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An ambient assisted living system for dementia patients

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Abstract: Dementia is a major health and social care challenge of today and the near future as a result of increased human lifespan. Currently, there is no therapeutic solution for dementia, but a solution for managing the wandering behavior of dementia patients can be provided by an ambient assisted living system. In this paper, the design and implementation of iCarus, which is an intelligent ambient assisted living system for dealing with wandering behavior in early stages of dementia, is described. The aim of iCarus is to provide independent living for elderly people and a cost-effective way of monitoring them. iCarus is a zone-based system that forms a safety net. When a wandering episode occurs, rule-based context reasoning is employed to determine the actions that are to be executed. These actions include warning the patient, navigating the patient to his home, sending notifications to the caregiver(s), and initiating a real-time tracking session for the caregiver and the emergency service. Also, caregivers are able to construct their own rules and extend the functionality of the system according to their own needs. Constructing new rules is done by an innovative user interface. As a case study, iCarus is described and evaluated with a scenario. In order to evaluate the usability of iCarus, a questionnaire was administered after the users tried the system. The results were then statistically analyzed and reported.

Key words: Ambient intelligence, ambient assisted living, context-awareness, context ontology, rule-based reasoning

1. Introduction

Dementia, including Alzheimer disease (AD), is one of the biggest global public health and social care challenges facing our generation. As a result of advances in medicine and technology, the average human lifespan has increased across the world. According to the World Alzheimer Report 2016, 47 million people live with dementia worldwide. By 2050, this number is estimated to increase to more than 131 million. Dementia also has a great economic impact. The total estimated cost of dementia has reached 818 billion US dollars worldwide [1].

Dementia is the decline of cognitive functioning, and it is associated with impaired memory, difficulty in communication, and reduced cognitive ability. This impacts the person's daily life and abilities such as thinking, remembering, and reasoning [2, 3].

People with early-stage dementia suffer from unpredictable wandering behavior, and they show a propensity to leave their residences and get lost. This can cause a number of adverse outcomes such as accidents, malnutrition, sleep disturbances, injuries, and in some cases death [4–6]. Studies estimate that 67% of dementia patients may exhibit wandering behavior, and half of those not found within a day suffer serious injuries or death [4, 7]. This behavior is a main concern for caregivers, as it requires continuous vigilance and being on

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alert all the time. Caring for a patient is an emotionally stressful task, and the caregivers experience feelings of confinement and immense stress as a result of the continuously degenerating behavior of the patient [4, 8].

Currently, there is no therapeutic solution for dementia. However, a solution for managing wandering behavior is possible by using information and communications technology (ICT) [8]. ICT offers the basis of ambient intelligence (AmI), which is a multidisciplinary paradigm built upon a pervasive and ubiquitous computing paradigm. AmI fosters an anthropomorphic human-centric computer interaction design, and it enables basic criteria to build intelligent environments, where devices weave themselves into the fabric of everyday life so that they are virtually invisible to us [9–11]. Context-awareness is a key factor in AmI systems, and AmI research is dependent on context-aware computing because of the fact that AmI systems must be personalized, sensitive (anticipatory), responsive, and adaptive [12]. Application of AmI technologies in the health domain introduces a new field called ambient assisted living (AAL). The aim of AAL systems is to enable people with specific needs to live on their own for longer periods of time than otherwise possible [13].

In this paper, the design and implementation of iCarus, an intelligent context-aware AAL system for managing wandering behavior in dementia patients, is described. iCarus is designed to remotely monitor patients and to take timely actions during a wandering episode. The aim of iCarus is to provide cost-effective monitoring of patients and to reduce the adverse consequences and financial burden of wandering episodes by assisting the patients and their caregivers. The intelligence of the system comes from the use of rule-based reasoning and the system being context-aware. When a wandering episode occurs, rule-based reasoning is performed to specify the action(s) that are going to be executed according to the situation's severity and user preferences. The key action is alerting the caregiver or an emergency service or both. The caregiver and the emergency personnel are able to track the patient on a map by using a smart phone or a computer in real-time. The wandering data of a wandering episode, including the navigation trace of the patient, time, and other context parameters, are stored for further research and investigations.

The contribution of iCarus is that caregivers are able to construct their own rules and extend the functionality of the system according their own needs, which is not supported by other work. Constructing new rules is accomplished by an innovative user interface. Thus, a flexible and extensible system is developed. There are related works considering just the spatial dimension or both spatial and temporal dimensions for decision making. However, in iCarus, in addition to spatial and temporal conditions, all of the context parameters can be used. The context is modeled using the context ontology encoded in OWL (Web Ontology Language). By using context-awareness in this work, the delivery of a personalized, adaptive, and anticipatory service is achieved. Also, in iCarus the caregiver can define new zone types and define rules using a newly defined zone type, which provides flexibility and is not supported by other related work. The iCarus system presented in this paper is novel and different from all other related work. As a case study, iCarus is described and evaluated with a scenario. In order to evaluate the usability of iCarus, a questionnaire was administered after the users tried the system. The results were then statistically analyzed and reported.

2. Related work

In this section, commercial products on the market are described, including WanderHelp [4], Kumar et al.'s work [14], iWander [3], LaCasa [7], and Rodriguez et al.'s work [15]. Finally, the iCarus system is compared with these surveyed works and then evaluated accordingly.

There are a number of commercial products on the market to track and monitor people. These products, which may not be cost-effective, charge a monthly fee and require dedicated units to be carried by the patients.

Digital Angel,[1] Wherify,[2] and GPS SmartSole[3] are wandering monitoring devices. These systems will alert caregivers when a patient has wandered out of a predesignated area [16]. WanderHelp [4] proposes an AAL solution for AD patients and their caregivers based on an intelligent agent platform. Its aim is to help caregivers reduce the risk of an adverse outcome in the event of a wandering episode in early-stage dementia patients. Essential to WanderHelp are the concepts of geo-fencing and zones. The zones are defined in both the spatial and temporal dimensions [4, 8, 11]. Kumar et al. [14] proposed a framework for real-time wandering management and an analytic tool for dementia patients, which can be beneficial to the patients. Its goal is to help doctors, caregivers, and family members by providing a tool to understand the nature of wandering [14]. iWander [3] aims to improve the quality of treatment for dementia patients using mobile applications. While running in the background, the application collects data from the device's sensors. The data are then evaluated using Bayesian network techniques. Considering the probability, iWander takes actions automatically that help navigate the patient to a safe location, informs caregivers, and sends the current location of the patient [3]. LaCasa [7] proposes a context-aware safety assistant to detect risky wandering behavior and to decide the type of required assistance. A decision-theoretic model determines the risk faced by the patient and decides on the appropriate action to take, such as prompting the patient or calling the caregiver [7]. Rodriguez et al. [15] proposed an ontological representation model to support interventions for wandering. This ontological model extends their ambient augmented memory system (AAMS), which supports the caregiver in implementing interventions based on external memory aids to the patient provided by mobile devices [15].

