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Dealing with uncertainty in a context aware pre-embarkation prompter system to support independent living

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We live in the information age, where many tasks are automated and many jobs are performed by machines. There has been a certain amount of fear about the rise of artificial intelligence (AI) and cognitive computing and its impact on traditional careers, but these developments are good news for people with disabilities. Elderly people who have lost some of their cognitive capabilities, and those who have life-long intellectual disabilities (ID) can avail of AI to become more independent and enjoy the same conveniences as the rest of society. Of course, this relies on making such systems accessible for this vulnerable group of users. Existing research has considered aids for activities of daily living including wayfinding for helping with commuting for ID service users. This work seeks to produce an assistive technology that supports people with intellectual impairment in the preparations for leaving an indoor space so that they may do so independently with only minimum interventions from the family or the caregiver.

Assistive technology, Intellectual disability, Activities of daily living, Context model, Context aware system, Uncertainty, Probabilistic reasoning, Presence detection, Indoor localisation, Wayfinding

1. INTRODUCTION

By 2030, the number of people aged above 60 across the world will be greater than the number of children [29]. The increase in the average age of the population has raised concerns for relatives of people with intellectual disability who are approaching adulthood, and those who care for senior citizens with cognitive impairment, about who will take care of the organisation of their daily activities such as commuting, medication plans and managing appointments [2].

The traditional solution to such concerns has been to place service users with intellectual disability in congruent settings where the person receives care and support in a protected environment. Such solutions may not be the optimum choice for a number of reasons. Apart from the cost implications, it has been shown that one carer might not able to handle the diverse needs of different service users [12]. Also being in a closed protected environment may even worsen the mental health of the service users [2]. For these reasons, in Ireland there has been a steady move from such congruent settings to independent living environments.

Assistive Technology (AT) and Ambient Assistive Living (AAL) offer technological solutions to support such situations. Technology is central to the completion of many contemporary tasks and therefore can be adapted to the needs of people with ID or impairments whether they are lifelong, or age-related. Recent advances in smartphone technology have increased the processing capacities and features of mobile phones allowing them to extend the scope of the services they can provide. Mobile phones are carried around constantly and by using appropriate mobile applications, information can be collected in them from different sources and harvested to support ID service users or ageing people who have lost part of their cognitive skill [16].

This work aims to bridge the gap between the features of existing mobile technology and the abilities of people with ID. In particular, this work focuses on the departure and arrival of service users, and understanding points in time when guidance may be needed. This work is inspired by the fact that people with ID may not be well placed to plan a journey and may sometimes lose track of tasks to be performed before leaving the house or even determining a suitable time to leave their current location. Also, they may not be able to interact with technology and access the wealth of information that is now available to "connected" embarking commuters. To make matters worse, the information acquired from the web services and different devices has a certain degree of uncertainty associated with it. While people without disability can use prior experience to judge the reliability of the available information, for prospective commuters with even mild impairments this uncertainty can be a source of confusion or anxiety [2].

This is also challenging from the point of view of developing a system, as usually the behaviour of computer applications is pre-defined and they can perform badly if a situation that is not defined arises. In fact, many real life problems are often modelled in a simplistic way [18].

2. KEY POINT OF LITERATURE REVIEW

The literature review has focused on reviewing previous AAL and AT research projects, particularly projects dedicated to people with cognitive impairments, in order to determine the general structure of such systems and to identify the challenges that the project can address.

2.1 Research projects in AAL and AT

A number of projects have focused on supporting independent living for ageing people and those with ID. The Gator tech smart house [7] is a laboratory that simulates a user's experience to evaluate newly developed AT for supporting people with cognitive, mobility, health, and other age-related impairments. It includes a cognitive assistant that acts as a reminder system in addition to guiding user to perform daily activities through the use of audio and visual cues. Adaptability is achieved in the system using a context management layer and knowledge layer that utilise ontology to perform reasoning. The SIMBAD (Smart Inactivity Monitoring using Array detector) system [27] is an alert system to detect falls in elderly people using an array of sensors and neural networks. The Intelligent System for Independent living and Self-care (ISISEMED) [17] project provides three bundles of services designed for people with mild dementia. The services include both support for daily activity living using a reminder system, unsafe situation detection, a smart door that monitors the time spent outdoors, wandering detection system and other components that monitor the health of users and alarm a secondary user in case of emergency. The ROSETTA project [15], also extends the time a person with dementia can live in their preferred environment. It consists of a day navigator, an early detection system and a surveillance system. The Poseidon project [13] provided wayfinding services for people with Down Syndrome, It includes a navigational system that supports the mobility of users.

