Event-based Home Safety Problem Detection Under The CPS Home Safety Architecture

Zhengguo YANG, Azman Osman LIM, Yasuo TAN
School of Information Science, Japan Advanced Institute of Science and Technology
1-1 Asahidai, Nomi, Ishikawa, Japan. 923-1211
{yangzg, aolim, ytan}@jaist.ac.jp

***Abstract*—This paper presents a CPS(Cyber-physical System) home safety architecture for home safety problem detection and reaction and shows some example cases. In order for home safety problem detection, there are three levels of events defined: elementary event, semantic event and entire event, which representing the meaning from parameter to single safety problem, and then the whole safety status of a house. For the relationship between these events and raw data, a Finite State Machine (FSM) based modeling is applied. Including the raw data, these are taken as input and output to the three levels of FSMs. By using this way of event composition, not only single safety problem, but also safety level of the whole house can be precisely described. In order to verify the mechanism of hierarchical FSMs and by using this mechanism, safety problems and safety level of a house can be correctly represented. And also verify that different levels of events can precisely representing what is happening. Two simulation cases are proposed: one is heat stroke and another is carbon monoxide poisoning. The simulation result shows that the simulation targets are satisfied.**

Keywords - Cyber-Physical Systems, Event-based Model, Service-based Model, Safety Problem Detection, Event Composition.

I. Introduction

There are many types of safety problems that may arise within a home environment. These safety problems can be classified into three big categories: safety of home appliances, safety of indoor environment and safety of interaction between home user and home appliance[2]. The occurrence of home safety problem always have three bad consequence: cause casualty or cause home property loss or both. So an effective approach for home safety problem detection and reaction is necessary. Even though some proposed systems can partially solve the problem, like [3][6][7][8], there are still some aspects that they didn't take into consideration. Firstly, the proposed system should not be an isolated system. Because not only the system that secure home safety, but also other systems like home theatre system may also be deployed in the home environment. By accompanying with these systems, there should have some interactions. Secondly, for easy management and cost saving, data aggregation, computation and reaction services should be deployed separately. Thirdly, One such a system should have the ability to cope with multiple home environments simultaneously. So a new home safety architecture is required.

Cyber-physical systems is a hot research topic recently. It is possible to apply event-based approach to CPS [5]. And proposed systems like [1] has improved the event-based CPS. And it has been applied to some areas[9][10]. But to the author's knowledge, there seems still something unsolved. Traditional event-based systems always take event as equivalent importance. But to the physical world events, it not always like this. Different event should have different significance, especially when some events contribute to the occurrence of a higher level event. So in this paper, a mechanism of FSM based modelling is proposed which take raw data and three levels of events with different significance as input/output. In relation with *event*, it is necessary to take actions after event is detected. In this research, the *action* is abstracted and provided as all kinds of services provided by different service providers. And the *Next Generation IP Network Promotion Forum* has proposed a service intermediary model for service supply[4], which our proposed architecture is based on this.

The proposed CPS home safety architecture is a mixture of event-based and service-based model for safety problem detection and reaction. Then a layered FSMs is given for event composition, which use the three levels of events and raw data as input and output to give an evaluation of single safety problem and safety level of a whole house. For simulation, two scenarios are given, which one is heat stroke and another is carbon monoxide poisoning. Based on these to verify the three levels of events and the layered FSMs are working properly.

The rest of this paper is organized as follows. In section two some preliminaries knowledge is given. Then the proposed CPS home safety architecture will be introduced in section three. Based on this home safety architecture, the layered FSMs for safety problems detection and safety level evaluation will be discussed in section four. Then section five gives the simulation cases. Finally, a conclusion is given.

II. Preliminaries

Home environment and home safety problems varies from home to home. Before move on to introduce the CPS home safety architecture and the mechanism of layered FSMs, some constraints and definitions should be given. In this section, the concept of home, home safety and definition of events will be introduced.

A. The definition of home

Home environment varies with respect to the kind and quantity of home appliances and home users living in. The biggest differentiation is that modern home appliance usually have the ability of networking while legacy home appliance don't have. So in this paper, the *home* is the inside environment of a modern house(including building or group of rooms) for people to live in, which is equipped with high-automated and networked home appliances to meet residents' daily requirement. And for home information gathering and control purpose, different kinds of sensors and actuators are deployed in the home environment. In that case, sensed data can be transmitted out and control commands can be transmitted in through the home gateway.