The comparison of iCarus with other related work is shown in Table 1. The commercial location-aware products consider only the spatial dimension of context, and they ignore other contextual parameters, which are important in making decisions. In other words, context-awareness encompassing location-awareness and context-awareness is superior to just location-awareness. WanderHelp considers the spatial and temporal dimensions of context. The other aspects of context are discarded. This work does not model context, does not employ context reasoning, and is not ontology-based. The works mentioned up to this point do not use artificial intelligence, and they cannot be tailored according to user needs. They just send notifications to caregivers if the boundaries are exceeded. Also, the definition of zones is static, meaning that it is hardcoded into the system and the end users (caregivers) cannot add new types of zones. Kumar et al.'s solution in [14] has a context model. However, the context model is not ontology-based, and it does not employ rule-based reasoning. iWander and LaCasa are context-aware, but they are not ontology-based, and they do not employ context reasoning. However, they have learning capability as a result of using machine learning techniques. These systems provide adaptive and personalized service through machine learning, but adding a new context parameter to the system is hard because it has to be analyzed and hardcoded into the system. However, in iCarus, instead of modifying the source code, extending the ontology and then adding new rules is sufficient. Rodriguez et al.'s solution in [15] includes a context ontology and employs rule-based context reasoning, but the end users of the system cannot add new rules and as a result of this they cannot adapt and personalize the system according to their own needs.

iCarus described in this paper is context-aware and includes an ontology-based context model, and rule-based reasoning is made over the context model to decide on the necessary actions. Without modifying the source code, new functionalities can be added to the system by defining new rules. The end users of iCarus can construct new rules according to their needs with the aid of an innovative user interface. The users do not have

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[1] https://www.computerworld.com/article/2589960/healthcare-it/digital-angel-to---watch-over-patients.html

[2] http://www.mightygps.com/wherify.htm

[3] http://gpssmartsole.com/gpssmartsole/

Table 1. Comparison of iCarus with other related work.

Related work	Awareness	Ontology-based	Context reasoning	Zone definition	User-defined rules
Commercial products	Location	No	No	Static	No
WanderHelp [4]	Location, time	No	No	Static	No
[14]	Context	No	No	N/A	No
iWander [3]	Context	No	No	N/A	No
LaCasa [7]	Context	No	No	N/A	No
[15]	Context	Yes	Rule-based	N/A	No
iCarus	Context	Yes	Rule-based	Dynamic	Yes

to know the syntax of the rule language. The zone definition in iCarus is flexible and dynamic. Thus, the users can create new zone types, and as a result iCarus provides adaptive and personalized service. Also, iCarus has an emergency protocol, which steps in when there is no Internet connection. As a result, iCarus is novel and different from the previously reviewed related works.

3. iCarus

3.1. Overview

iCarus is an AAL system, which is tailored for citizens who suffer from cognitive decline and specifically, AD. iCarus is based on the assumption that dementia patients can pursue many of their daily activities normally, but at any time, a wandering episode may occur. iCarus realizes an outdoor tracking mechanism, which provides unobtrusive and remote services to patients and caregivers. Blackburn [17] and Miskelly [18] proved that zone alarms or electronic tagging are effective, reliable, and successful for wandering detection [16]. iCarus is also a zone-based system, where the patient's environment is partitioned into zones that can be defined in both spatial and temporal dimensions by default. The spatial dimension can be a polygon or a circle defined on a map. It is the caregiver's duty to define zones for the patient. By default, there are 3 types of zones. In the green zone, the patient is considered safe at all times. The patient's home is an example of the green zone. The red zone indicates areas that are dangerous for the patient. A busy road is an example of the red zone. The orange zone is regarded as green zone if the temporal constraint is met. Otherwise, it is regarded as red zone.

In addition to spatial and temporal dimensions, iCarus also supports considering other contextual information such as proximity to the caregiver, stage of dementia, weather, day of the week, time spent in a zone, age, and other demographic parameters.

iCarus is a rule-based system, and rule-based reasoning is used to determine the actions that are going to be taken when a wandering episode occurs. According to the situation's severity and the user's preferences, one or more of the actions are taken. These actions can be warning the patient by audio and text prompts, providing the patients with navigation assistance for going home, sending notifications to the caregiver(s), initiating a tracking session for the caregiver and/or emergency service, and calling and/or texting the caregiver and/or an emergency service.

In iCarus, caregivers can define new zone types according to their needs, which is not supported by the other related works. For example, the caregiver can create a new type of zone such as the "blue zone", and this zone can be used in defining new rules. The rules can be defined through a novel user interface. For example, in the new rule, the caregiver can assert "IF the patient is in the blue zone and the weather is sunny, and the temperature is greater than 30 °C, THEN notify caregiver".

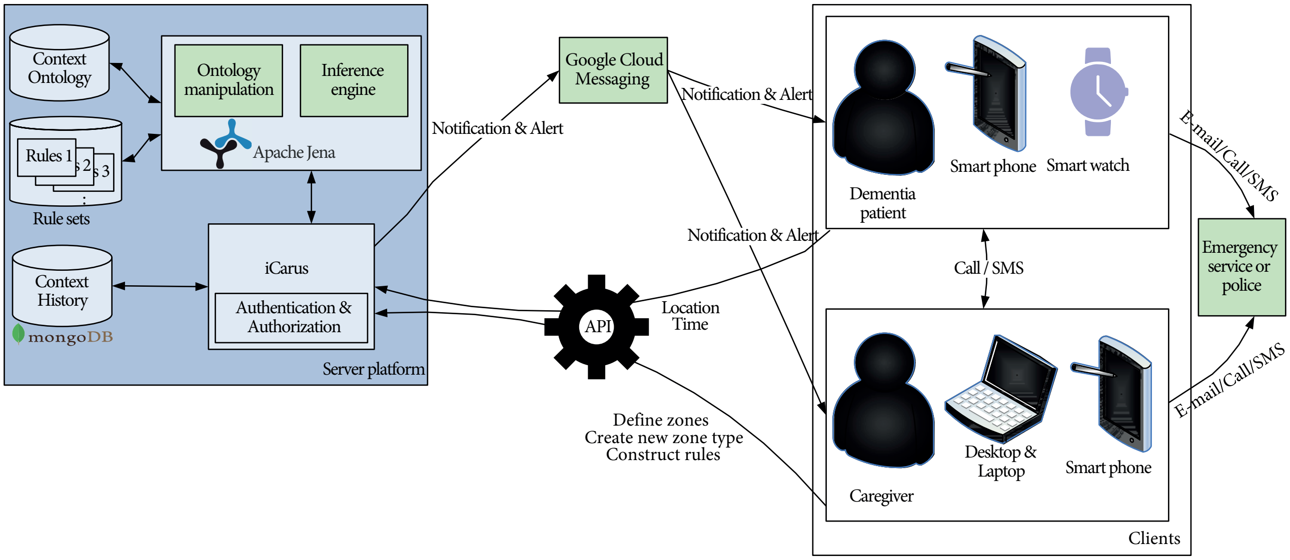

Figure 1. System architecture of iCarus.

The rules regarding green, red, and orange zones are the protected base rules, and the caregivers cannot change these rules. This is introduced to prevent errors, because these rules provide the basic functionality.

3.2. System architecture

In this section, the system architecture of iCarus is described as shown in Figure 1. The system is a context-aware AAL system, and it is a distributed client server system. It is realized as a web service with client applications designed for standard mobile devices. The server has role-based security in terms of authentication and authorization.

iCarus has server, caregiver, and patient components. All of these components should have Internet access because they run in collaboration and they should be able to communicate with each other.

3.2.1. iCarus server platform

The server side consists of a server computer, iCarus server component, context ontology, rule set, and context history database. The server computer is connected to the Internet. The Jena[4] framework is used to manipulate ontologies and to perform rule-based reasoning. Every patient is assigned his own rule set. However, caregivers can define new rules to extend functionality through a novel user interface. The advantage of this approach is that reasoning is decoupled from the source code of the system. As a result, a flexible and extensible system is implemented. By defining new rules, new functionalities can be added to the system without modifying the source code of the program.