The literature review of AAL and AT projects showed that they focused on providing services for either managing indoor activity or for outdoor mobility. Given the research focus on these two domains, the services that can be provided during transition between indoors and outdoors should also be considered to be important, but such transition services were not covered explicitly in the literature. So this work focuses on preparing the user to embark from a location and therefore will be called a pre-embarkation system. From all of the systems studied, elements that we are interested in for the pre-embarkation system, are cognitive orthotics, context aware models and dealing with uncertainty. Each of these topics will be explored in the next sections.

2.2 Cognitive Orthotics

In addition to AAL projects there are several assistive technology tools that provide services for people with ID and they are collectively referred to as cognitive orthotics. This category of AT is intended to support people with cognitive impairments. The primary aim of cognitive orthotics is to train persons who lack an intellectual capacity to gain or regain that capacity [5]. This approach is inspired by the cognitive rehabilitation theory that has proven that it is possible to develop the intellectual capabilities of ID service users [24]. A reminder system is an example of such a system. It is designed to remind the user of different actions such as taking medication at prescribed times [20].

Several assistive technologies have been developed for reminding and prompting users. For example, the Kognit storyboard [21], provided guidance to carry out daily activities for people who suffer from Alzheimer's Disease. Information about users and their environment is obtained from analysing images taken from glasses worn by users. The services are provided through the use of a robot that also reminds the users of the tasks that they have to do during the day such as taking medication. The reasoning is performed using natural language processing. Care [6] is a reminder system that has two modes; picture frame mode when the user is away from it and recommender mode when the user is in the proximity of the frame or when it is triggered by an event. The recommender mode pushes suggestions to the user based on the information acquired from sensors installed in its indoor environment. MOBUS [19] is another platform that provides a service for planning the daily activities of a person with ID. The planning algorithm in this system is performed by a high processing machine based on Hierarchical Task Network (HTN) Planning and pushing the resulting suggestion to users in either their mobile phones or PDA which is also equipped with a chat service to the caregiver. In addition there are Mobile Multimedia technologies such as, Smart Prompting Technology [3], Cyberminder [1], Assistive Cognition Prompting System, Forget-Me- Not [14], COACH[9] and Google Calendar[22].

2.3 Context-aware models

Context and context-awareness are key enablers of self-adaptability of an AT system. Many definitions are available in the literature, but arguably the most referenced is Dey's definition [4] which states that context is **"**any information that can be used to characterize the situation of entities (whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves.**"**. There are several context modelling approaches such as key-value models, mark-up scheme models, graphical models, object based models, logic based models and ontology based models [18].

Context reasoning is the mechanism that allows a context aware system to infer higher level information or data close to human language by combining low level information collected from different resources [18].

2.4 Context aware models and uncertainty

One way to minimise the effect of uncertainty is to understand how context information is obtained. To reflect such uncertainty, context aware models associate Quality of Context (QoC) parameters [25] which link the quality, accuracy and granularity of the data feed with the context information.

The context reasoning component also deals with the imperfection of data by detecting faulty data and can assess the uncertainty of data. Context reasoning is used to manage uncertainty through pre-processing of data which comprises of removing outliers and comparing multiple resources to check the validity of data. Several algorithms can be used for this purpose, such as a decision tree, naive Bayes, hidden Markov models, support vector machines, k-nearest neighbour, artificial neural networks, Dempster-Shafer, ontology-based, rule-based and fuzzy reasoning [18]. The application of Bayesian networks was identified as a suitable approach for this work, as it is based on causal relationships between different context information. The next section presents a brief description of Bayesian networks.

2.5 Bayesian networks

Bayesian networks are directed acyclic graph models that represent the probabilistic relationship between several random variables. The random variables are presented as nodes in the graph while the dependency relationship between them is modelled as a uni-directional arc between dependent nodes. The occurrences of different scenarios are quantified using probability tables stored at each node. Prior probabilities refers to the probabilities obtained from prior data[11].

