A CYBER-PHYSICAL SYSTEM FOR ELDERS MONITORING

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Abstract: In a new life style, elders can stay in multiple places instead of a single place. The new life style has two features, i.e. multiple scenarios and changes of status of elders, which lead challenges to traditional elder monitoring systems in cooperation and flexibility. This paper presents a new cyber-physical system for elders monitoring, which is divided to two layers, a sub-system layer and a global service layer. Active databases with real-time event-condition-action rule reasoning system are used as core components in sub-systems and the global service to detect risks and cooperate with other systems actively, intelligently, and at real-time. Structure of an ECA rule reasoning system is flexible, in which ECA rules can be adjusted on-the-fly. We discuss some properties in the cyber-physical system, including cooperation among sub-systems, flexibility and real-time property. At last, we present a case study to validate our works.

1 INTRODUCTION

As a person grows older, it is more and more dangerous that he/she lives independently in the home. Thus, many elders decide to relocate from their homes to nursing centers. It is common, following such a relocation, for a person to become depressed due to their lack of independence (Augusto and Nugent, 2004).

Over the past decade, a new life style becomes widespread: elders stay in multiple places, e.g. homes, nursing centers, parks, pathways, etc. instead of a single place. Elders can be taken care by nurses in the nursing center in the daytime and keep their independences, privacies and personal interests in some other time.

The life style has two features, i.e. 1) multiple scenarios and 2) changes in the status of an elder, e.g. healthy, indisposition, ill seriously, etc.

The two features lead two challenges: cooperation and flexibility. Suppose an elder with heart disease has a cold in the home. Both the monitoring system in the home (home system) and the monitoring system in nursing center (nursing system) should enhance the monitoring level to prevent a possible heart attack caused by the cold. Here, information about the elder should be provided by the home system to the nursig system, so cooperation between the two systems is necessary. Meanswhile, both systems should support to modify contents of monitoring to fit changes of status of the elder, so systems should be flexible.

However, traditional elder monitoring systems are stable and independent, so they lack cooperation mechanism and flexibility.

In this paper, we present a cyber-physical system for elders monitoring. The system is divided to two functional layers, sub-systems and a global service. A sub-system is arranged in each scenario to collect data from elders and environment, and detect risks intelligently. The global service manage all sub-systems. Active database with real-time event-condition-action (ECA) rule reasoning system is used as a core component to provide abilities of intelligent and real-time reasoning to sub-systems and the global service.

Through the global service, sub-systems can cooperate with others. Meanwhile, the structure of each active database is flexible, in which ECA rules can be added, modified or removed on-the-fly.

The rest of the paper is organized as follows: section 2 expresses related works; section 3 addresses the functional framework of our system; section 4 introduces design of our system; we validate our works in section 5; conclusions and future works are stated in section 6.

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2 RELATED WORK

Classical methods and systems in traditional elder monitoring systems fall into three categories, i.e., intelligent and wearable devices, video data processing and intelligent reasoning.

In the first category, (Park, Won, etc., 2003) introduces several intelligent devices. (Korhonen, Parkka, etc., 2003) presents users' requirements and the state of the art on wearable sensors.

In the second category, (Tseng, Wang, etc., 2007) presents an intelligent sensor with a mobile video camera. (Tabar, Keshavarz, etc., 2006) fuses data from sensors and images from cameras to monitor falling of elder.

In the third category, (Augusto and Nugent, 2004) present a set of ECA rules to monitor health of elders. (Li, Lin, etc., 2004) presents the real-time event detection service to handle event and data from distributed sensor networks. (Noury, Virone, and Creuzet, 2002) presents a decision algorithm with rules to localize a human in the home.

Although these methods and systems have researched on availability, reliability and efficiency in elder monitoring, none of them consider flexibility and intelligent cooperation among more than one monitoring systems.

3 FUNCTIONAL FRAMEWORK

Figure 1 illustrates the functional framework of our cyber-physical system for elders monitoring. In the framework, the system is divided to two functional layers, sub-systems and a global service center.

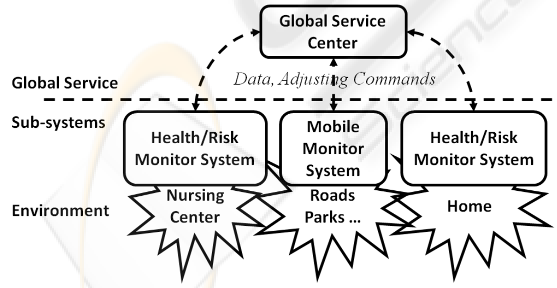

Figure 1: Function layers the cyber-physical system for elders monitoring.

A sub-system is placed in each scenario, in order to 1) collect data from elders and environment, 2) detect risks from data and giving alarms actively and at real-time, 3) exchange information with the global service, and 4) adjust its contents of monitoring.