The context history is maintained for performing further scientific studies, data analytics, and data mining to discover more in-depth information about the wandering behavior in dementia patients. MongoDB[5] is used for storing context history. The instant (immediate) context is important for reasoning and decision-making. On the other hand, once a specified amount of time passes, we can store the data in the context history database.

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[4] http://jena.apache.org/

[5] http://www.mongodb.com/

For example, the patient's location changes continuously over time and we want to store location information with the timestamp, which are time series data. MongoDB is a document-oriented NoSQL database and time series data are shown to suit MongoDB well [19]. MongoDB is chosen as a document-oriented NoSQL database because it is secure, scalable, and flexible and it provides a rich set of tools and features.[6]

iCarus supports multiple clients and client devices, and it provides a common RESTful (Representational State Transfer) API (Application Programming Interface) for all types of client devices such as desktop computers, smart phones, and smart watches. iCarus API enables the client devices to make use of the functionality of user authentication and authorization and essential services for wandering management. The key services for wandering management are identified and abstracted from the internal implementation of the algorithm. The API calls are made using HTTP method calls such as get, post, update, and delete. If there is a need to add new services, it can be easily performed without affecting the previous services.

For sending alerts to users, we need a push notification service. Implementing a push notification mechanism for mobile devices is not an easy task, because mobile devices are resource-limited, and they do not have a persistent Internet connection. To solve these problems, Google provides Google Cloud Messaging[7] (GCM), a free service that enables developers to send messages between servers and client apps. By default, the GCM service is also capable of storing messages when a receiver is not connected to the Internet. By using GCM, the burden of cloud messaging is transferred to an external server for free.

3.2.2. iCarus client applications

A number of applications targeting desktop, web, and mobile smart phones can act as a client. To enforce security and to protect sensitive personal and medical data, the clients are authenticated and access permissions are granted based on the user privileges. This protects the system from unauthorized access. The OAuth 2.0[8] protocol is used for authorization.

For the mobile applications (caregiver application and patient application), Google's Android platform is used. Android SDK[9] (Software Development Kit) provides high-level libraries to interface with the hardware and to develop Android applications. A host of Android-based mobile devices (smart phones, smart watches, and tablet computers) produced by different manufacturers are available, which is cost-effective [3].

iCarus runs in the background as a service, and when it receives push messages, the activity will wake up and interrupt the patient or the caregiver. iCarus works under the premise that the patients carry their devices with them. According to the research, older patients who are not familiar with using such devices can be taught to use them [4, 20].

Similar to iWander, iCarus is designed to operate autonomously, and it requires minimal patient intervention in order to be learned easily by the patient. iCarus adopts a user-friendly and unobtrusive interface. Unless irregular activity is detected, no interactions are required. Because older adults may have difficulty using touch screens, the input is provided through the use of large and easy-to-press buttons to avoid the use of the software keyboard of the device, which requires precise haptic perception. If the patient requests, the text on the screen can be read out loud using text-to-speech libraries. Finally, styles and themes have high contrast color schemes and big fonts are used to provide easy reading for the elderly [3, 21].

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[6] http://www.mongodb.com/mongodb-architecture/
[7] http://developers.google.com/cloud-messaging/
[8] http://oauth.net/2/
[9] http://developer.android.com/

As mentioned earlier, the patient mobile application runs in the background and periodically polls the GPS sensor of the mobile device. Research suggests that GPS accuracy in dementia wandering systems using mobile phone technology is reliable enough for similar systems [3, 22]. Every time the location changes, the patient mobile application sends the current location to the server. Android is responsible for detecting location changes. When the server receives this message, it determines the zone the patient is in, calculates speed and heading direction, and adds this information (facts) to the ontology to construct the current context of the patient. As a result, a high-level context is obtained from low-level location data. The other dynamic contextual information (such as time, weather, proximity to the caregiver, etc.) is also added as facts to the ontology. Then the rule-based reasoning is applied over this constructed context. As a result, a sequence of actions (new facts) is inferred. This sequence of actions may include a combination of the following actions:

- Warning the patient: The patient is warned to return back to the safe zone by a text and an audio notification. It has been shown that such intervention may help bring dementia patients out of the demented state [3, 23]. Audio, visual, and text directions are presented on a map to the patient to help them navigate to a safe zone. If the patient does not enter a safe zone in a certain period of time, the application proceeds to the next action.

- Sending alert notification to the caregiver(s): The purpose of the alert is to inform the caregiver, to establish bidirectional communication with the patient, and to share the patient's location and navigation information. When an alert is received, the caregiver can track the patient on a map. If none of the caregivers respond, the application proceeds to the next action.

- Achieving a line of voice communication: The smart GSM device of the patient calls the caregiver with the speakers turned on. The patient might respond to a familiar voice.

- Sending notification to emergency service or police: If supported by the emergency service, the patient application sends a message informing the authorities about the situation, the current location, heading direction, and speed through SMS or e-mail.

- Calling an emergency service or police: The smart GSM device of the patient calls the emergency service with the speakers turned on. Emergency personnel can track the mobile GSM device to a certain degree. As a result, the local police station can be informed of the situation. The caregiver can also send a command to the patient's device to call the emergency service in urgent cases.

The sequence of actions is forwarded to the mobile device of the patient. Then the patient application processes the actions one by one sequentially. If the caregiver is convinced that there is no danger for the patient, then the caregiver can cancel the alert. If the patient is in the red zone and none of the caregivers respond in a predetermined time, the application sends a notification to or calls the emergency service, because the life of the patient might be in danger.

By communicating with the patient and evaluating location and navigation information, the caregiver can decide what to do. If the caregiver concludes that the life of the patient is in danger, he/she can call the emergency service or the police and provide them with the web address of the caregiver application and a code, which is valid for a limited amount of time. Then the emergency personnel can track the patient through a web browser after entering the provided code and dispatch rescue personnel.

The iCarus patient application monitors the Internet connection, and if the Internet connection is lost, it includes an emergency protocol where it can act on its own without the need of the server. In this mode, it provides basic functionality and does not make use of reasoning. It only considers green, orange, and red zones, discarding user-created zone types, which is sufficient for the safety of the patient.

Besides tracking the patient, the caregiver can define zones, new types of zones, and rules through the mobile, desktop, or web applications. The caregiver can also define reminders for the patient.

3.3. Context ontology

Context is modeled with context ontology[10] encoded in OWL. By using OWL, domain ontologies are defined and shared across different platforms and people. An ontology refers to a formal representation of a set of concepts in a specific domain and the relationships between those concepts [15, 24]. The Protégé[11] ontology editor is used to develop context ontology. During the development, other related works [15, 25–29] on how to develop a context ontology are taken into consideration and the best practices from these work are adopted. The advantages of modeling the context using an ontology are providing knowledge sharing, knowledge reuse, and logical reasoning support.

3.4. Context reasoning

In this section, the utilization of rule-based reasoning made over the context ontology is described. The high-level context is derived from the low-level context data by reasoning. In this case, whether the patient may be in danger or not is deduced. If the patient is in danger, then an action plan, consisting of a combination of sequential actions, is deduced. These actions are explained in Section 3.2.2.

In iCarus, each patient is assigned the default rule set in the beginning. The rules are constructed based on the grounds presented in [3, 4, 6, 7, 16]. The most important rules of the default rule set are shown in Table 2. In the consequents of the rules, AP represents an action plan and it is created before reasoning. So are *ActWarning*, *ActNotification*, and *ActEmergencyNotification*, representing, warning the patient and sending notification to the caregiver and to the emergency service, respectively.