Using probabilistic models based on Bayes' rule to understand the human cognition is a common practice in computational modelling of human cognition modelling [10]. It uses both the information from prior experiences and the current observed data. In addition, a BN can be translated to a statement like 'variable A causes variable B', so that the system can train users to regain part of their cognitive capability by providing the reasons for any suggestions [10].

Probabilistic modelling can be part of context modelling to increase the adaptability of the overall context aware system; Truong et al. [28] showed how a BN can be used as part of context awareness modelling where an ontology context model is overlaid with a probabilistic model based on Bayesian networks. This leads to the definition of new probabilistic class objects called p-class and new relationships between probabilistic classes within the new model. The p-class contains a set of attributes which can be simple or complex depending on whether they are at the root nodes or at other nodes in the Bayesian network. An attribute can be discrete or continuous - in the first case a conditional probability table is associated with it and in the second case a probability distribution is associated with it.

3. AIMS AND OBJECTIVES

The aim of this project is to support independent mobility for a person with ID, by providing direct assistance for mobility aspects of activities of daily living and by automating the planning of journeys, thereby minimising the intervention required by the carer and family of the person with ID. The resulting system will be a reminder system referred to as a ***pre-embarkation system*** because the service provided is for supporting the preparation required to move between locations. The pre-embarkation system will prompt the users by:

- Reminding the user of the task to be performed prior to leaving the house
- Indicating the time to leave the location when the user is ready and in the event that the user is not ready to leave, calculate an alternative departure time.

In order for the pre-embarkation system to guide the user, it acquires core data or context information from two main resource categories; web-services to acquire information about environmental parameters such as real time bus at specific bus stops or weather data, and from sensors on the user's phone, or installed at the user's indoor space that collect information about the user's indoor environment, such as indoor temperature and indoor location, and their current activities. Based on this perspective, it is envisaged that a pre-embarkation system should evaluate this context information and "push" suitable suggestions to the user. The initial step therefore will enumerate the different context information that should be acquired. This will be done in a manner that imitates the different steps taken by the majority of adults when leaving the house basing their decision on different information acquired from web services and local sensors.

Adults also accumulate user experience and knowledge from each web service and identify a level of uncertainty with each source of information. To mimic this ability, the pre-embarkation system will acquire prior knowledge or collect historical data and describe the different challenges associated with acquiring such data and transforming it into "knowledge". This prior data will be used as an additional source of context information to identify activity patterns of the occupants of a measured space to augment the service of the embarkation system provided in it to ID service users. The prior knowledge will be determined for each separate piece context information. The user's habitual patterns will also be analysed.

Context awareness is an important part of any AAL system where interaction between different context information is modelled and where reasoning is performed to yield suitable suggestions to push to the users. In fact, this can be viewed as knowledge or "rules of interaction" about how the synthesis of different context information will lead to a suitable decision. As a part of this work, a suitable context aware model called ContextUML [26] has been identified to model the interaction between different context information.

ContextUML assumes that interaction between context information will occur according to pre-defined rules. This is often unfeasible as it is not possible for a model to reflect all the different scenarios of interactions. Also, the application of a rigid model might not work if unfamiliar situations arise. The aim of this work is to augment such rigid models by relaxing the relationship between context information through defining a probabilistic relationship between the core context information. In addition to classifying context information into two types of context information; **deterministic context information** that does not change with space and time **and probabilistic context information** that is uncertain and changes with time, space, and situations.

3.1 Research Questions

How could a system that incorporates the chosen context model deal with a combination of deterministic and uncertain situation information and how can uncertainty be part of the reasoning that mimics the human way of dealing with uncertainty in order to bridge the "usability gap"?

4. PROBLEM STATEMENT

This work is a step toward creating an AT system for embarkation that supports people with ID. Specifically it helps by preparing an individual with cognitive impairment for a journey. The experience of starting a journey between two locations can be stressful to a person with ID as they may lack the cognitive capabilities to remember certain key tasks that they must perform before leaving the house (dressing appropriately for the weather, remembering important things such as their bus pass, phone, keys…). Unlike other citizens, they often cannot access supporting information such as information that is available from web services or read the information available about their environment. Even if an ID service user accesses the information they may not have the skills to incorporate it to plan the day accordingly. The majority of commuters can easily access this type of supporting information and use it to make preparations for a journey. Other cognitive skills that might be difficult for people with ID to master is how to deal with uncertainty, in fact uncertainty such as the non-arrival of a bus or unexpected changes in a daily schedule, can be a great source of anxiety for these users [23]. So this AT aims to minimise such uncertainty to obtain for its users a similar level of comfort as users without ID.