The global service is used to 1) receive and synthesize data from sub-systems, 2) detect risks globally, 3) transmit data, and 4) adjust contents of monitoring in sub-systems.

With these functions, the cyber-physical system will fit for the new life style. Sub-systems can cooperate with each other by transmitting information through the global service. Meanwhile, monitoring contents in all sub-systems can be adjusted by the global service.

4 DESIGN

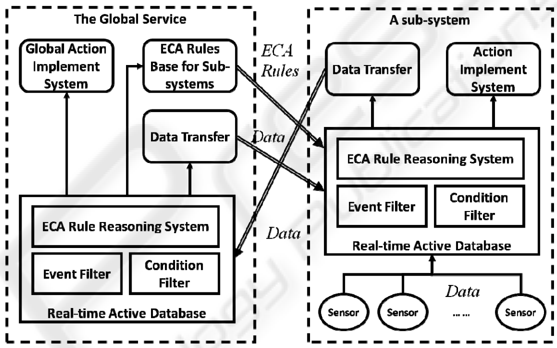

Figure 2: Structures of the global service and sub-systems.

In order to realize aforementioned functions, sub-systems and the global service should have abilities of active, intelligent and real-time reasoning. Moreover, the structure of reasoning should be flexible so that contents of reasoning should be adjusted. In order to support cooperation among sub-systems and the global service, a communication mechanism should be set up among them.

Figure 2 shows structures of sub-systems and the global service.

In each sub-system, several kinds of sensors are used to monitor all useful data from elders and environment. Data received from sensors and the global service is sent to the active database.

With ECA rules, an active database is able to anticipate potential or actual hazardous situations and intelligently discern how to best advise related persons locally or what to send to the global service.

In an active database, the event filter and the condition filter extract external events and condition values from original data. An ECA rule reasoning system with a real-time reasoning algorithm is used to detect composite events, evaluate conditions, and trigger actions at real-time depending on ECA rules. Active database has a flexible rule base, in which ECA rules can be adjusted on-the-fly.

Some actions are implemented in the local action implement system to react local risks. Other actions are implemented in the data transfer to send suitable information to the global service.

In the global service, an isomorphic active database processes information from sub-systems and gives out global actions. Some actions are implemented in the global action implement system to react for global risks. Some are implemented in the data transfer to send suitable data to suitable sub-system. Others are implemented in the ECA rules base for sub-systems to choose a suitable set of ECA rules and send them to a sub-system.

4.1 Cooperation

Information exchanged among sub-systems and the global service is packed in XECA, a XML-based language that we defined, including ECA rules, events, conditions, actions, commands, etc. The model and visual specification tools of the XECA can be found in our previous work (Qiao, Zhong, etc., 2007) and (Liu, Qiao, etc., 2008). Technically, textual data can be easily passed from one site to another, with traditional distributed technologies (CORBA, JMI, etc.).

In the architecture, a sub-system can cooperate with any other sub-systems indirectly through the global service. Cooperation among systems is transformed to cooperation among reasoning systems. Inference results in a sub-system are considered as external events for other reasoning systems.

4.2 ECA Rule Reasoning System

As the core of active database, ECA rule reasoning system can detect risks and trigger appropriate actions actively, intelligently and at real-time. The structure is shown in Figure 3.

In our ECA rule reasoning system, there are five layers:

Input Interface: Through input interface, XECA-based commands are sent into the ECA rule reasoning system. The textual processor checks all commands, compiles them to binary information and sends them to correct places.

Unit-Mail Management Layer (UMML): In the layer, commands for adjusting ECA rules are implemented without stopping the inference process. New ECA rules are translated to temporary units and stored in the unit producer. Commands for adding are implemented in the merging module by merging temporary units into the rule base. Furthermore, commands for removing are implemented in the removing module, by removing invalid units in the rule base.

Open Rule Base: The rule base holds ECA rules and provides suitable ECA rules to the inference layer. In the rule base, ECA rules are stored as a loose coupling structure called unit-mail graph (UMG), in which each composite event or each condition in ECA rules is packed in a unit.

In the rule base, each unit is physically independent of others, which makes it is easy to add or remove units in the rule base. Meanwhile, logically, units consist of a directed graph which ensures inference can run smoothly.

Inference Layer: In the inference layer, the inference core detects composite events from external events, evaluates conditions and triggers actions. With UMG, the dynamic process of inference is transformed to a “receive, process, and send mails” model. Details of UMG and the “receive, process, and send mails” model can be found in (Li, Qiao, etc., 2009).

Output Interface: In the output interface, condition queries and actions are translated to XECA and sent out.