The first rule of the table is for the neutral zone. If the patient enters the neutral zone, the actions that will be taken are warning the patient and sending notification to the caregiver. If the patient does not enter the safe zone in a certain amount of time then the caregiver is notified. The second rule of the table is for the red zone. If the patient enters the red zone, the actions that will be taken are warning the patient, sending notification to the caregiver, and finally sending notification to the emergency service. If any one of the caregivers does not respond for a while, then a notification is sent to the emergency service. In the orange zone rule, the time constraint is checked. The actions in the consequent are the same as the red zone rule. The remarkable thing in this rule is the introduction of the custom built-in *checkTime()*. The Jena framework is extended by defining a new primitive named "*checkTime*" to achieve this.

The last rule is an optional rule. The caregiver can activate or deactivate optional rules. The cold weather rule is for protecting patients during cold weather. The current weather condition is retrieved from reliable and dedicated services via the Internet. If the patient is in the neutral zone and the temperature is less than 5 °C, then the same actions will be taken as for the red zone rule, because there is mortal danger.

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[10] The developed context ontology can be accessed from `https://github.com/ozgunyilmaz/ContextOntology`

[11] `http://protege.stanford.edu`

Table 2. The default rules used in reasoning.

Rule description	Rule
Neutral zone	(?p locatedIn ?z) $\wedge$ (?z hasType "NeutralZone") $\Longrightarrow$ (?p hasActionPlan AP) $\wedge$ (AP hasAction ActWarning) $\wedge$ (AP hasAction ActNotification)
Red zone	(?p locatedIn ?z) $\wedge$ (?z hasType "RedZone") $\Longrightarrow$ (?p hasActionPlan AP) $\wedge$ (AP hasAction ActWarning) $\wedge$ (AP hasAction ActNotification) $\wedge$ (AP hasAction ActEmergencyNotification)
Orange zone	(?p locatedIn ?z) $\wedge$ (?z hasType "OrangeZone") $\wedge$ (?z hasStartTime ?t1) $\wedge$ (?z hasEndTime ?t2) $\wedge$ (checkTime(?t1,?t2)) $\Longrightarrow$ (?p hasActionPlan AP) $\wedge$ (AP hasAction ActWarning) $\wedge$ (AP hasAction ActNotification) $\wedge$ (AP hasAction ActEmergencyNotification)
Cold weather	(?p locatedIn ?z) $\wedge$ (?z hasType "NeutralZone") $\wedge$ (?p hasWeather ?w) $\wedge$ (?w hasTemperature ?c) $\wedge$ (lessThan(?c, 5)) $\Longrightarrow$ (?p hasActionPlan AP) $\wedge$ (AP hasAction ActWarning) $\wedge$ (AP hasAction ActNotification) $\wedge$ (AP hasAction ActEmergencyNotification)

3.5. Rule construction tool

In iCarus, the caregivers can also construct their own rules. To illustrate this feature, a case study is presented, where the caregiver adds a new rule to the system. This scenario demonstrates the usefulness of introducing new rules by the caregiver. According to the scenario, the patient likes going for a walk in the park near his home. There is no danger in the park, but if the weather is sunny and hot, the patient may get heatstroke. iCarus is designed to handle this kind of situation. In this case, the caregiver can construct a new rule to be notified when this occurs. First, the caregiver should create a new zone type, say the blue zone, and then define the blue zone to contain the park. Now the caregiver can use the blue zone for constructing new rules.

The rule construction tool of the desktop application is shown in Figure 2. In the rule construction window, standard Protégé icons are used for OWL classes (yellow circle), object properties (blue rectangle), and data properties (green rectangle). The "no entry" sign is used for restrictions. On the left-hand side of the window, the antecedent part of the rule is constructed through the tree visual. In the tree, the structure of the contextual information of the patient, which is acquired dynamically by traversing the ontology, is presented in a hierarchical manner.

The caregiver constructs the rule by adding or removing restrictions to data properties. The restrictions are limited to relational and comparison operators such as equals, does not equal, greater than, less than, greater than or equal to, and finally less than or equal to ($=$, $<>$, $>$, $<$, $>=$, $<=$). If the range of the data property is an enumeration, then the user is obliged to choose from the available values while creating the restriction to prevent user errors. The blue zone restriction in Figure 2 is an example of this situation, where the user chooses the blue zone among the available zones. The restrictions are listed under the related data properties as children of the related data properties.

The pseudocode of the rule construction algorithm is given in the Algorithm. For clarity and simplicity, a simplified version of the developed algorithm is given. It assumes that the correct input is provided and it

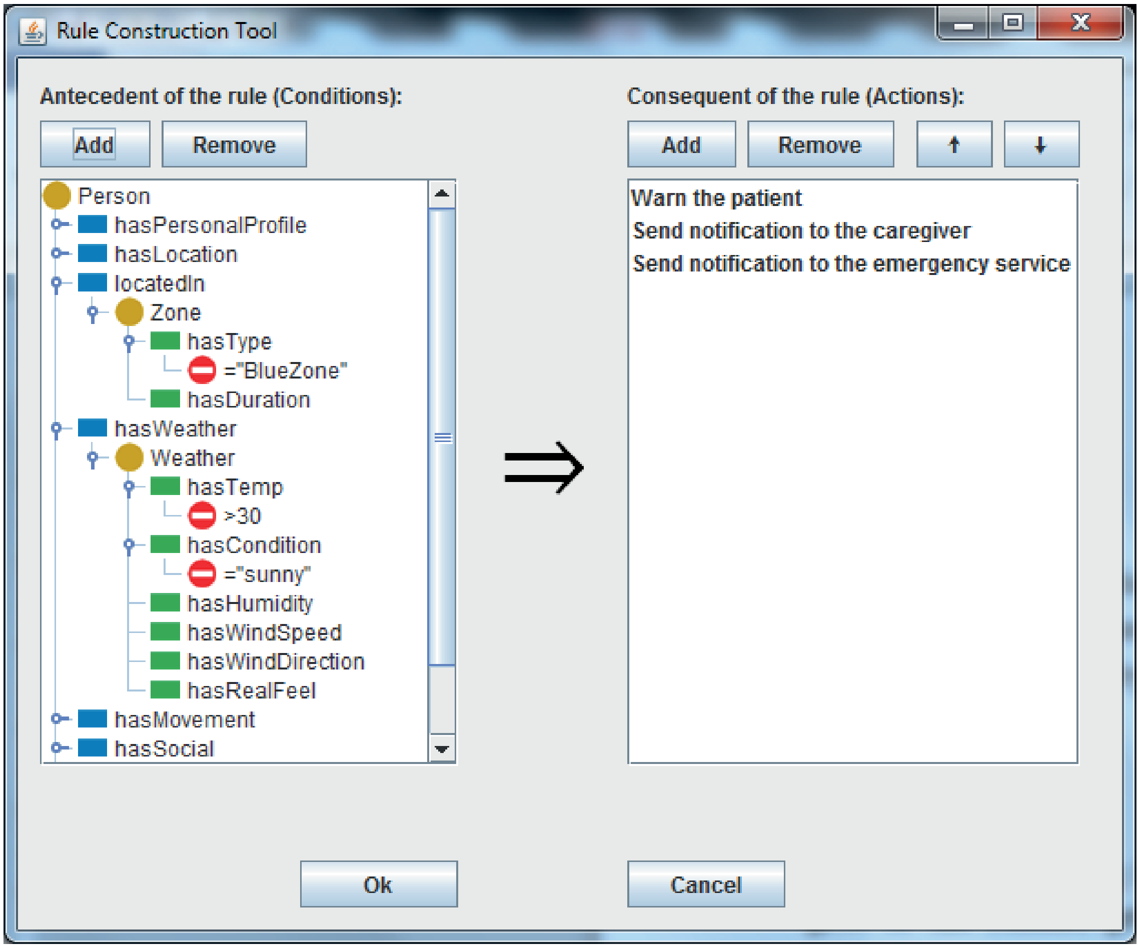

Figure 2. The rule construction tool.

does not check for errors. Jena rule syntax details are also omitted for clarity and simplicity. Only the main idea for the rule construction is listed.

