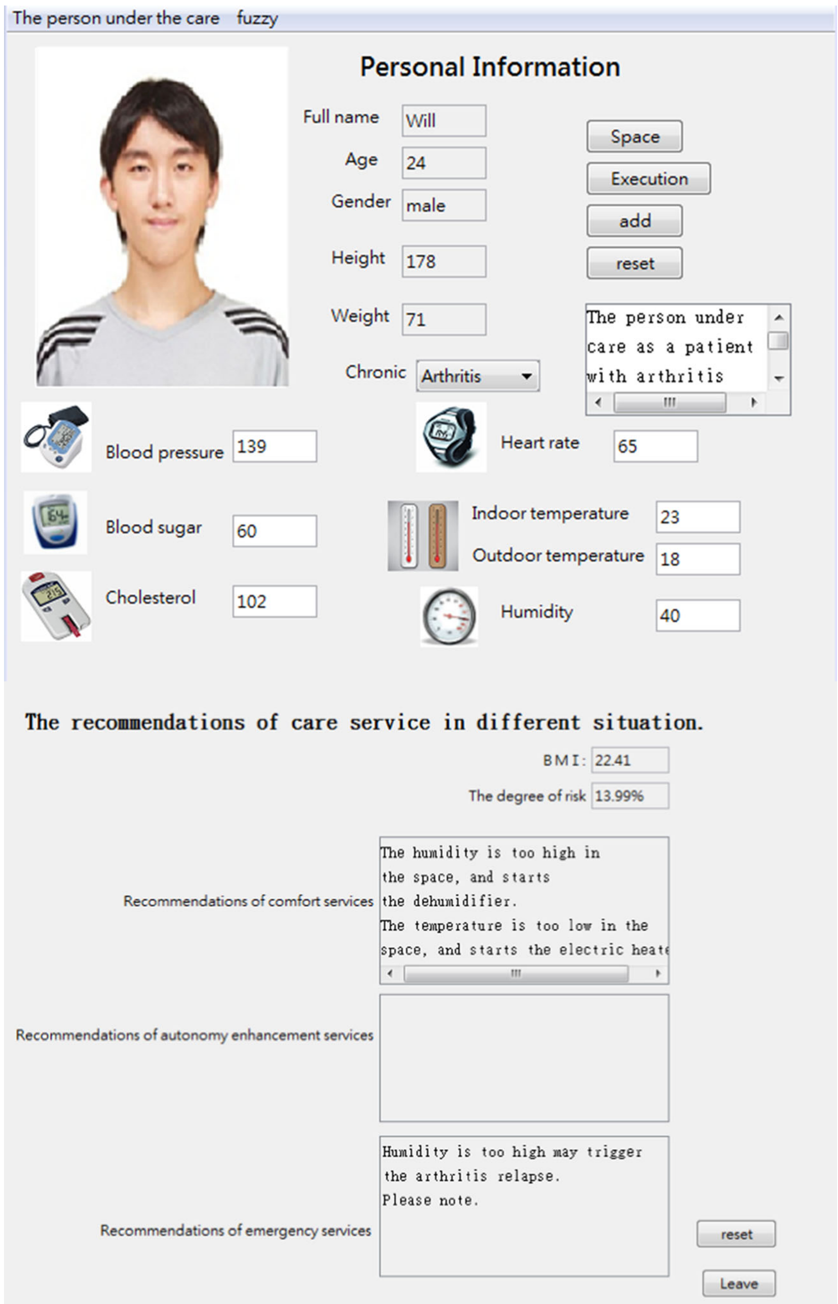


Fig. 15 **a** Input of context of the person under care as a patient with arthritis, **b** Inference service and advice for arthritic

Define categories and relationship between categories

Only when the ontology range, behavior ontology, and environment ontology are determined can the category, and the relationship between category and subcategory, be defined. Therefore, this study plans the knowledge ontology architecture of the context-aware space interactive care system, as shown in Fig. 10. Five ontology categories are analyzed, including (1) behavior; (2) chronic disease; (3) space; (4) measurement; (5) service. The five ontology categories have subcategories, and their relationships are represented by, and are part of the correlation indices, and the related resources of the database are obtained, which is helpful to the research of ontology, as shown in Fig. 11a–e.