B. The definition of home safety

Such a *home* is said to be safe means that existing home appliances and the environment are dependable for home users to live in. And the dependability of a home is the ability of delivering justifiable services to make a ease and safe life for home users.

There are three kinds of safety: the safety of home appliances, the safety of indoor environment and the safety of interaction between home user and home appliance[2]. The safety of home appliances is that home appliances should work under their designed specification and should not cause emergency situations to the environment and home users. The indoor environment should not cause malfunction of home appliances and injury or death to home users. And the safety of interaction between home user and home appliance means no injury and death to home user and no malfunction to home appliance.

C. Definition of events

There are four type of events defined actually: elementary event, semantic event, entire event and service event, which service event is not covered in this paper.

1) *Elementary Event*: the event that excited by abnormal change of raw data. e.g. the temperature value changes beyond the threshold value.
2) *Semantic Event*: it represents a safety problem that is generated by one or more elementary events. e.g. heat stroke may be caused by the events of abnormal change of temperature and humidity.
3) *Entire Event*: it represents the emergency level of a house. Three levels are defined: *green* represents the safety situation; *yellow* is that the occurrence of one or more safety problems may cause property loss; and *red* denotes casualty and property loss or just casualty.
4) *Service Event*: it related to services that will be used in future research.

A more detailed explanation will be discussed in section four.

III. The CPS Home Safety Architecture

The CPS Home Safety Architecture is proposed to detect and react to home safety problems and emergency situations precisely and timely. By proposing this architecture, the concept of *Service Intermediary model* and *CPS* is applied. For safety problem detection, the event-based approach is applied while a service-based approach is used for safety problem reaction.

Some assumptions are made before *the CPS Home Safety Architecture* is given. First, all home appliances are networked, and can be sensed by all kinds of sensors and actuated by actuators. Second, the home gateway and the service intermediary have sufficient capability to process huge real-time data. Lastly, all related computing devices and database are connected through wired and/or wireless networks.

A. Description of the Proposed Architecture

The proposed *CPS Home Safety Architecture* is shown in figure 5. It consists of four main parts: Home Environment, Home Gateway, Service Intermediary and Service Provider.

The *Home Environment* is the place that residents live in with different kinds of networked home appliances to meet residents' daily requirement. It is the environment that safety problems may happen. Therefore many different kinds of sensors and actuators are deployed, and sensed data can be transmitted out and the control commands can be transmitted in through the *Home Gateway*.

The *Home Gateway* is the gateway of the networked home environment to the outside world. It has the ability to execute services and control commands through actuators. There are two databases here, one for logging of detected events and another is a local service database to provide prescribed services.

The *Service Intermediary* aggregates services from different service providers and maintains locally. Also, the safety level of the entire home environment can be evaluated here. Based on this evaluation, appropriate services are chosen for reaction. There are also two databases here, one is for logging the detected event and another is the cloud service database.

The *Service Provider* designs, publishes and updates concrete services to the *Service Intermediary* for further use.

B. System Component Description

The components description of the proposed architecture is shown in figure 6. The home environment consists of home users, home devices and the space among them. Sensors that deployed in the home environment and send sensed data to the *Elementary Event Generator* in the *Home Gateway*. For the realization of the *Elementary Event Generator*, the first level of the layered FSM is applied, which will be introduced in the next section. The generated elementary events then transmitted to the *Semantic Event Generator* for next level event generation within the *Home Gateway*.

As can be seen from figure 6, there are two black arrows come out of the *Semantic Event Generator*, which one of them goes to the *Controller* in the *Home Gateway*. Normally, this *Controller* is not working until the connection between *Home Gateway* and *Service Intermediary* is disconnected. And it is for emergency use. The another black arrow goes to the *Entire Event Generator* within the *Service Intermediary*. And this means the transmission of generated semantic events. The second level of the layered FSM is the realization of the *Semantic Event Generator*.

The safety level of the home environment, which is represented by entire events, is evaluated by the *Entire Event Generator*. And the evaluation result is transmitted to the *Controller* in the *Service Intermediary*. Then the *Controller* informs the *Service Integrator* to integrate necessary services. These services will be distributed by *Service Distributor* to the *Service Executor* in the *Home Gateway*. Finally, actuators will be controlled to achieve some targets that make the home safe.