To construct the antecedent of the rule, all of the restrictions are traversed. For each restriction, the related clauses are added to the antecedent list by going from bottom to top on each hierarchy level. Then these clauses stored in the antecedent list are formed into a conjunction. If there is more than one restriction for a data property then these restrictions are also formed into a conjunction. During this traversal, the *addAntecedent()* method is responsible for introducing unique variable names for each ontology class (yellow circle) in the tree by combining the class name and a number. A clause is added only once, meaning that repeating clauses are discarded.

On the right-hand side of the window, the consequent part of the rule is constructed through the list visual because we do not need a hierarchy here. The user can choose from available actions and can change the order by using the above buttons. The actions are obtained from the ontology dynamically.

The constructed rule is shown in Figure 3. Note that the clauses in line 1 come from the zone restriction (=“BlueZone”) related to the *hasType* data property, the clauses in line 2 come from the weather condition restriction (=“sunny”) related to the *hasCondition* data property, and the clauses in line 3 come from the weather temperature restriction (>30) related to the *hasTemperature* data property. For the consequent of the

Algorithm: Pseudocode of the rule construction algorithm

```
Rule r = new Rule();
foreach restriction in antecedent_tree do
    prop = restriction.getParent();
    cls = prop.getParent();
    while prop $\neq$ null do
        r.addAntecedent(cls, prop, restriction);
        restriction = cls;
        prop = cls.getParent();
        cls = prop.getParent();
    end
end
r.addConsequent(getRootVarName(), “hasActionPlan”, “AP”);
foreach item in consequent_list do
    r.addConsequent(“AP”, “hasAction”, item.getIndividualName());
end
```

rule, clauses related to each action in the list are added to the rule, which is depicted in Figure 3 in lines 4–6.

By using the rule construction tool, the end users can construct their own rules without any assistance or without the need to know the syntax of the rule language. Thus, users are able to introduce their own rules providing personalization and adaptation, which is important in AmI.

```
1   (?person1 locatedIn ?zone1) ∧ (?zone1 hasType “BlueZone”) ∧
2   (?person1 hasWeather ?weather1) ∧ (?weather1 hasCondition “sunny”) ∧
3   (?weather1 hasTemperature ?temperature1) ∧ (greaterThan(?temperature1, 30)) ⟹
4   (?person1 hasActionPlan AP) ∧ (AP hasAction ActWarning) ∧
5   (AP hasAction ActNotification) ∧
6   (AP hasAction ActEmergencyNotification)
```

Figure 3. The constructed rule for the scenario.

4. Case study

In this section, iCarus is described with a case study, where a fictionalized dementia patient (George) goes to the farmers’ market and gets lost, and then iCarus intervenes and notifies the fictionalized caregiver (Mary) of the patient. For this purpose, all of the required ontology individuals regarding the patient and the caregiver are created and added to the system ontologies. The patient and the caregiver mobile applications are installed on two Android-supported smart phones, each having built-in GPS receivers and a connection to the Internet. The desktop application is also installed on a computer and is ready to be used by the caregiver.

According to the scenario, George is a 70-year-old male recently diagnosed with AD. He lives with his wife, Mary, who does not have any memory impairment and she is George’s caregiver. They use iCarus to cope with George’s disease, and Mary defines zones for George using her laptop computer. George enjoys going to the farmers’ market every Wednesday morning, which helps him cope with the increased anxiety and depression that affects him. Mary thus defines the farmers’ market and the roads that lead there as an orange zone with time constraints indicating that George can go there every Wednesday morning.

One Wednesday morning, George takes his smart phone and leaves home to go to the farmers' market. His smart phone realizes this as regular activity and does nothing. After George finishes his shopping, on the way home, he gets lost, caused by spatial disorientation, and he goes beyond the zone limits. His smart phone first warns him to return back to the safe zone, and then it also offers directions to navigate him home. Since George is in a demented state, he does not respond. When the smart phone realizes that this attempt was futile, it sends a notification to Mary informing her of the situation, as shown in Figure 4. After clicking on this message, Mary can now track George on a map using a mobile smart phone as shown in Figure 5 or on a computer.

Figure 5 depicts the zones defined by Mary. The green zone is George's home, and he is safe there all the time. George's extended neighborhood is an orange zone. This zone is defined to let George wander there and talk to people every day, and it is restricted to daytime. The purpose is to provide George freedom as much as possible while keeping him safe; therefore, he cannot wander there after sunset. Another orange zone is the farmers' market area and the route to the farmers' market, and this zone is restricted to every Wednesday morning. Dangerous places, such as busy roads, are defined as red zones. In the figures, the location of the user and the recent way points passed are also shown to the caregiver on the map by the blue path and arrow. The arrow shows the heading direction and indicates that the user is moving. The location of the patient, the distance between the patient and the caregiver, the direction headed, and speed information are also shown to the caregiver. This information on the map is updated in real time continuously. The location and the direction the caregiver is heading in are also shown to the caregiver by the blue dot (or arrow if moving).

Returning to our scenario, Mary calls George and tells him to calm down and wait for her. While Mary is en route to George's location to pick him up, she can track him by using her smart phone. Later, Mary enters this event as a wandering episode in her computer for it to be used in further analysis. This scenario shows that iCarus is useful in finding patients and provides a safer life for the patient, the caregiver, and the family.

5. Evaluation and discussion

5.1. Power consumption of the patient mobile application

Power consumption of a smart phone running only the patient mobile application is measured across different settings (i.e. no movement, walking outdoors, and fast movement). In the "no movement" setting, the patient is considered to be at home. In the "fast movement" setting, the patient is inside a car traveling with an average speed ranging between 70 and 80 km/h. The patient mobile application is tested because it continuously uses GPS, which drains the battery quickly. The battery should last long enough to send the location of the patient in the case of a wandering episode.

A Sony Xperia Z2 is used as the test phone. The Trepn Profiler[12] application is used for benchmarking battery consumption. This application is compatible with the test phone. During testing, the screen of the mobile phone was switched off and 3G wireless mobile telecommunication technology, which provides enough bandwidth, was used for the Internet connection. For each setting, power consumption was measured for 1 h and across 10 trials. Then average power consumption (in mW) and standard deviation were calculated. These values are given in Table 3. As a result, if the patient was moving, the GPS sensor consumed more power.

The theoretical battery capacity of the Sony Xperia Z2 is 12,200 mWh. Therefore, for each setting, theoretical battery life per one charge can be calculated by dividing the battery capacity by average power consumption per hour. As shown in Table 3, the battery life is 61 h, 42 h, and 30 h, respectively. These

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[12] https://developer.qualcomm.com/software/trepn-power-profiler

numbers are acceptable because the battery will last for at least one day even if the patient is in a fast moving vehicle. Then the caregiver can charge the patient's phone. Also, the phone can be used with a battery charger case, which doubles the battery capacity of the phone.