The knowledge ontology of the context-aware space interactive care system - relationship between category and subcategory is described, as follows:

1) Ontology category of behavior: the probable behaviors of the person under care shall receive special attention, and three subcategories are set, including memory-decay, fall-down, and insomnia, as shown in Fig. 11a.
2) Ontology category of chronic disease: this study assumes that the person under care is suffering from a chronic disease, and the first five of the top ten chronic diseases in Taiwan are used as the five subcategories, including arthritis, cardiovascular disease, diabetes, respiratory disease, and cancer. If the person under care has one of the said diseases, the ontology category of chronic disease assists the fuzzy inference mechanism to make correct judgments, thus, providing appropriate services, as shown in Fig. 11b.
3) Ontology category of space: the space environments of home are defined, and five subcategories are set: stairs, kitchen, bedroom, toilet, and living room. The environmental measurement subcategory of the ontology category is measured for triggering. As the probably triggered events in different spaces are different, it is necessary to continuously monitor which space category the person under care is in, as shown in Fig. 11c.
4) Ontology category of measure: monitoring the physiological information of the person under care and the living space environment, and two subcategories are set: environment and user, and each has five factors, as shown in Fig. 11d, which are the criteria for the care system to judge the health and safety of the person under care.
5) Ontology category of service: represents the probably executed service, and three subcategories are set: emergency-treatment, comfort-services, and autonomy-

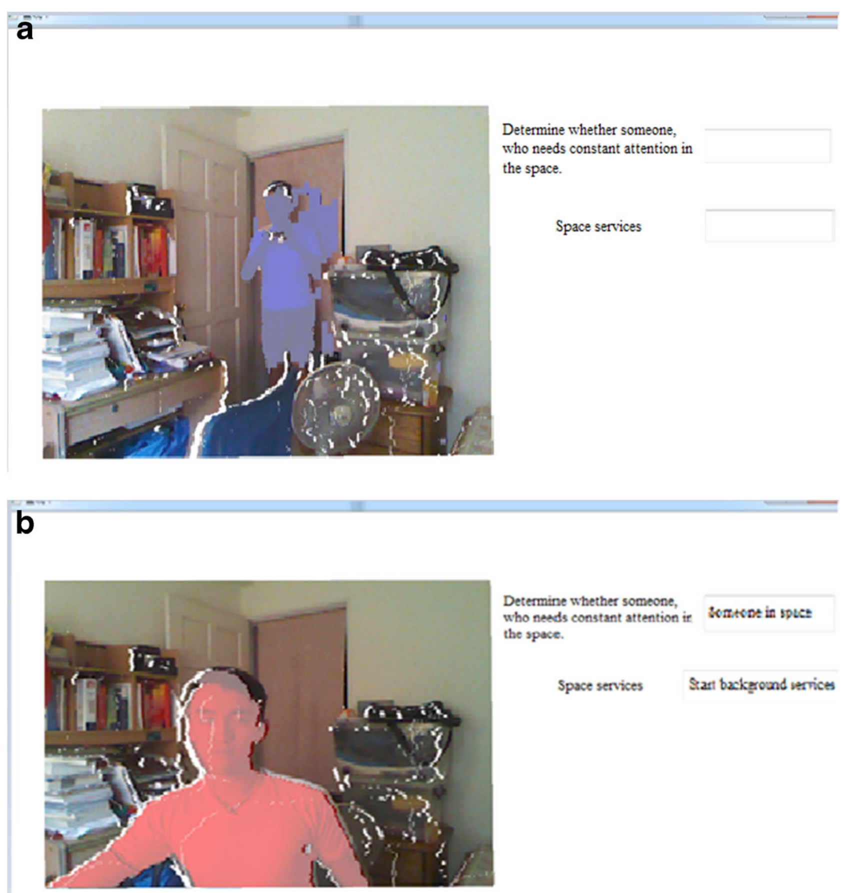


Fig. 16 **a** No person under care in the space, **b** A person under care in the space

