AN ADAPTIVE SYSTEM TO CONTROL CONSUMER ELECTRONICS BASED ON EARTHQUAKE EARLY WARNING

Takashi Kokawa, Ryota Sakamoto, Hitoshi Ogawa, Victor V. Kryssanov
Faculty of Information Science and Engineering, Ritsumeikan University, Kusatsu, Shiga, Japan

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Abstract: In Japan, earthquakes happen on a regular basis. There is an earthquake early warning system operated by the Japan Meteorological Agency. By sensing P-waves, it can notify people a few seconds before the earthquake reaches them. Since only few seconds are left, it is often difficult for people to act with consideration on who is where at the moment, what consumer electronics should be turned off, and how to ensure a family's safety in their house. We developed a system that supports people with control of network-connected home appliances when an earthquake occurs. The system utilizes three types of control rules: general, family-related, and personalized for each type of consumer electronics. As there can often be operational conflicts if applying the rules simultaneously, a conflict-resolving mechanism is implemented, based on an optimisation algorithm for weighted constraint satisfaction problems. A pilot study of the system deployment is described, and its results are briefly discussed in the light of the related work. Conclusions are drawn, and future plans are outlined.

1 INTRODUCTION

About 2000 earthquakes happen every year in Japan, so that this country is often called earthquake-ridden. It is a serious problem to prevent the occurrence of secondary earthquake-provoked disasters, such as fires, short-circuits, etc. With the recent advent of consumer electronics networks, real-time earthquake information can be received by every household, and it can thus be used to control consumer electronics and reduce the risk of the secondary disasters.

Real-time information about the seismic activity is provided by the earthquake early warning system (Doi, 2002) operated by the Japan Meteorological Agency (JMA). By sensing primary waves (P-waves), this system can notify people, e.g. via the Internet, several seconds before the earthquake reaches them.

There has been developed an automatic consumer electronics control system by the Japan Electronics and Information Technology Industries Association (JEITA, 2005). When an earthquake early warning is received, the system provides services such as alarming people, stopping gas, opening doors, etc. This system does not, however, comply with the specific situation of each particular household (i.e. information about who live in, where they are, what they currently do, etc. is not utilized by the system).

In this paper, we propose an intelligent consumer electronics control system for earthquake-caused disaster prevention. The system uses family-specific knowledge and provides for generally a higher level of safety for the family members than other systems having similar goals.

The system realizes an agent-based architecture, and it is thus quite reliable in earthquake conditions. Agents are installed in every room (e.g. of a house). Each room agent is autonomous, monitors electronic appliances and the human status in the room, and controls the electronics when an earthquake happens. For the control, countermeasure agents processing different types of rules are developed. During an earthquake, a countermeasure agent receives earthquake information and selects appropriate constraints from an electronics control set. A room agent operates the electronic appliances based on the constraints. As there can often be conflicts when applying control rules obtained from different countermeasure agents simultaneously, a conflict-resolving mechanism has been implemented, and the system finds an optimised control set of rules by solving a weighted constraint satisfaction problem with achievement parameters.

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In the following sections, the earthquake early warning system is first outlined. Second, the proposed system architecture is presented. Next, it is explained how the system agents act. The control of home appliances in an earthquake situation is analysed through a pilot study. Finally, related work is discussed, and conclusions are given.

2 THE EARTHQUAKE EARLY WARNING SYSTEM

All earthquakes produce two types of shock waves: primary waves (P-waves) and secondary waves (S-waves). P-waves arrive first and rarely cause any damages. S-waves arrive next and often result in destruction and loss of lives. The earthquake early warning system operated by JMA utilizes current seismic data, such as the magnitude of an earthquake and the place of its occurrence, obtained by sensing and processing P-waves. Since P-waves are normally propagated about twice as fast as S-waves (excepting for the case of epicentral earthquakes), the system can provide earthquake information seconds to tens of seconds before the damaging wave hits an area. The system is presently deployed on an experimental basis, and various organizations and companies participate in the experiment.

In the presented study, a program developed by the Japan Weather Association and the Earthquake Research Institute at the University of Tokyo is used to calculate the expected seismic intensity and time of the S-wave arrival at a specific location for a given earthquake.