Table 3. Power consumption of the patient mobile application.

	No movement (indoors)	Walking (outdoors)	Fast movement (car)
Average power consumption (mW)	198.82	293.32	403.63
Standard deviation	20.49	29.66	38.76
Battery life (h)	61	42	30

5.2. User evaluation

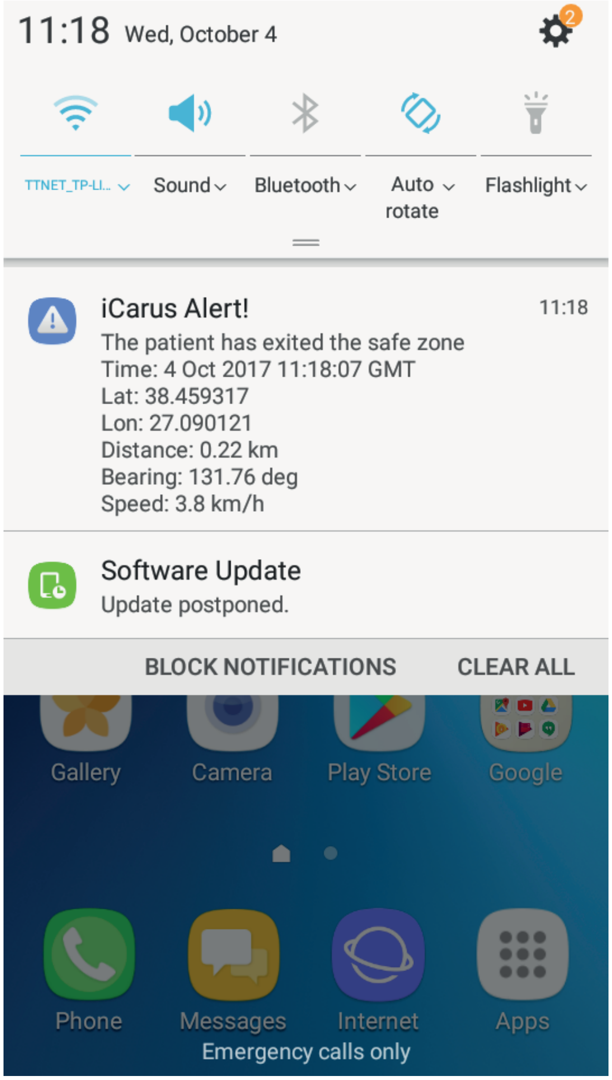
In order to evaluate the usability of the prototype system, a questionnaire using a five-point Likert-type scale was constructed. Although there a number of questionnaires available, it was necessary to construct a questionnaire specific to the features of the system. The questionnaire was designed based on the literature [4, 30]. The questionnaire is shown in Figure 6. The original questionnaire was in Turkish. All of the participants were Turkish citizens. The questionnaire consisted of five sections: demographic data, experience of technologies, experience of dementia, usability evaluation, and open-ended feedback. Experience of technologies and dementia were captured by a series of dichotomous questions. The usability evaluation section consisted of 12 five-point Likert-type items (questions). Initially, the participants were requested to fill in the first 3 sections of the questionnaire. After giving information about dementia and wandering behavior, the system was explained to each participant. Then each participant was given an instruction sheet requesting them to accomplish some tasks for defining zones, tracking, and defining rules. The participants acted both as a patient and a caregiver one at a time. The patient's movement was simulated. The tracking mechanism was demonstrated by generating a simulated alert. On completion, the remaining sections of the questionnaire were filled in.

All data were analyzed using SPSS 25. The reliability of the questionnaire was tested by Cronbach's alpha coefficient. Cronbach's alpha measures internal consistency, which is how closely related a set of items are as a group. It is considered to be a measure used to assess the reliability of a scale. It is a number between 0 and 1. Generally, an alpha of 0.7 or above is considered acceptable. Higher values of alpha are more desirable. An alpha of 0.9 or above is regarded as excellent internal consistency [31].

In addition, descriptive statistics and two types of inferential statistics were used. Although evaluating Likert data differs, standard nonparametric approaches were used [4, 32], namely the Mann–Whitney U test for comparing 2 groups and the Kruskal–Wallis test for comparing 3 or more groups. After testing, U and P values are calculated and if the P (probability) value is less than 0.05, then it is interpreted that there is a statistically significant difference between the groups. As P decreases, the significance increases [33]. Individual data are summarized using the median (Mdn) and interquartile range (IQR), because nonparametric tests are used. The IQR shows if there is a consensus (lower score) or not (higher score) for an item.

5.3. Results

Cronbach's alpha of the questionnaire was 0.92, which suggests very good internal consistency and reliability. The system was evaluated by 44 users, consisting of 24 males and 20 females and all between the ages of 19 and 64. From a technology perspective, 86.4% of the subjects were familiar with using smart phones; however,



iCarus Alert! 11:18
The patient has exited the safe zone
Time: 4 Oct 2017 11:18:07 GMT
Lat: 38.459317
Lon: 27.090121
Distance: 0.22 km
Bearing: 131.76 deg
Speed: 3.8 km/h

Software Update
Update postponed.

Figure 4. The received notification.