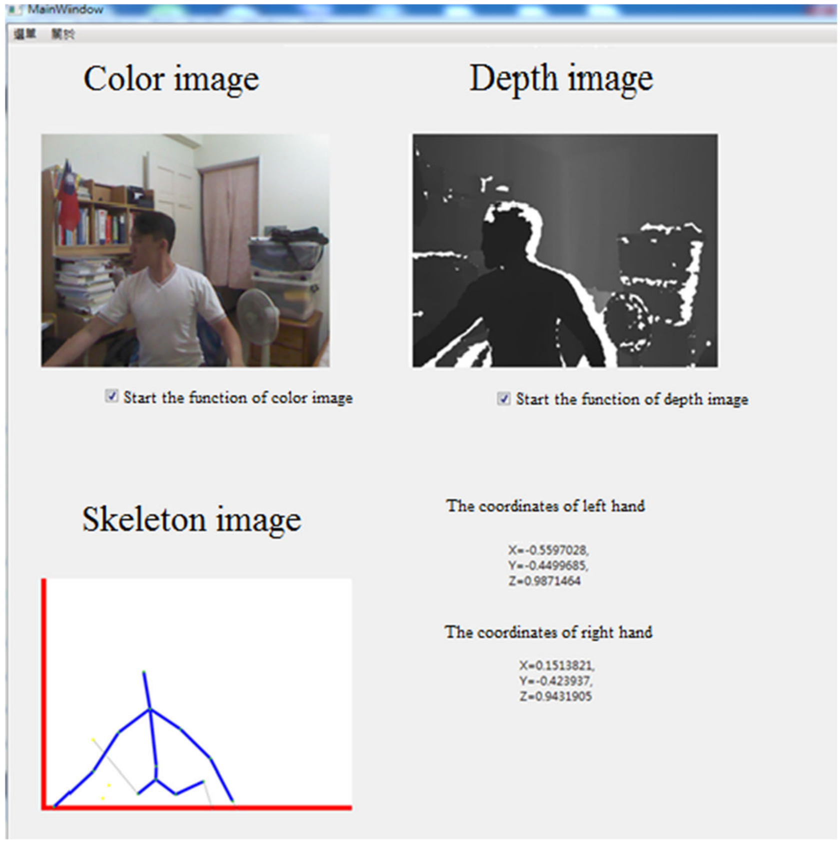


Fig. 17 Motion-sensing interface of spatial interaction

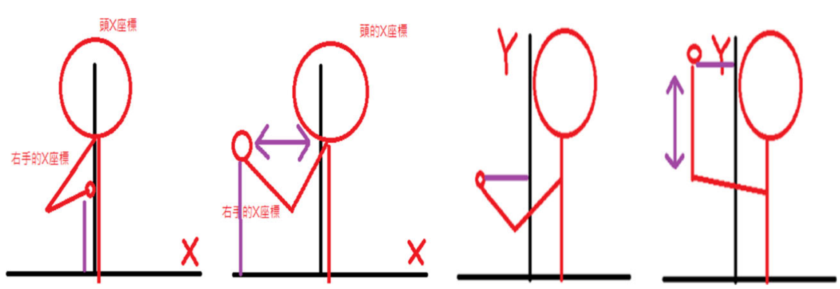
enhancement. The ontology category of the measure imports data, the fuzzy inference mechanism extracts the required data from the other three ontology categories, and the person under care can be provided with the corresponding services in the correct place and at the correct time, as shown in Fig. 11e.

Construction, operation and display of system

Based on the operation process of the research objective context-aware space interactive care system of this study, the major functions are as shown in Fig. 12.