3 AGENT-BASED ARCHITECTURE

To achieve a high level of operational robustness and autonomy, the proposed system implements a multi-agent architecture. There are several types of agents.

A room agent monitors a room to get the personal status and the consumer electronics status, and it then saves the data to the household status database. The method of obtaining information may differ for each agent, e.g. who is in the room can be monitored using either web-camera or RFID tags. A countermeasure agent proposes countermeasure rules for earthquake disaster prevention, which are specific to the place of a room agent's installation. When an earthquake occurs, all countermeasure agents propose control actions, which may be inconsistent because of different knowledge possessed by the agents. A conflict resolution method is used to find a balanced solution for all the agent surroundings.

The system operates as follows (Figure 1). An earthquake information agent (EIA) at each house is a "JAVA wrapping" of the program processing earthquake early warning data. An EIA receives an earthquake early warning from JMA and calculates the S-wave arrival time and the expected seismic intensity. The EIA sends a message to three countermeasure agents, which are an earthquake countermeasure agent (ECA), a personal care agent (PCA), and a precondition for consumer electronics control agent (PCCA). The ECA utilizes the knowledge of general countermeasures for earthquake disaster prevention. The PCA applies the knowledge of personalized countermeasures by utilizing family-related information. The PCCA makes use of the knowledge of specialized countermeasures to control home appliances. The countermeasure agents propose constraints to room agents. After a room agent communicates or attempts to the countermeasure agents to update its rules, it generates, through resolving achievement-weighted constraints, a set of instructions to control the electronics set up in the room.

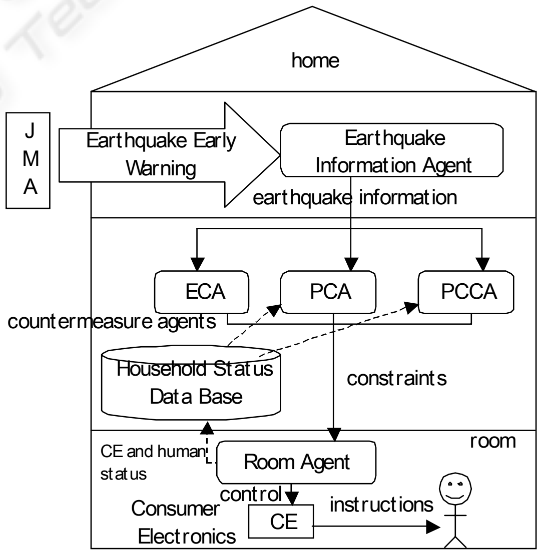

Figure 1: The system architecture.

4 CONSTRAINTS FOR THE ELECTRONICS CONTROL

A room agent decides on consumer electronics control by solving an achievement-weighted constraint satisfaction problem, AWCSP (Kokawa and Ogawa, 2004). The AWCSP solver is an enhanced reasoning method for constraint satisfaction problems (CSP) that allows for obtaining an optimised solution when constraints are too strict. The AWCSP is represented with a set of variables, a domain of values for each variable, and a set of constraints in a way similar to the classic CSP (Walliser *et al*., 2004). It also requires a set of constraint weights and a set of constraint achievement degrees defined.

Consumer electronics states and human actions are represented with variables as follows: a set of consumer electronics states, $CE = \{ce_1, ce_2, ce_3, \ldots, ce_n\}$, where n is the number of electronic appliances installed; a set of human actions, $ACT = \{act_1, act_2, \ldots, act_m\}$, where m is the number of the family members. Domain sets of the variable values are represented as follows: $D_{CE} = \{d_{ce_1}, d_{ce_2}, \ldots, d_{ce_n}\}$, and $D_{ACT} = \{d_{act_1}, d_{act_2}, \ldots, d_{act_m}\}$, respectively.

Constraints for the variables are produced by the countermeasure agents by utilizing the relevant knowledge. In a room agent, a set of constraints is represented as $C = \{c_1, c_2, \ldots, c_k\}$, where k is the number of constraints which are sent from countermeasure agents.