IV. Event-based Safety Problem Detection

Based on the architecture introduced in the previous section, with the purpose of detecting these events, a layered FSM based modelling is applied, which is shown in figure 1.

The raw data comes from sensors that deployed in the home environment. *Elementary Event* is excited from raw data, which represents one aspect of thing, e.g. temperature changes abnormally. The *Semantic Event* has the rich knowledge to represent a single safety problem. The *Entire Event* gives the overall description of the safety level of a house.

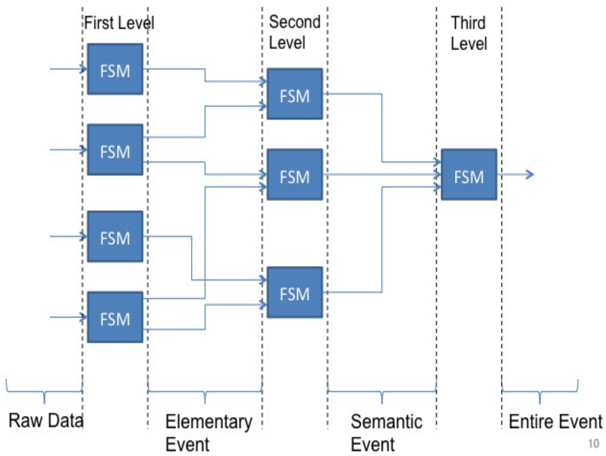

Fig. 1. Layered FSMs with raw data and events as input/output

A. Definition of Event Sets

To represent these defined events mathematically, the representation of event sets are defined as follows.

$$E = \{EL, EM, EN, ES\} \tag{1}$$

where EL represents the event set of elementary event; EM means the event set of semantic events; EN denotes the event set of entire event and ES means the event set of service events.

The generic representation of each single event shows as follows and they belong to the corresponding event set.

$$el_{ID} \in EL, em_{ID} \in EM, en_{ID} \in EN, es_{ID} \in ES \tag{2}$$

B. Event Definition

For each single event, they have some properties to represent their characteristic. As service event is not covered in this paper, the generic form of elementary event, semantic event and entire event is defined as follows.

$$e = \{e_{type}, t, l, s\} \tag{3}$$

where e_{type} is the event type, which represents what event it is; t is the time when the event generated; l is the location where the event occurrence, which is represented by using the form of $[h, r]$(h is house ID, r is room ID); s is the significance of each event in contributing to next level event.

Because not all low level events has the same importance in contributing to their adjacent high level event. Each low level event is assigned a value to represent how important it is when corresponding low level events are taken as input to generate next level event. For a single event, its significance should satisfy $s \in [0, 1]$. And for a group of events that contributing to a higher level event, the sum of significance of these events should satisfy $\sum s \leq 1$. When the sum of significance is above a threshold significance value means that a new next level event has a high possibility be generated. One way to generate the threshold significance value is by engineers with rich experience in analyse safety problems.

C. The Relationship of Event Types

The relationship between event types is simple. For elementary event type and semantic event type, they satisfy equation 4.

$$em = \{\bigwedge_{i=1}^{N} el_i | N \in Integer, el_i \in EL\} \tag{4}$$

Because there are some semantic events' occurrence may in the same room or maybe in different rooms. So the relationship between semantic event and entire event should satisfy equation 5.

$$en = \{\bigwedge_{i=1}^{room\_num} \left(\bigwedge_{j=1}^{event\_num} em_j, l_i \right) | em_j \in EM, l_i \in [h, r]\} \tag{5}$$

D. Definition of FSMs

As mentioned earlier in this section, the layered FSM has three levels, which takes the raw data and events as input and output. To each level of FSM, a detailed explanation is required. Actually, all the three levels of FSM have the same form of definition, a five-tuples, which represented as follows.

$$M = \{Q, \Sigma, \Gamma, \delta, q_0\} \tag{6}$$

where M is a FSM; Q means the finite set of state; Σ is a finite set of input; Γ is the finite set of output; δ is the transition function and it's alway have the form of $\delta : \Sigma \times Q \rightarrow \Gamma \times Q$. And q_0 is the initial state. But for each level of FSMs, they have different content.