The construction and use of system functions are described, as follows:

1) User interface: developed by JAVA language. In the environment of JVM, the interface is made by API of JAVA Swing. The GUI enables the person under care to connect and interact with the system.
2) User context: as the user and sensors import data, the context information of the physiology and home environment of the person under care is continuously stored in the MySQL database.
3) JENA API:JENA: JENA is a JAVA program of with an open semantic web framework, which supports ontology



a Gesture judgment of right hand wave

b Gesture judgment of right hand raise up

Fig. 18 **a** Gesture judgment of right hand wave, **b** Gesture judgment of right hand raise up

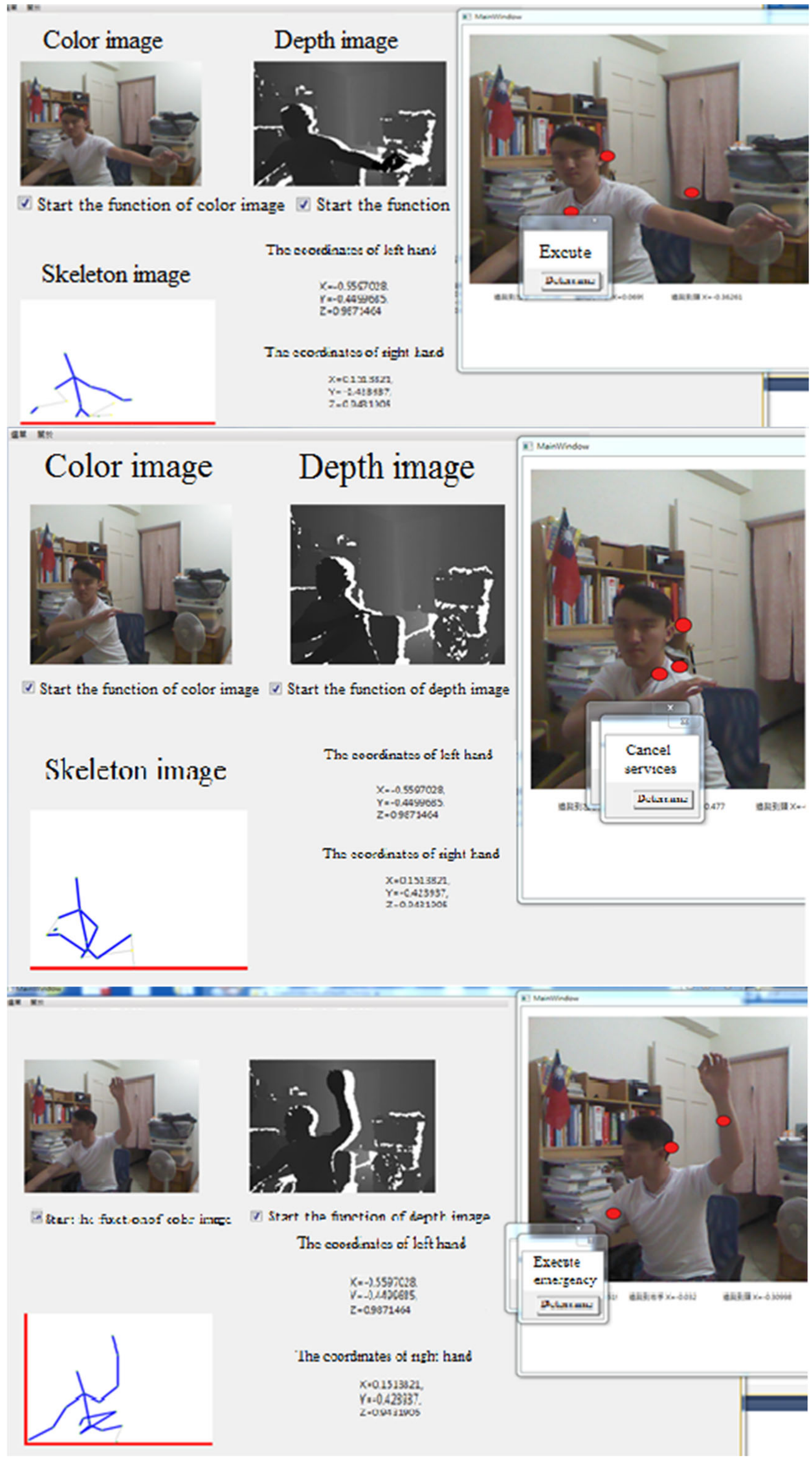


Fig. 19 **a** Execute autonomous service, **b** Cancel autonomous service, **c** Execute emergency service

language. The API extracts the data of user context, and compiles the RDF graph.