The ECA handles general countermeasure rules for earthquake disaster prevention, which are usually pre-defined. Constraints of the agent are represented as ECc_j , where j is the rule number. The PCA deals with family-related rules by utilizing information about the current status of each family member (as well as of other people in the rooms), and the corresponding constraints are represented as PCc_m. The PCCA processes personalized rules based on a control policy defined for the house, and its constraints are represented as $PCCc_m$. The policy can be set up to allow for sending camera-recorded data to a server; it would then be possible to use the video for rescue operations or in an analysis.

Below, this is a fragment of the knowledge of countermeasure agents:

```
state(A, B) means that A implies B.

ECA:
Rule1: IF (Seismic intensity >= 2)
     Send a Constraint
     ECc1 {state(cei, Speaker), cei =
            "Announce(earthquake
            information)", i = 1,…, n}
Rule2: IF (Seismic intensity >= 3)
     Send a Constraint
     ECc2 {state(cei, Heater), cei =
                      "OFF", i = 1,…, n}
Rule3: If (Seismic intensity >= 4)
     Send a Constraint
     ECc3 {state(cei, Door), cei =
                    "Open", i = 1,…, n}
Rule4: If (Seismic intensity >= 4)
     Send Constraints
     ECc4 {acth = "Hide under
                      furniture", h
                      is a person}
     ECc5 {state(cei, all electronics),
                      cei = "Off", i
                      = 1,…, n}

PCA:
Rule1: IF (There is a person h)
     Send a Constraint
    PCc1 {state(cej, light), cej = "On",
           cej is near h}
Rule2: IF (Seismic intensity =< 2 and a
       person h is sleeping)
     Send a Constraint
     PCc2 {acth = "Keep sleeping"}
Rule3: If (Seismic intensity >= 3 and
          "There is a child at home")
     Send a Constraint
     PCc3 {acth = "Accompany the child"}

PCCA:
Rule1: If (Seismic intensity =< 3 and
             "Video is recording")
     Send a Constraint
     PCCc1 {state(cei, Video), cei!=
                   "On" , i = 1,…, n }
Rule2: If (Seismic intensity >= 5 and
          "Agreement for recording")
     Send a Constraint
     PCCc2 {state(cei, Camera), cei =
                      "Record" , i =
                      1,…, n}
```

Owing to the different knowledge bases of the countermeasure agents, constraints generated by the agents may often conflict. For the conflict resolution, a method that utilizes weights assigned to the constraints has been proposed (Lau, 2002). A set of constraint weights is represented as $W = \{w_1, w_2, \ldots, w_k\}$, k is the number of constraints. When only the constraint weights are used, some rules may get completely ignored, e.g. when the seismic intensity is over 4, the ECA sends ECc_4 for room agents. If there is no furniture to hide under it in the room, the ECc_4 is never satisfied, and the room agent produces no instructions. The room agent should, however, recommend a substitute action for the person, such as “Stay away from dangerous objects”. If one tries to represent this agent behaviour with weighted constraints, the rules become complicated, and it becomes difficult to maintain the integrity of the agent rules.

To cope with this problem, achievement degrees are defined for the constraints. If a constraint is fully satisfied, the room agent chooses a variable value having the highest achievement degree. An achievement degree is represented as a parameter showing to what degree the constraint is achievable in the given situation. The achievement parameter thus consists of a variable and a threshold. The set of achievement variables $A = \{a_1, a_2, \ldots, a_k\}$ represents the “satisfaction degree”. The set of achievement thresholds $F = \{f_1, f_2, \ldots, f_k\}$ gives thresholds that the values of a_k must achieve to make the constraints satisfied.

The achievement degrees for ECc_4 are presented in Table 1. ECc_4 is to issue recommendations that would help maintain a higher safety level for the family members. A safety level is a mapping to the achievement degree of the constraints; the safety level of the action defined in a constraint makes the achievement degree 100%, the lowest level corresponds to the achievement degree 0% (i.e. no action).

The achievement degrees for consumer electronics -related constraints, such as ECc_2, are determined by the number of appliances actually turned off.

Table 1: Safety levels and recommended actions.