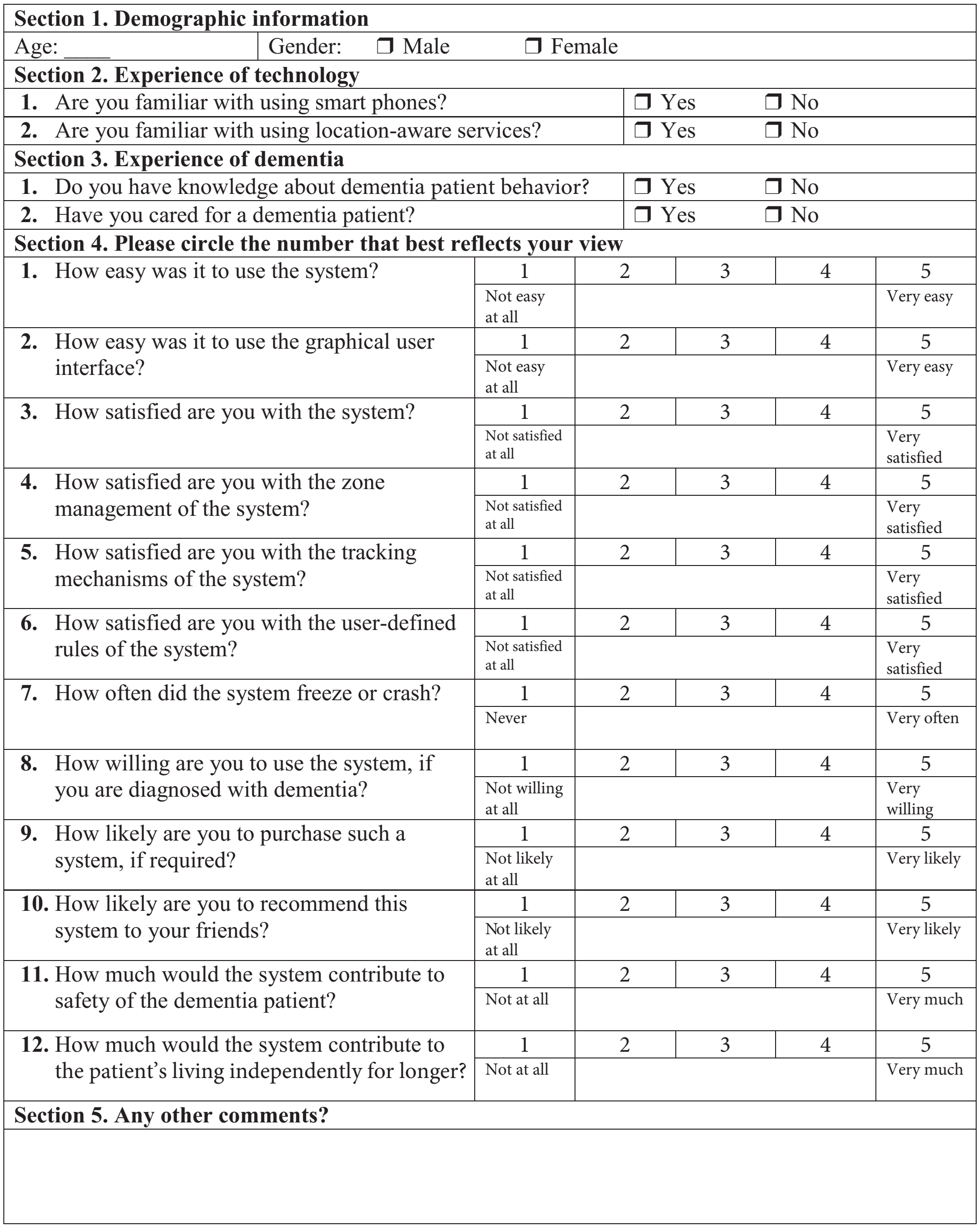
Patient's Navigation Information

Location (Lat, Lon):	38.459317, 27.090121
Distance (km):	0.22
Bearing (degrees):	131.76
Speed (km/h):	3.8

Figure 5. Patient tracker window of the caregiver mobile application.

only 54.5% of them were familiar with using location-aware services. In the case of dementia, 56.8% of the group claimed they had previous knowledge about dementia patients' behavior and 13.6% claimed they had experience of taking care of a patient.

The frequency table of the answers given by the participants is shown in Table 4. The mean, standard deviation (SD), median, and IQR for each of the items of the questionnaire are shown in Table 5. The results show overall user satisfaction of the system. For example, concerning the ease-of-use of the system, the median was 4 (IQR = 1). In the case of user satisfaction, the median was 4 (IQR = 1). Most of the subjects were satisfied with the zone management (Mdn = 4, IQR = 0), tracking mechanisms (Mdn = 4, IQR = 2), and user-defined rules (Mdn = 4, IQR = 1). The median was 4 for every item except item 7, which was reverse-scored and measured the reliability of the system. The median was 5 (IQR = 1), meaning that mostly there were no freezes or crashes.



Section 1. Demographic information

Age: _____	Gender: ☐ Male ☐ Female

Section 2. Experience of technology

1. Are you familiar with using smart phones?	☐ Yes ☐ No
2. Are you familiar with using location-aware services?	☐ Yes ☐ No

Section 3. Experience of dementia

1. Do you have knowledge about dementia patient behavior?	☐ Yes ☐ No
2. Have you cared for a dementia patient?	☐ Yes ☐ No

Section 4. Please circle the number that best reflects your view

1. How easy was it to use the system?	1	2	3	4	5
	Not easy at all				Very easy
2. How easy was it to use the graphical user interface?	1	2	3	4	5
	Not easy at all				Very easy
3. How satisfied are you with the system?	1	2	3	4	5
	Not satisfied at all				Very satisfied
4. How satisfied are you with the zone management of the system?	1	2	3	4	5
	Not satisfied at all				Very satisfied
5. How satisfied are you with the tracking mechanisms of the system?	1	2	3	4	5
	Not satisfied at all				Very satisfied
6. How satisfied are you with the user-defined rules of the system?	1	2	3	4	5
	Not satisfied at all				Very satisfied
7. How often did the system freeze or crash?	1	2	3	4	5
	Never				Very often
8. How willing are you to use the system, if you are diagnosed with dementia?	1	2	3	4	5
	Not willing at all				Very willing
9. How likely are you to purchase such a system, if required?	1	2	3	4	5
	Not likely at all				Very likely
10. How likely are you to recommend this system to your friends?	1	2	3	4	5
	Not likely at all				Very likely
11. How much would the system contribute to safety of the dementia patient?	1	2	3	4	5
	Not at all				Very much
12. How much would the system contribute to the patient's living independently for longer?	1	2	3	4	5
	Not at all				Very much

Section 5. Any other comments?

Figure 6. The questionnaire.

The subjects were mainly willing to use the system (Mdn = 4, IQR = 1) and to purchase such a system (Mdn = 4, IQR = 1), if required. In the open-ended feedback section, some of the subjects stated that health insurance should cover the expenses of the system. Most of the subjects indicated agreement with the idea that the system would contribute to the safety of dementia patients (Mdn = 4, IQR = 0) and to patients living independently longer (Mdn = 4, IQR = 0), because IQR values were zero.

The Mann–Whitney U test was used for all of the comparisons, except age, which required comparing more than 2 groups and therefore the Kruskal–Wallis test was used. Neither gender nor age influenced any

Table 4. Frequency table of the answers given by the participants.

Answers	Items											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	2	0	0	0	0	0	0
2	1	1	1	1	2	2	0	2	2	1	1	1
3	5	9	5	4	11	12	2	8	7	8	2	5
4	25	19	22	31	19	21	19	19	24	21	32	30
5	13	15	16	8	12	7	23	15	11	14	8	8

Table 5. User evaluation results.

	Items											
	1	2	3	4	5	6	7	8	9	10	11	12
Mean	4.14	4.09	4.20	4.05	3.93	3.66	4.48	4.07	4.00	4.09	4.07	4.02
SD (σ)	0.70	0.80	0.73	0.61	0.85	0.96	0.59	0.85	0.78	0.77	0.59	0.63
Median	4	4	4	4	4	4	5	4	4	4	4	4
IQR	1	1	1	0	2	1	1	1	1	1	0	0

items. The subjects who were familiar with using smart phones found the graphical user interface easier to use (U = 185, P = 0.013), because the P-value was less than 0.05. Those who were familiar with location-aware services found the system easier to use (U = 331, P = 0.016). Those who had previous knowledge about dementia patients' behavior were of the opinion that the system would contribute to the safety of dementia patients (U = 310, P = 0.028). Those who had cared for a dementia patient were more satisfied with the tracking mechanisms of the system (U = 179, P = 0.025) and believed that the system would contribute to safety of dementia patients (U = 182, P = 0.018).

6. Conclusion

In this paper, the design and implementation of iCarus, which is an intelligent context-aware AAL system for dealing with wandering behavior in early-stage dementia patients, is presented. The aim of iCarus is to provide independent living for elderly people and a cost-effective way of monitoring them. iCarus promotes a user-friendly and unobtrusive interface. Unless irregular activity is detected, user intervention is not required.

iCarus is a rule-based system where zones are defined in both spatial and temporal dimensions by default. Caregivers can also define their own zone types based on other context parameters and they are able to construct their own rules and extend the functionality of the system according to their own needs. These are not supported by other related works. As a result, a flexible and extensible system is developed. Constructing new rules is done by an innovative user interface. Thus, the users do not need to know the syntax of the rule language. In this scheme, context reasoning is decoupled from the source code of the system.