4) User's knowledge ontology database, Protégé: based on ontology, the user context is converted into different knowledge ontology categories, and a knowledge ontology database is formed. Protégé 3.4.1 is used for construction. The database enables the care system to automatically interpret the correlation between objects, thus, the autonomous operation of the care system is more coincident with the principle of context awareness.

5) Fuzzy inference mechanism: the changes in user context must be processed by the fuzzy inference mechanism in order to feedback appropriate care services to the user. The data in the knowledge ontology database are not only the basis of inference, but also the source of available information from inference results.

Development environment and tools

The context-aware space interactive care system in this study is developed mainly by the JAVA program language and Swing API. JENA and Protégé are JAVA program languages. The software tools for development are as shown in Table 9.

Construction software of fuzzy inference module

In the selection of a simulation tool, it is expected to validate whether the fuzzy rules in the fuzzy knowledge base conform to the predicted trend. The common fuzzy logic simulation tool is Fuzzy Logic Toolbox-MATLAB, which not only enables the user to instantly observe the designed membership function plots, but also generates three-dimensional simulation graphics according to the fuzzy rules edited by the user.

FML is a markup language that can describe the fuzzy inference theory. The FML Editor is similar to Fuzzy Logic Toolbox-MATLAB, meaning it instantly observes the designed membership function plots, and generates three-dimensional simulation graphics of fuzzy rules. However, the three-dimensional simulation graphics generated by FML Editor can adjust the number of simulation meshes according to user requirement. The larger the mesh number, the smaller the mesh area, the higher the precision of simulation, the longer the computing time.

Therefore, this study selects the simulation tools of MATLAB and FML Editor, and uses the physiological input variables of the person under care for graphical simulation, as shown in Fig. 13. In addition, the physiology context of the person under care (fuzzy set) is taken as the input variable, the risk value is the output variable, as inferred by the Mamdani fuzzy rules, there are 288 fuzzy rules used, and the generated simulation graphics is as shown in Fig. 14.

Display of system operation

The key point of this study is to provide the elderly and chronic-care persons with personal home care services, in order to reduce the demand for labor, such as family or nursing personnel, and to lessen the time, money, and resources for care.

The actual operation process and menus are shown, as follows, and different user's contexts are assumed; how the system implements spatial interaction by Kinect, and how the context-aware mechanism infers proper care services according to the health status of the person under care.

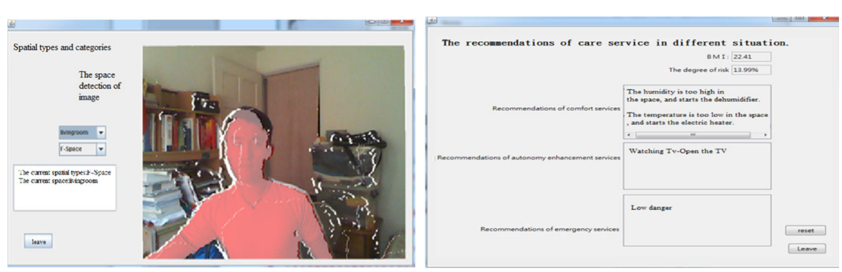
Context assumption 1: The person under care is a patient with arthritis

1) Input of physiological information of the person under care and spatial information

   When there are sensors on the person under care and in the living space for detection and obtaining data. The user interface is entered, the personal physiological information of the person under care (Fig. 15a) and the environmental information are entered and stored.
2) Risk level and advice on care

   When the physiological data of the person under care and space variables are entered, the Execute button is pressed. In this context case, the ontology database of context of the person under care is used as the background knowledge for fuzzy inference. The risk level after inference is displayed in the result column, and the emergency service and advice informs the person under care that the arthritis will recur in the current environment, as shown in Fig. 15b.
3) Execution of system services

   The main characteristic of the care system developed in this study is that the person under care can interact with the system in the living space, and can obtain the required services. The actual operation process is described, as follows.