For the first level FSM, $Q = \{normal, abnormal\}$; Σ is the subset of raw data; Γ is the subset of elementary event and $q_0 = normal$. When refers to the second level FSMs, $Q = \{safe, transforming, unsafe\}$; Σ is the subset of elementary event; Γ is the subset of semantic event and $q_0 = safe$. For the third level FSM, $Q = \{green, yellow, red\}$, where *green* means everything is normal; *yellow* denotes property loss and *red* means casualty or casualty and property loss. Σ is the subset of semantic event; Γ represents the subset of entire event and $q_0 = green$.

When evaluate the transition function, the significance is used. A transition is enabled when the sum of significance of the same level events is greater or equal to a threshold significance, which these events contribute to the occurrence of a next level event.

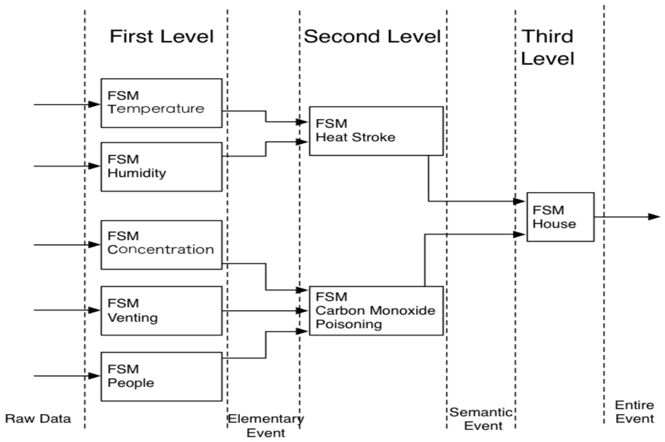

Fig. 2. Layered FSM to show the simulation cases

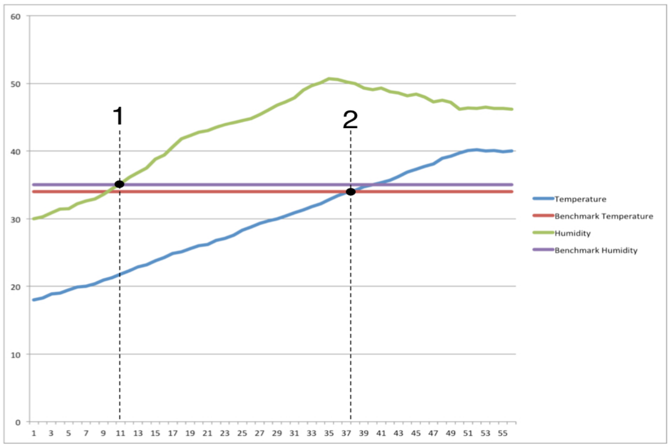

Fig. 3. Related data of temperature and humidity that contribute to heat stroke

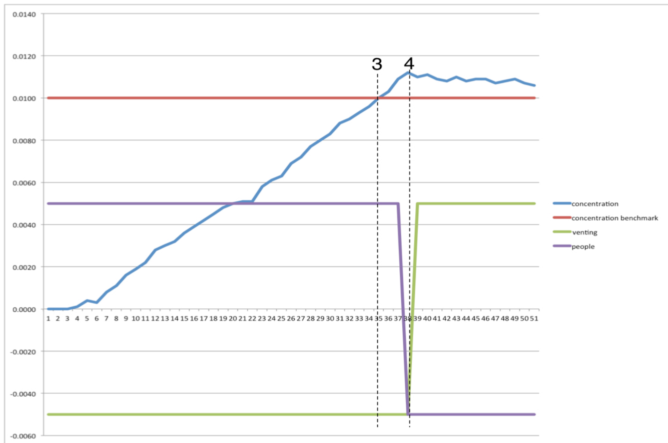

Fig. 4. Related data that contribute to carbon monoxide poisoning

V. Simulation Cases

In order to verify our work, two simulation cases are proposed. One is heat stroke and another is carbon monoxide poisoning. According to the two simulation cases, some simulation targets are supposed to be verified. The first is that the mechanism of hierarchical FSM conversion works correctly. From raw data, different levels of events can precisely representing what is happening. By using the mechanism of layered FSM, home safety problems can be precisely detected and safety level of a house can be correctly evaluated. The layered FSM that represents the two simulation cases is shown in figure 2.