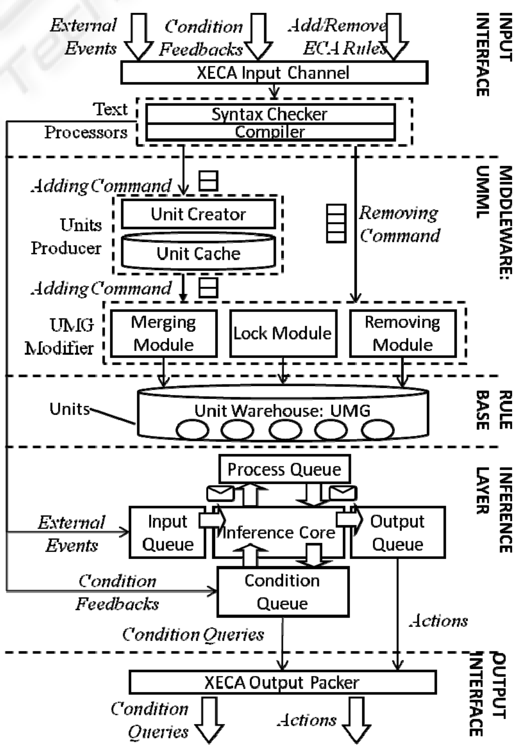

Figure 3: Structure of the ECA rule reasoning system.

4.3 Flexibility

With the UMML, adding and removing ECA rules are transformed to adding and removing units in UMG. Because the UMG is loose coupling, it is not necessary to stop the entire reasoning system when units are being added or removed. Four mechanisms ensure ECA rules can be added and removed on-the-fly:

Loose Coupling mechanism means relations among units are loose coupling.

Lock/Unlock mechanism means a unit cannot be called by other threads when it is locked.

Top-Down mechanism means the merging module and the removing module add units and delete units in top-down order.

Roll-Back mechanism makes the rule processing mechanism avoid unexpected errors.

4.4 Real-time Algorithm

In the inference layer, an “any time” real-time algorithm called RTIAE is used to ensure actions be given out at real-time.

Logically, in the inference core, units consist of a directed rule graph. In RTIAE, the reasoning is accomplished via heuristic search. The purpose of heuristic search is to find a path from a specific entrance node (without incoming edges) to an exit node (without outgoing edges) so that the time consumed for traveling along this path is as short as possible. During the search, the expected path will be expanded with a node selected via the value of the heuristic function.

The metric to evaluate the performance of the inference algorithm is reasoning success ratio, which is defined as the ratio of number of actions found within a given deadline. The simulation results demonstrate that the RTIAE takes advantages over depth-first algorithm in term of reasoning success ratio for variation of several parameters, i.e., the laxity and the number of events occurring in the system. Details of the real-time algorithm can be found in our previous work (Qiao, Li, etc., 2008).

5 CASE STUDY

In this section, we design three cases to validate our works.

5.1 Devices and Programs

We use some wireless sensors which are manufactured by Crossbow Technology® to collect data. Sensors communicate with a computer with a gateway MIB520.

We develop the active data base in Java with Eclipse platform. Communication mechanism is developed with JMI. Three active databases run in three laptops to perform as sub-systems in the home, the nursing center and the global service respectively. Laptops are connected by an intranet.

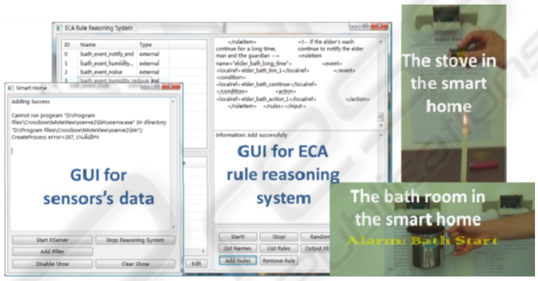

Figure 4: GUIs of our systems and experiment scenarios.

5.2 Case I

In Case I, we validate the function of a single reasoning system. ECA rules are listed in Table 1.

Table 1: ECA rules for Case I.

Rule 1: (home)	
On	"1 hour after the stove is open" and "the elder does not leave the home"
If	the fire is still on
Do	loud sounds "Risk of fire!"

Table 2: Experiment 1 for Case I.

Event	enter home	open stove	
$\mathbf{t_{Event}}$	10:01:23 am	10:02:45 am	
Action			Risk of Fire!
$\mathbf{t_{Action}}$			11:02:45 am

Table 3: Experiment 2 for Case I.

Event	open stove	close stove
$\mathbf{t_{Event}}$	11:05:45 am	11:30:22 am
Action		
$\mathbf{t_{Action}}$		

Results for Case I are shown in Table 2 and Table 3. We enter home, open the stove and waits for 1 hour. An alarm is given out expectably. Then, we open the stove again, and close it in 1 hour. No alarms are given out. Results show that our ECA rule reasoning system works well.