a Space type   b Service execution of spatial inference

Fig. 20 **a** Space type, **b** Service execution of spatial inference

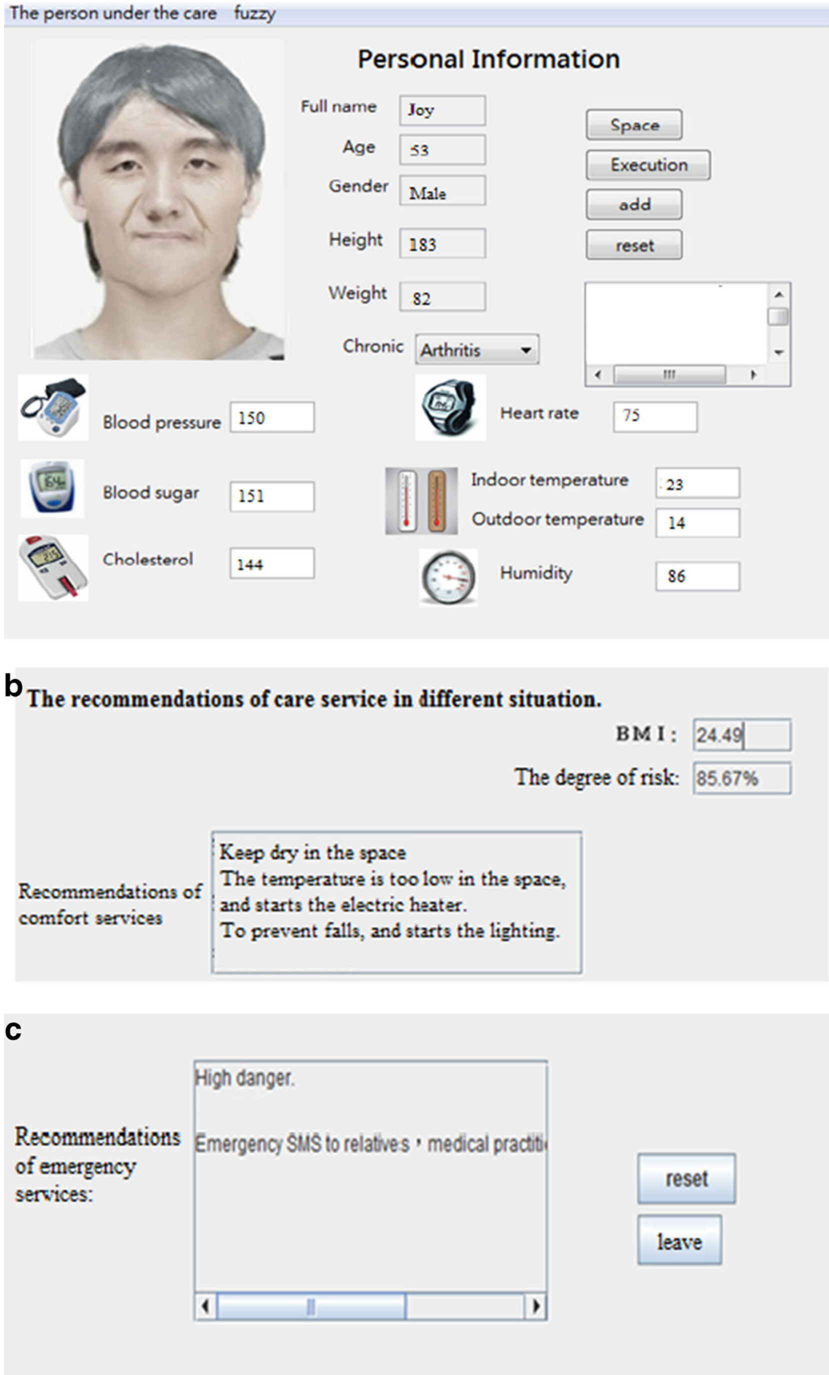


Fig. 21 **a** Context input of the person under care as a senior citizen with arthritis, **b** Fall-down prevention service - switch on lighting, **c** High danger level

(1) Detection of the person under care in the space and judgment of space type

The Kinect sensors are mounted in various living spaces, and codes are set in the care system for identifying sensor placement. Ensure the Kinect sensor is switched on, and the built-in infrared CMOS camera and Kinect SDK software capture the depth image functional equation - DepthImageFrame fram=e.OpenDepthImageFrame(), to capture the 3D depth image. The depth image is formed by using an infrared transmitter to emit light spots and receive signals; as there is no color distortion, it is unnecessary to correct the camera lens.