Safety level	Action group
5	Hide under furniture (table, etc.)
4	Stay away from dangerous objects (window, vase, etc.)
3	Be accompanied.
2	Make a contact (via IP phone, video phone, etc.)
1	Report location.
0	No action required.

Weights are assigned to the constraints at the time of constraint definition. The general countermeasures and maintaining the family members’ safety have higher priorities and, hence, higher weights, while other rules have lower weights (see Table 2). Achievement thresholds for the constraints are dynamically calculated by the countermeasure agents, depending on the time remaining until the earthquake and current information collected by room agents.

Table 2: Constraint Weights.

Constraint	Weight
ECc_1	4
ECc_2	6
ECc_3	5
ECc_4	5
ECc_5	3
PCc_1	4
PCc_2	3
PCc_3	5
$PCCc_1$	1
$PCCc_2$	2

Assignments of values to the variables are made via an optimisation procedure. Room agents produce sets of assignment values corresponding to achievement degrees higher than the achievement threshold of a constraint. Room agents calculate M an “optimisation degree” of the set as the following sum:

$$M = \sum_{i=1}^{n} \begin{cases} w_i & (\text{if } f_i = 100) \\ w_i \times \dfrac{a_i - f_i}{100 - f_i} & (\text{else}). \end{cases}$$

If a constraint c_i is completely satisfied, the corresponding summand is the constraint’s weight w_i. Otherwise, the added value is the product of the constraint’s weight w_i and the distance of the achievement degree value a_i to the achievement threshold f_i; n is the total number of constraints.

5 PILOT STUDY

In this section, we describe an example of the application of the developed system to control the situation in a room with a predefined environment during an earthquake (also, see the definitions of the constraints in the previous section).

```
The environment of room A:

State(ce1, TV),
dce1 = {"Entertainment channel", "News
   channel", "Sports channel", "Off"};
State(ce2, Speaker),
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d_ce2 = {"On", "Announce(x)", "Off"};
State(ce3, Room light),
d_ce3 = {"On", "Off"};
State(ce4, Corridor light),
d_ce4 = {"On", "Off"};
State(ce5, Camera),
d_ce5 = {"Record", "On", "Off"};
State(ce6, Heater),
d_ce6 = {"On", "Off"};
State(ce7, IP phone),
d_ce7 = {"Connect(room y)", "Off"};
State(act1, Family member),
d_act1 = {"Watch TV", "Hide under
  furniture",     "Stay away from
  dangerous objects", "Be accompanied",
  "Make a contact", "Report location",
  "No action required"};

ce1 = "Entertainment channel",
ce2 = "On",
ce3 = "On",
ce4 = "Off",
ce5 = "Off",
ce6 = "On",
ce7 = "Off",
act1 = "Watch TV"
```

There is a child in room B. (Other details of the surroundings of room B are omitted.)

Case 1:

The system processes an earthquake early warning: the seismic intensity is 5 and the remaining time is 15 seconds. Table 3 lists constraints for the room agent that are sent from countermeasure agents. Achievement thresholds are set as follows. The constraint c_2 "turn off all the heaters" must be completely satisfied, and its achievement threshold is therefore 100%. It is possible to simultaneously announce both the earthquake information and instructions to the people, and the achievement threshold of "announce the earthquake information " is 100%. Since the domain of c_8 is binary, the achievement threshold f_8 is 0%. c_5 does not have to be fully satisfied if there is a higher priority constraint, and the achievement threshold f_5 is 20%, because there are only "less dangerous" electronic appliances in the room (if the room is a kitchen, this achievement threshold would however be more than 50%). As there is no door lock in room A, the constraint c_3 does not have to be satisfied, and the value of f_3 is 0%. There is a person in room A, therefore lights must be turned on near the person, and the value of f_6 is set 100%. The achievement thresholds f_4 and f_7 are 40% and 60%, respectively, because there is a child in room B, who should be contacted via the IP phone or accompanied.