5.3 Case II

Table 4: ECA rules for Case II.

Rule 2: (home)	
On	"1 hour after the stove is open" and "the elder leaves the home" and "the elder does not enter the home"
If	the fire is still on
Do	provide data the global service "Alarm: Risk of Fire: Home"
Rule 3: (global service)	
On	"Alarm: Risk of Fire: Home" is received, between arrival at and departure from the nursing center
If	[null]
Do	transmit data to the nursing center "Alarm: Risk of Fire: Home"
Rule 4: (nursing center)	
On	"Alarm: Risk of Fire: Home" is received, between arrival to and departure from the nursing center
If	[null]
Do	loud sounds "Alarm: Risk of Fire: Home"
Rule 5: (nursing center)	
On	the elder arrives the nursing center
If	[null]
Do	provide data to the global service "Data: Arrival of the elder: Nursing Center"
Rule 6: (nursing center)	
On	the elder leaves the nursing center
If	[null]
Do	provide data to the global service "Data: Departure of the elder: Nursing Center"

In Case II, we validate cooperation among sub-systems and the global service. ECA rules are listed in Table 4.

Results for Case II are shown in Table 5. We open the stove and leave home. When we arrive at the nursing center, the sub-system notice the global service this arrival. In 1 hour after we open the stove, an alarm is sent by the home system to the global service and transmitted immediately. When the alarm is received by the nursing system, it alarms with loud sounds. Because laptops are in the same intranet, time for communications can be ignored. Results show that our cooperation mechanism works well.

5.4 Case III

In Case III, we validate ability of the global service to adjust ECA rules in sub-systems. ECA rules are listed in Table 6.

Table 5: Experiment 3 for Case II.

Sub-system in Home (Home)				
Event	open stove	leave Home		
t_{Event}	12:11:23 pm	12:12:33 pm		
Action			Home Alarm to Global	
t_{Action}			13:11:23 pm	
The Global Service (Global)				
Event	Arrival at NC	Home Alarm		
t_{Event}	12:30:22 pm	13:11:23 pm		
Action			Alarm to NC	
t_{Action}			13:11:23 pm	
Sub-system in Nursing Center (NC)				
Event	arrival at NC		Alarm from Global	
t_{Event}	12:30:22 pm		13:11:23 pm	
Action		Arrival at NC to Global		Notify the elder
t_{Action}		12:30:22 pm		13:11:23 pm

Table 6: ECA rules for Case III.

Rule 7: (nursing center)	
On	the elder falls over
If	[null]
Do	provide data to the global service "Data: Fall Over: Nursing Center"
Rule 8: (global service)	
On	"Data: Fall Over: Nursing Center" is received
If	[null]
Do	send two commands to home: A command for removing Rule 9 in XECA A command for adding Rule 10 in XECA
Rule 9: (home)	
On	1 hour after the elder enter the bath room
If	[null]
Do	Notify the global service "Risk of bath"
Rule 10: (home)	
On	30 minutes after the elder enter the bath room
If	[null]
Do	Notify the global service "Risk of bath"

Results for Case III are shown in Table 7. We fall over in the nursing center. Then the report is sent to the global service. The global service sends out two commands to the home system. Then, the home system replaces Rule 9 with Rule 10. Results show that the function of adjusting ECA rules works well.

Table 7: Experiment 4 for Case III.

Sub-system in Nursing Center (NC)			
Event	falls over		
t_{Event}	14:09:01 pm		
Action			Fall over to Global
t_{Action}			14:09:01 pm
The Global Service (Global)			
Event	Fall over		
t_{Event}	14:09:01 pm		
Action		Command for removing Rule 9	Command for adding Rule 10
t_{Action}		14:09:01 pm	14:09:01 pm
Sub-system in Home (Home)			
Timestamp	before 14:09:01 pm	14:09:01 pm	after 14:09:01 pm
ECA Rules	Rule 9	null	Rule 10

6 CONCLUSIONS AND FUTURE WORK

Although many works have been done on elder monitoring systems, none of them can fit multi-scenarios and changes of status of elders. To solve above problems, we present a cyber-physical system for elders monitoring. In the system, sub-systems are used to monitor status of elders and environment, and a global service is used to manage all sub-systems. Active databases with real-time event-condition-action (ECA) rule reasoning systems provide abilities of intelligent and real-time reasoning to sub-systems and the global service. In comparison to traditional independent elder monitoring systems, our cyber-physical system enhances flexibility, cooperation among sub-systems and real-time property. At last, we design three cases to validate our works.

In the future, more researches could be done with the cyber-physical system for elders monitoring.

Firstly, in our system, inferences are real-time, but real-time property in communications among sub-systems should be researched in the future.

Secondly, ability of description of the model of ECA rule should be enhanced.

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