Fig. 22 Context inference & Spatial location

According to the following focus of the Kinect sensor and calculation of depth data: outside the detection range of Kinect, as marked in blue – it means nobody is in this space, as shown in Fig. 16a. If there is somebody in the Kinect detection range, as marked in red – it means somebody in this space, and the space type is F-Space, as shown in Fig. 16b.

(2) Detection and judgment of motion-sensing interaction

Gesture language is used as the media of communication between the person under care and the system. The color image, depth image, skeleton image, and skeleton coordinates of the Kinect sensor are used. The interface display is as shown in Fig. 17.

The SkeletonFrame frame=e. OpenSkeletonFrame() is executed when the person under care steps into the detectable range of the Kinect sensor, the human body tracking is started, and the skeleton coordinates are captured.

This study designed four gestures: right hand wave, left hand wave, right hand raise up, and left hand raise up, as judged by 2D coordinate marker method. Judgment of right hand wave: the X-coordinate joints of the right hand and head are captured, and checks whether the right hand X-coordinate joint is greater than the head X-coordinate joint +0.5; if yes, it is identified as a right hand wave. The left hand wave is judged in the same manner. Judgment of right hand raise up: the Y-coordinate joints of the right hand and head are

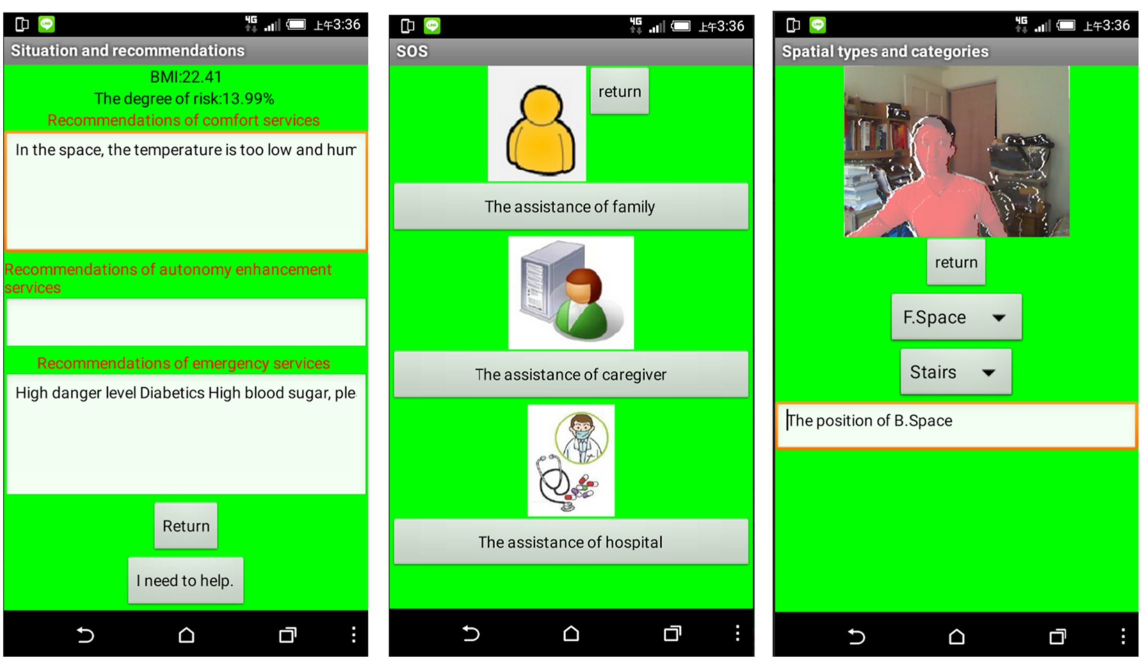


Fig. 23 **a** Context and advice **b** Emergency **c** Spatial pattern and type

captured, and checks whether the right hand Y-coordinate joint is greater than the head Y-coordinate node +0.5. If yes, it is identified as right hand raise up. The left hand raise up can be judged in the same manner, as shown in Fig. 18a and b.