There is a conflict between c_4 and c_7: there is no furniture in room B. Depending on the remaining time, the safety levels of the family member in room A and of the child in room B are balanced by the corresponding achievement thresholds. If there is enough time to go to the child's room, act_h is specified as follows: "Hide under furniture" and "Accompany the child". Based on the values of M calculated for each possible scenario, the system generates the following set of variable values (this set corresponds to the greatest M obtained):

```
ce1 = "Off",
ce2 = "Announce (earthquake
                 information, 'Go to
                 room B')",
ce3 = "Off",
ce4 = "On",
ce5 = "Record" (to record the result of
         the family member's action),
ce6 = "Off",
ce7 = "Off",
act1 = "Accompany the child"
```

Achievement degrees assigned to the variables are given in Table 3. The optimisation degree M is equal approximately to 24.

Table 3: Constraint parameters in Case 1.

c_i	Received constraint	w_i	f_i	a_i
c_1	ECc_1	4	100	100
c_2	ECc_2	6	100	100
c_3	ECc_3	5	0	0
c_4	ECc_4	5	40	60
c_5	ECc_5	3	20	57
c_6	PCc_1	4	100	100
c_7	PCc_3	5	60	100
c_8	$PCCc_2$	2	0	100

Case 2:

Same as Case 1, but the remaining time is 5 seconds. The achievement threshold f_4 becomes 80%, as for anyone in room A, it is now impossible to reach room B before the earthquake hits. The action recommended is to hide under the desk, and the countermeasure to increase the safety level of the child may, depending on the phone location, be to talk to the child via the IP phone. The recommended actions to control the consumer electronics are then as follows (also see Table 4):

```
ce1 = "Off",
ce2 = "Announce (earthquake
      information, 'Hide under the desk
      and talk to the child via the IP
      phone')",
ce3 = "On",
ce4 = "Off",
ce5 = "Record",
ce6 = "Off",
ce7 = "Connect (room B)",
act1 = "Hide under the desk and use the
        IP phone"
```

Table 4: Constraint parameters in Case 2.

c_i	Received constraint	w_i	f_i	a_i
c_1	ECc_1	4	100	100
c_2	ECc_2	6	100	100
c_3	ECc_3	5	0	0
c_4	ECc_4	5	80	100
c_5	ECc_5	3	20	43
c_6	PCc_1	4	100	100
c_7	PCc_3	5	60	66
c_8	$PCCc_2$	2	0	100

The calculated optimisation degree M is equal approximately to 23.

Case 3:

Same as Case 1, but the seismic intensity is ≤ 2. The expected effect of the earthquake is not severe. The system only announces the earthquake information and/or changes the TV channel to news. There is only one constraint ECc_1, and it can be fully satisfied.

6 A LITTLE RELATED WORK

Most of the studies reported in the literature deal with earthquake early warning systems to merely provide for efficient and effective announcement of the earthquake information (e.g. Doi, 2002; Wu *et al*., 2004). There were, however, reports in the past 2 years about developed systems that have goals and capabilities similar to the ones pursued in the presented study.

The system proposed by the JEITA (JEITA, 2005) is an automatic consumer electronics control system developed in Japan. A similar system was developed by the Seismic Warning Systems Incorporated (SWS), using the earthquake early warning in the west coast of the U.S (SWS, 2004). These systems can control the electronics for the earthquake secondary disaster prevention by using the corresponding earthquake early warning systems: e.g. they can shut off gas, issue warnings, open door locks and so on. The systems have, however, to have countermeasures defined for every possible scenario in advance, and if the environment changes, the recommended actions may become ineffective or even dangerous. Besides, the consistency of the system knowledge bases is hard to maintain due to the changing surroundings.

The system developed in the presented study is able to adapt to dynamic environments, as each room agent monitors its room and updates the system knowledge- and data-bases. Furthermore, the proposed system ensures a high level of operational transparency by providing access to its data- and knowledge-bases for its users. This is a unique feature that, to our knowledge, is not present in any other systems having similar purposes.

7 CONCLUSIONS

In the presented study, a prototype of an intelligent adaptive system to control consumer electronics based on earthquake early warning has been developed. The system has an agent-based architecture, and it controls home electronic appliances via solving an achievement-weighted constraint satisfaction problem. A pilot-study of the deployment of the system was outlined, and some typical situations of the system operation were considered.

Presently, the system works with a simulator to examine various households and earthquake-related situations. We are planning to test the system in a real environment in the near future.

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