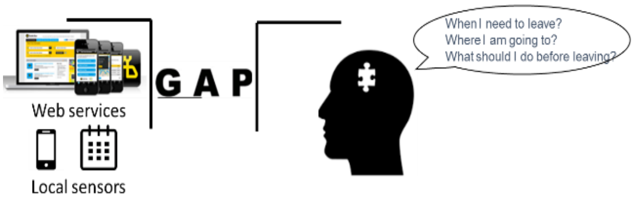

Figure 1: *The system should answer three questions based on information from web services and context parameters sensed by local sensors*

5. RESEARCH METHODOLOGY

A literature survey was performed about the components of a general AT and AAL and of AAL to support cognitive ability. A suitable context aware model that could be augmented to integrate probabilistic elements was also sought. The context components that were identified were:

Presence detection; detecting human occupancy in the indoor space and identifying predictive patterns of human occupancy of a space whether it is home or work to push appropriate suggestions.

Proximity detection: detecting the moment a person is leaving the house by tracking departure activity such as movement in close proximity to a door.

Bus time arrival: minimising the waiting time of the user at the bus stop by including other parameters that might delay the bus arrival such as weather, time-of-day.

Activity detection: It is important to recognise that the user will have performed certain activities before leaving the indoor space. Therefore the project will include a component that detects activities of the user based on combining information from sensors or using sensors on a mobile phone to record activity information on a phone.

The second step is to establish prior information and knowledge for each component. The research lab was used as the test space for both the presence, proximity and activity detection while for the bus arrival component, data was collected from the real time bus web service.

The third step integrates the information acquired from the different components into a suitable context aware model that will be augmented using a similar paradigm to [28].

Finally, the evaluation of the AT will take place at the office and the performance of the augmented context aware model will be compared to the performance of the original context aware model in terms of the accuracy of leaving the place and whether the user has completed the required tasks before leaving the place.

6. INITIAL RESULTS

6.1 Presence Occupancy component

A study was performed in a research office environment of a system for detecting human occupancy, using a combination of two different low cost technologies - Bluetooth RSSI's signals and smart plugs connected to the user's desktop and monitor [8]. Both measurement methods were translated into occupancy profiles for the study subjects by comparison with a paper journal entry of occupancy. The occupancy profile data was collected first for one week and compared to the manual occupancy journal and indicated a high level of accuracy (table 1).

An additional eight weeks of data was collected and this augmented dataset will be used to create a probability predictive model based on historical activity data in the workplace, and will predict the probability of occupancy that will deduce the most probable embarkation behaviour of the participant.

6.2 Proximity and tracking component

The aim of this part of the work is to determine the indoors proximity of the user to the exit door and the different patterns that imply the intention of leaving the indoor space. A second piece of experimental work was performed in the biomedical engineering and assistive technology (BEAT) lab of the Greenway Hub Building in the new DIT campus in Grangegorman Dublin. A 10 x 4 meter grid of location dots were placed on the open floor area, such that the distance between each two neighboring crosses was one metre.

Table 1: *Accuracy of using Bluetooth and Power consumption for the presence detection*

	Method used	O/O	O/NO	NO/O	Precision	Recall	F-score
P 1	Bluetooth based	1479	14	24	0.99	0.98	0.99
	Power Consumption	1275	277	63	0.82	0.94	0.88
P 2	Bluetooth based	933	22	71	0.97	0.92	0.92
	Power Consumption	1060	212	89	0.83	0.92	0.87
P 3	Bluetooth based	1537	3	75	0.99	0.95	0.97
	Power Consumption	1324	211	95	0.86	0.93	0.89
P 4	Bluetooth based	1574	99	197	0.94	0.88	0.91
	Power Consumption						

For this experiment, a movable tripod on which a mobile phone was fixed was used. The height of the phone was fixed to 80 cm above the ground as it is approximately table height and it was noted that a user would hold the phone at a similar height. Three Raspberry Pi Model Bs (indicated by an antenna icon in Figure 3 which have on-board BLE transceivers), acted as anchor nodes receiving the RSSI signal from the phone. Each Raspberry Pi was placed on a tripod at a similar height to the phone. The 3 Pi's were placed at fixed recording positions at three of the 4 corner points A1, A4 and J4 as shown in figure 2.