The right hand wave means the care system will execute autonomy-enhancement, as shown in Fig. 19a; the left hand wave means the system will shut down, as shown in Fig. 19b. The right hand raise up means the care system will execute emergency service; the left hand raise up means the system will shut down, as shown in Fig. 19c.

(3) Example description

When the person under care enters the detection range of the Kinect sensor, according to the sensor codes in the system, somebody is in the living room, and the space type is F-Space (Fig. 20a). The wave gesture of the person under care is detected by the motion-sensing mechanism, and the care system is logged in by a right hand wave. According to the spatial location and the user's knowledge ontology database, the person under care may want to watch television, thus, the TV assistant of the autonomy enhancement service will be executed to turn on the TV (Fig. 20b); and corresponding services are provided in different living spaces.

Context assumption 2: The person under care is a senior citizen

1) The input of physiological information of the person under care and spatial information is as shown in Fig. 21a.
2) Risk level and advice on care

   When the physiological data of the person under care and space variables are entered, the Execute button is pressed. In this context case, the ontology database of context of the person under care is used as background knowledge for fuzzy inference. The risk level after inference is displayed in the result column. The comfort-services advice informs that the person under care is likely to fall, especially when walking on stairs, and accidents are likely to occur if lighting is insufficient. Therefore, the comfort-services are provided – meaning the staircase lighting system is switched on, as shown in Fig. 21b.
3) Execution of system service

   If the person under care falls by accident or is in high danger (Fig. 21c), the motion-sensing mechanism detects the wave gesture of the person under care, the care system is logged in by raising up the right hand, and the emergency service is executed.

Application to remote control and access

The server-side menu and function of the context-aware space interactive care system are applied to a desktop computer, and can be controlled by hand-held devices, such as the smart phone or tablet PC. The remote control and access are described, as follows.

1) Log in: according to the functions, i.e., context inference and spatial location categories. If the family or the person under care wants to obtain the present physiological and home environment conditions of the person under care, the "context inference" can be clicked. If the family wants to know the location of the person under care, the "spatial location" can be clicked, as shown in Fig. 22.
2) Service advice and SOS function: if the family or the person under care clicks the "context inference" button, the context and advice after inference are entered, and the current condition of the person under care is judged by the service advices of "comfort services, autonomous assistance, and emergency service", as shown in Fig. 23a. If the person under care is suffering from diabetes, and current blood sugar is relatively high, it is high risk level. Therefore, the "I need help" button can be pressed to contact family or a medical institution, as shown in Fig. 23b.
3) Spatial location: when the family receives a message from the person under care, the location of the person under care, as well as the space type, can be confirmed by the function of spatial location, as shown in Fig. 23c.

Conclusion and future studies

The context-aware home care system developed in this study can enable senior citizens and chronic-care persons to live alone safely and comfortably, as the advice and early warning of the system prevent emergencies. This study applied multiple theories in the care system, and adopted the fuzzy inference module as the core theory. First, the context and space were set, and the physiological information of the person under care and home environment were used as the source of input variables. The input variables were given a specific description in the ontology concept, and converted into various ontology categories. Finally, human judgment was inferred by the fuzzy inference mechanism, and the service was feedback to the person under care. Due to study limitations, the information of different input variables was not captured by different sensors; and the input variables of physiological information and home environment only referred to literature without related expert advice. Actual devices were expected to build the care system in the future, and the experts of related domains could provide more accurate knowledge to enrich the knowledge ontology database of user context, rending the fuzzy inference result of the care system more accurate, and the services more effective and user-friendly.

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