A. Heat Stroke

Recent years in summer, the weather becomes hotter and hotter. On the other hand, Japanese has the conscious of power saving and air-conditioners are turned off from time to time. In such a situation, heat-related illnesses especially heat stroke becomes a killer to old people and young babies.

For environment factors, the effectiveness of sweating in cooling the body is dependent on both the environmental temperature and the humidity[11]. For simplicity, the relationship between indoor temperature and humidity is that when temperature increase, relative humidity decrease; when temperature decrease, relative humidity increase[12]. Generally speaking, when the temperature and humidity above a certain value, people will suffer from discomfort. According to [13], the benchmark temperature is 34°C and humidity is 35%.

Because of the simulation targets and the analysis above, the change of room temperature and humidity is shown in figure 3. Left hand side humidity of dashed line 1 means the humidity is under normal value, which the FSM of humidity is in normal state and the output elementary event type is normal. Right hand side humidity of dashed line 1 is under abnormal value and the output elementary event is abnormal. Left hand side temperature of dashed line 2 means the temperature is under normal value, which the FSM of temperature is in normal state and the output elementary event is normal. While the temperature value on the right hand side of dashed line 2 means in abnormal state and the output elementary event is abnormal.

It is assumed that the significance of abnormal temperature event is 0.6 and the significance of abnormal humidity event is 0.4. If the threshold significance is set to be 0.7. In such a case, both right hand side temperature and humidity of dashed line 2 means the occurrence of heat stroke, which is the output of semantic event.

B. Carbon Monoxide poisoning

Carbon monoxide poisoning is also a common safety problem. Carbon monoxide is an odorless and colourless gas that can cause sudden illness and death. It can be produced by stoves, lanterns, burning charcoal and wood, gas ranges and heating systems, etc. Whether a carbon monoxide poisoning would happen depend on the the carbon monoxide concentration, venting condition and whether people around. Based on these three parameters, figure 4 shows how the data that contribute to the occurrence of carbon monoxide poisoning. When the value of venting is smaller than 0 that means venting machine is turned off. When the value of people is greater than 0 that means there is people around. In the above two situations, elementary events of abnormal should be generated. For the carbon monoxide concentration, when the value is above the benchmark value that means an elementary event of abnormal be generated.

The significance of carbon monoxide concentration, venting condition and whether people around are 0.4, 0.3 and 0.3. The threshold significance is set to be 0.7. In such a case, the time between dashed line 3 and 4, the FSM of carbon monoxide poisoning is in unsafe state and a semantic event that represent carbon monoxide poisoning is generated.

According to the simulation result in figure 3 and 4, from the simulation time 35 to 37 the house is in state *red* and the generated entire event consist of semantic event of carbon monoxide poisoning. And from the simulation time 37 to 38, the generated entire event consist of semantic events of heat stroke and carbon monoxide poisoning. When the simulation time is greater than 38, the generated entire event consist of semantic event of heat stroke. In conclusion, the simulation targets are verified based on the two simulation cases.

VI. Conclusion

This paper proposed a CPS architecture for home safety problem detection and reaction. The CPS home safety architecture use a combination of event-based and service-based approaches, which the event-based is for safety problem detection and the service-based is for safety problem reaction. And this paper is mainly focus on safety problem detection.

For safety problem detection, three levels of events are defined: elementary event, semantic event and entire event. By using these events and raw data, a mechanism of layered FSM has been proposed for event composition. In order to verify our work, two simulation cases are proposed. According to the simulation result, the simulation targets are satisfied.

There are many future works should be done. For example, sensor data simulation to simulate abnormal situations. And also the service part for safety problem reaction.