When a wandering episode occurs, the rule-based reasoning is employed to determine the action(s) that are to be executed according to situation's severity and the user preferences. These actions include warning the patient, navigating the patients back to their homes, sending notifications to the caregiver(s), initiating a real-time tracking session, and calling or texting the caregiver and the emergency service. The caregiver or the emergency service personnel can track the patient on a map by using the caregiver mobile application, the web application, or the desktop application. The system acts autonomously and it shows proactive behavior.

The rule-based context reasoning is performed over the context ontology to derive high-level context from low-level contextual data. Delivery of a personalized, adaptive, and anticipatory service, which is crucial for ambient intelligence, is achieved by using context-awareness. Rule construction is demonstrated with a scenario. The iCarus system proposed in this paper is novel and different from all of the other related works by combining these features in one system. As a case study, iCarus is described and evaluated with a scenario. In order to evaluate the usability of iCarus, a questionnaire is administered after the users tried the system. The results are then statistically analyzed and reported. The results show overall user satisfaction with the system. The subjects were mainly willing to use the system and to purchase such a system in case it is needed. Most of the subjects agreed that the system would contribute to safety of dementia patients and to longer independent living of the patient. As a future work, collaboration with dementia experts from other disciplines and evaluation of this system with real dementia patients are planned.

References

[1] Prince M, Comas-Herrera A, Knapp M, Guerchet M, Karagiannidou M. World Alzheimer Report 2016: Improving Healthcare for People Living with Dementia: Coverage, Quality and Costs Now and in the Future. Technical Report 2016. London, UK: Alzheimer's Disease International, 2016.

[2] Alzheimer's Disease Education and Referral Center. Alzheimer's Disease Fact Sheet. Technical Report 2010: NIH Publication No. 08-6423. Silver Spring, MD, USA: National Institutes of Health, 2010.

[3] Sposaro F, Danielson J, Tyson G. iWander: An Android application for dementia patients. In: 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology; 2010. pp. 3875-3878.

[4] Wan J, Byrne CA, O'Grady MJ, O'Hare GMP. Managing wandering risk in people with dementia. IEEE T Hum-Mach Syst 2015; 45: 819-823.

[5] Cipriani G, Lucetti C, Nuti A, Danti S. Wandering and dementia. Psychogeriatrics 2014; 14: 135-142.

[6] Algase DL, Moore DH, Vandeweerd C, Gavin-Dreschnack DJ. Mapping the maze of terms and definitions in dementia-related wandering. Aging Ment Health 2007; 11: 686-698.

[7] Hoey J, Yang X, Quintana E, Favela J. LaCasa: Location and context-aware safety assistant. In: 2012 6th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth) and Workshops; 2012. pp. 171-174.

[8] Wan J, Byrne C, O'Hare GMP, O'Grady MJ. Orange alerts: Lessons from an outdoor case study. In: 2011 5th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth) and Workshops; 2011. pp. 446-451.

[9] Weiser M. The computer for the 21st century. Sci Am 1991; 265: 94-104.

[10] Remagnino P, Foresti GL. Ambient intelligence: a new multidisciplinary paradigm. IEEE T Syst Man Cy A Jan 2005; 35: 1-6.

[11] Wan J, Byrne C, O'Hare GMP, O'Grady MJ. OutCare: Supporting dementia patients in outdoor scenarios. In: Setchi R, Jordanov I, Howlett RJ, Jain LC, editors. Knowledge-Based and Intelligent Information and Engineering Systems. Berlin, Germany: Springer, 2010. pp. 365-374.

[12] Cook DJ, Augusto JC, Jakkula VR. Ambient intelligence: technologies, applications, and opportunities. Pervasive Mob Comput 2009; 5: 277-298.

[13] Kleinberger T, Becker M, Ras E, Holzinger A, Müller P. Ambient intelligence in assisted living: enable elderly people to handle future interfaces. In: Stephanidis C, editor. Universal Access in Human-Computer Interaction. Ambient Interaction. Berlin, Germany: Springer, 2007. pp. 103-112.

[14] Kumar A, Ma M, Lau CT, Chan S. A framework of real-time wandering management for person with dementia. In: Proceedings of the 8th International Conference on Computer Modeling and Simulation; 2017. pp. 146-150.

[15] Rodriguez MD, Navarro RF, Favela J, Hoey J. An ontological representation model to tailor ambient assisted interventions for wandering. In: AAAI Fall Symposium: Artificial Intelligence for Gerontechnology; 2012.

[16] Lin Q, Zhang D, Chen L, Ni H, Zhou X. Managing elders' wandering behavior using sensors-based solutions: a survey. Int J Gerontol 2014; 8: 49-55.

[17] Blackburn P. Freedom to wander. Nurs Times 1988; 84: 54-55.

[18] Miskelly F. A novel system of electronic tagging in patients with dementia and wandering. Age Ageing 2004; 33: 304-306.

[19] Parikh S, Stirman K. Schema design for time series data in mongodb. 2014. https://www.mongodb.com/blog/post/schema-design-for-time-series-data-in-mongodb.

[20] Lekeu F, Wojtasik V, van der Linden M, Salmon E. Training early Alzheimer patients to use a mobile phone. Acta Neurol Belg 2002; 102: 114-121.

[21] Fisk AD, Czaja SJ, Rogers WA, Charness N, Czaja SJ, Sharit J. Designing for Older Adults: Principles and Creative Human Factors Approaches. Boca Raton, FL, USA: CRC Press, 2009.

[22] Miskelly F. Electronic tracking of patients with dementia and wandering using mobile phone technology. Age Ageing 2005; 34: 497-499.

[23] Heard K, Watson TS. Reducing wandering by persons with dementia using differential reinforcement. J Appl Behav Anal 1999; 32: 381-384.

[24] Gruber TR. A translation approach to portable ontology specifications. Knowl Acquis 1993; 5: 199-220.

[25] Gu T, Wang XH, Pung HK, Zhang DQ. An ontology-based context model in intelligent environments. In: Proceedings of Communication Networks and Distributed Systems Modeling and Simulation Conference; 2004. pp. 270-275.

[26] Hervás R, Bravo J, Fontecha J. A context model based on ontological languages: a proposal for information visualization. J Univers Comput Sci 2010; 16: 1539-1555.

[27] Kim E, Choi J. An ontology-based context model in a smart home. In: International Conference on Computational Science and Its Applications; 2006; Berlin, Germany: Springer. pp. 11-20.

[28] Mitchell M, Meyers C, Wang AIA, Tyson G. Contextprovider: Context awareness for medical monitoring applications. In: 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society; 2011. pp. 5244-5247.

[29] Wang XH, Zhang DQ, Gu T, Pung HK. Ontology based context modeling and reasoning using OWL. In: Proceedings of the Second IEEE Annual Conference on Pervasive Computing and Communications Workshops; 2004. pp. 18-22.

[30] Nielsen J. Usability Engineering. San Diego, CA, USA: Academic Press, 1993.

[31] Kline P. The Handbook of Psychological Testing. 2nd ed. London, UK: Routledge, 2000.

[32] Norman G. Likert scales, levels of measurement and the "laws" of statistics. Adv Health Sci Educ Theory Pract 2010; 15: 625-632.

[33] Weaver KF, Morales V, Dunn SL, Godde K, Weaver, PF. Mann-Whitney U and Wilcoxon signed-rank. In: Weaver KF, Morales V, Dunn SL, Godde K, Weaver, PF, editors. An Introduction to Statistical Analysis in Research: With Applications in the Biological and Life Sciences. New York, NY, USA: John Wiley & Sons, 2017.