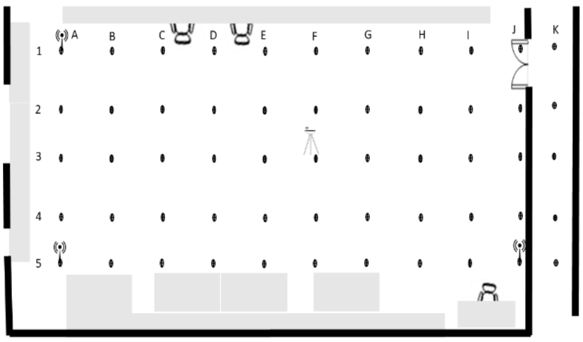

Figure 2: *Overview of the experimental environment, the figure illustrates the furniture and dimensions of the experimental space*

The proximity method is based on a "finger printing" method so a radio map of the signal at each position was constructed by collecting 100 measurements from each Pi at every position and for two cases; the first case the phone is in the hand of the user and in the second case the phone is placed on a tripod to remove the influence of absorption of the Bluetooth signal by the user's body. Figure 3 summarises the findings. The next step is to create a model that predicts the intention of users based on the measured signal from the Pis.

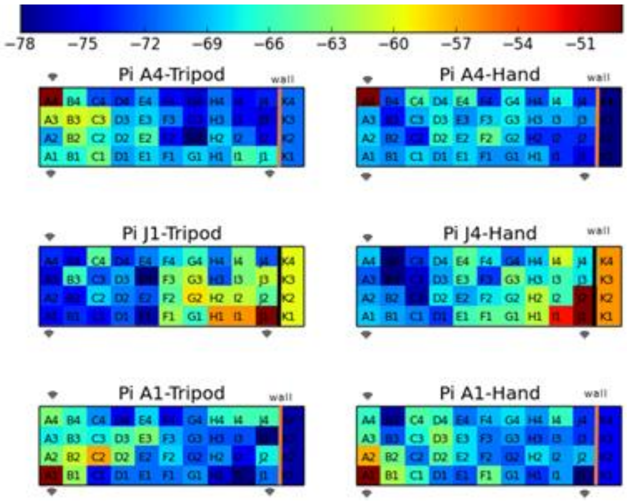

Figure 3: *Heatmap showing mean RSSI values for the Three Pi's at different position*

6.3 Bus arrival estimation

One month's data was collected for a specific bus route that consists of the time indicated by a web service for the bus to arrive and the actual time of the bus arrival. Then a prior probability was obtained from the collected data to be used in a dynamic Bayesian network that consists of the arrival time indicated by the web service provided by the bus company, and the predicted time indicated by prior historical data.

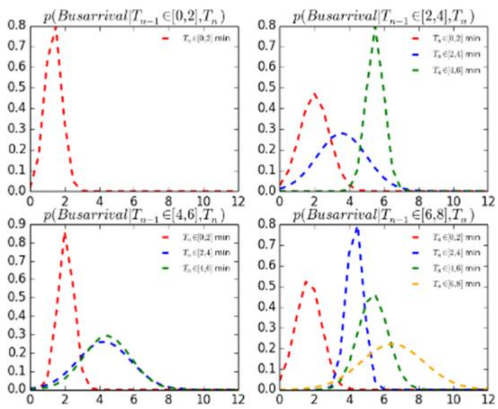

Figure 4: *The likelihood probability for the current minute T_n for each previous minute T_{n-1} (c) The posterior probability for the joint probability of the published times at T_n and T_{n-1}*

7. Main contributions being proposed

Some projected contributions of this work can be summarised in the following points:

- Development of a hybrid contextUML-based model that deals with uncertainty/extends a well-established context model by including a probabilistic engine to account for uncertain context-information and to infer higher level context information that allows the system to adapt to different situations.
- Demonstrating how that hybrid context-aware system can be applied to the problem of pre-embarkation for commuting ID service users.
- Development and utilisation of a tracking system based on client server architecture between three BTLE gateways that communicates the detected signal in real time to one master gateway that estimates the location of the user and its intention to leave or stay in the space.
- Minimising the current waiting time at the bus stop for ID service users to minimise stressful situations.

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