References

[1] Ying Tan, Mehmet C. Vuran, steve Goddard, "Spatio-Temporal Event Model for Cyber-Physical Systems", 29th IEEE International Conference on Distributed Computing Systems Workshops, pp. 44-50, 2009

[2] Zhengguo YANG, "A Safety Model for Highly Networked Home Environment", Master thesis, School of Information Science, Japan Advanced Institute of Science and Technology, 2012

[3] Hui-Huang Hsu, Po-Kai Chen, Chi-Yi Lin, "RFID-Based Danger Prevention for Home Safety", 2010 2nd International Symposium on Aware Computing (ISAC), pp. 56-60, 2010

[4] Next Generation IP Network Promotion Forum, http://ngnforum.nict.go.jp/

[5] Carolyn Talcott, "Cyber-Physical Systems and Events", Software-Intensive Systems, LNCS 5380, pp. 101-115,2008

[6] Hui-Huang Hsu, Po-Kai Chen, Chi-Yi Lin, "RFID-Based Danger Prevention for Home Safety", 2010 2nd International Symposium on Aware Computing (ISAC), pp. 56-60, 2010

[7] Pushpa Kumar, Nary Subramanian, Kang Zhang, "SaViT: Technique for Visualization of Digital Home Safety", Eighth IEEE/ACIS International Conference on Computer and Information Science, pp. 1120-1125, 2009

[8] Lydie du Bousquet, Masahide Nakamura, Ben Yan, Hiroshi Igaki, "Using formal methods to increase confidence in a home network system implementation: a case study", Innovations in Systems and Software Engineering, Volume 5, Issue 3, pp. 181-196, 2009

[9] Don.S, Eunmi Choi, Dugki Min, "Event Driven Adaptive Awareness System for Medical Cyber Physical Systems", 4th International Conference on Awareness Science and Technology(iCAST), 2012

[10] Jaipal Singh, Omar Hussain, Elizabeth Chang, Tharam Dillon, "Event Handling for Distributed Real-Time Cyber-Physical Systems", 2012 15th IEEE International Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing, pp. 23-30

[11] H. Grogan, P. M. Hopkins, "Heat stroke: implications for critical care and anaesthesia", The Board of Management and Trustees of the British Journal of Anaesthesia 2002, pp. 700-707

[12] http://stream2.cma.gov.cn/pub/comet/FireWeather/S290Unit5TemperatureandRelativeHumidityRelationships/comet/fire/s290/unit5/print.htm#z4_0

[13] Maria Nedealcov, Zaharia Nedealcov, "Evaluation of Thermal Comfort Degree in Canicular Days - Record for the Republic of Moldova's Territory", Present Environment and Sustainable Development, vol. 6, no. 1, 2012.

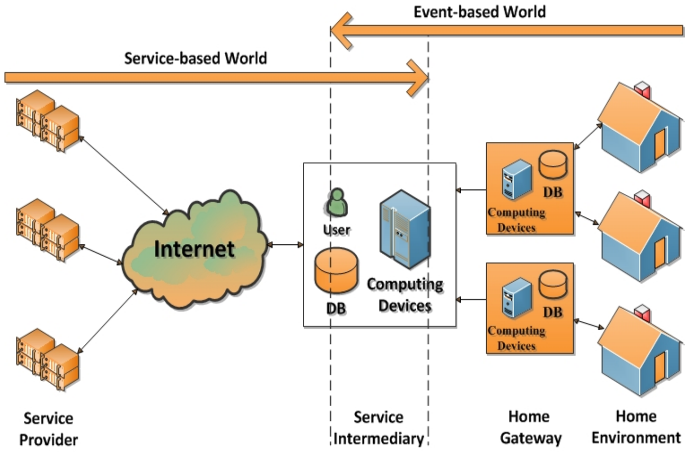

Fig. 5. The CPS Home Safety Architecture

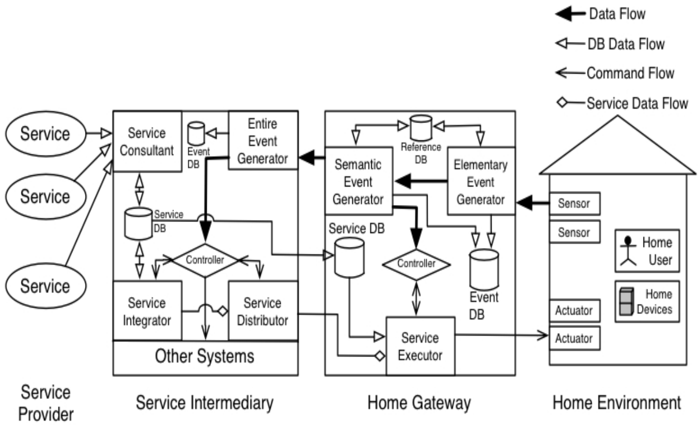

Fig. 6. System components description