DELIVERABLE 2.4a

Implementation and integration of context-aware planner

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Short description

Task T2.4. – Implementation and integration of context-aware planner, is broken down into 3 stages (i.e. D2.4a, D2.4b and D2.4c) over the 3 years of the ACCOMPANY project. This deliverable D2.4a reports the first stage of work done to implement a first proof-of-concept prototype of a context-aware planner based on a sensor network installed in the Robot House home environment, and running on a Care-O-bot® 3 robot.

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1 Introduction

Robots that can adapt their functionality to match their environment and task situations are highly desirable, especially in the field of robotic home companions. Robotic companions not only need to be able to support users in their home environments with their activities of daily living (ADL), but also need to be socially adaptive by taking into account users' individual differences, environments and social situations as well as behave in a socially acceptable manner in order to gain acceptance into the household. To behave in such a socially acceptable manner while providing ADL support, robots will need to be context-aware, taking account of any contextual information relevant to its services and improve on delivering these services by adapting to the users' requirements.

According to Dey and Abowd (1998), *a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task.*

Much research in the field of context-aware systems originates from the field of ubiquitous computing. For example, Marc Weiser (Weiser, 1991) envisioned a scenario in which computational power (of machines) is available anywhere, embedded within the human environment (i.e. walls, chairs, clothing etc.) making information available at our fingertips. In general this allows for mobile applications to discover and take advantage of contextual information (i.e. time, location etc.) in order to adapt their services to increase usability and effectiveness, without requiring direct user intervention (Baldauf, Dustdar and Rosenberg, 2007).

One example of an early context-aware system was the Active Badge Location System introduced by Want et al. (1992). The system provided user location context to a receptionist operating a switchboard, who could then forward telephone calls to a telephone located close to the intended recipient. The emphasis on location information as one of the most useful and widely used attributes of context has continued and led to the development of many location-aware systems such as intelligent tour guides (Abowd et al., 1997, Sumi et al., 1998; Cheverst et al., 2000).

Contextual Information related to location is particularly useful for autonomous systems such as Robotic Companions. User location context is key to many services that a robotic companion can perform, as many of these depend on the robot knowing where the user is and how to physically approach the user for interaction, i.e. to offer a drink or provide urgent information.

Context-aware systems are not limited to location-aware systems; Dey et al. (1999) introduced a Conference Assistant system which combines contextual information from both time and location of the users to provide attendees with information related to the presentation that is happening in these locations. Context-aware systems are also widely used in the fields of human-computer interaction, artificial intelligence, computer vision (Crowley et al., 2002) and e-commerce (Palmisano et al., 2008). With no common definition of what is meant by, or included in the term "context", in the field of context-aware systems, different researchers define context differently depending on the specific requirements of a particular context-aware system. Some of these definitions are presented below:

Dey, Salber and Abowd (2001) define context as:

> "…*any information that can be used to characterize the situation of an entity. An entity is a person, a place, or a physical object or computational object that is considered relevant to the interaction between a user and an application, including the user and applications themselves*".

While this definition has been described as quite vague, Winograd (2001) argues that it is intended to be general enough to cover a variety of research on context-aware interaction. He goes on to argue that:

> *"…something is context because of the way it is used in interpretation, not due to its inherent properties. The voltage on the power lines is a context if there is some action by the user and/or computer whose interpretation is dependent on it, but otherwise is just part of the environment."*

Chaari et al (2006) agree with Winogard's definition and consider context as an operation whose definition depends on the interpretation of the particular operations involved on an entity at a particular time and space, rather than inherent characteristics of the entity itself.

Context instances are categorised into two main context dimensions in the literature. These are external vs. internal (Prekop and Brunett, 2003; Gustavsen, 2002) and physical vs. logical context (Hofer et al. 2002). The external/physical context dimension refers to contexts that can be measured directly by hardware sensors such as location, light, sound, movement, touch, etc. The internal/logical dimension refers to contexts that are specified by the designer and captured or obtained from monitoring user interactions (i.e. the user's goal, tasks, emotional state etc., cf. Baldauf, Dustdar and Rosenberg, 2007).

Context has proven to be a useful concept in many different fields, especially for mobile applications, and we believe this technology will also be very useful for robotic companions which are intended to interact directly with their users. It is well known that people rely on context to establish the baseline of their interaction, and as such it would be advantageous for a robot companion to be able to use contextual information for planning and performing its tasks, and thus gain the users' trust for being perceived as intelligent, friendly, capable and reliable. This also might help overcome trust issues that may arise with users that may not be familiar with the robot or new technology, such as some elderly people, thus gaining acceptance when inserted into their homes.

With incorporating robot control that uses context, we might be able to minimise some of the safety concerns users might have such as their dislike of situations when robots block their path, move behind them or move on a collision path towards them when they move in a shared space with robots (see discussion of these issues in Koay. et al., 2006, 2007).

Contextual information will also provide a robot with the ability to sense users' interactions with their surroundings and be aware of their activities (i.e. low level activities such as knowing that the user is sitting on a sofa or opening a drawer etc., as well as high level activities such as watching TV or making hot drink etc. cf. Schmidt, Beigl and Gellersen, 1998; Duque et al., 2012, submitted) in order for the robot to take the initiative to proactively support them in their everyday tasks.

The contents of this deliverable are organised in the following chapters:

Chapter 2: Discusses the requirements for the context-aware planner based on the task requirements for the set-up of the environment.

Chapter 3: Discusses the Activity Recognition System we create to contextualise information.

Chapter 4: Presents the first proof-of-concept prototype context-aware planner.

Chapter 5: Conclusions.

2 Requirements for context-aware planner

When designing a context-aware planner for robotic home companions the first step is to try to understand the users, their everyday life, and their requirements with respect to the services a robot companion may be able to provide in order to support and maintain their independence in their daily life (cf. ACCOMPANY D1.1 and D1.2). Based on this information, we can explore the capabilities of the robot, especially in terms of activities and tasks that the ACCOMPANY robot is capable of carrying out for users in their living environments. The services that can be provided by the robot are not fixed but will be expanded as the understanding of the users' needs progresses, or as new technology becomes feasible for implementation. The current services derived from the scenarios presented in D1.3 can be divided into two main categories: 1) cognitive prosthesis (e.g. reminder) and 2) physical assistance (e.g. fetch and carry etc.).

Generally, cognitive prosthesis involves tasks such as reminding the user of their schedules (i.e. medication, sending a birthday card, telephoning their family etc.) or notifying the user of events within their immediate surrounding that require their attention (i.e. fridge door has been open for 5 minutes, ringing of doorbell etc.).

Physical assistance involves activities such as moving around the user's environment and helping the user carrying objects as well as fetching.

The target for the ACCOMPANY robot is that it should be able to provide a variety of **notifications**, **reminders**, and **fetching** or **carrying** tasks which will support independent living scenarios of users in household environments such as those studied in the UH Robot House, as well as the two other test environments based in the Netherlands and France.

To achieve this target, the ACCOMPANY robot needs to be aware of the activities of the users, their environment and their situation. This contextual information can often be derived from sensors such as those used in smart homes (Kasteren, Englebienne and Kröse, 2010; Chen, Nugent and Wang, 2012; Korpipaa and Mantyjarvi, 2003). Raw sensory data from these sensors can be converted into meaningful semantic symbolic expressions that can then be used to describe activities of the users, events in their environment, or their overall situation. These semantic symbolic expressions can be as simple as an action performed by the user, such as sitting down, which can be directly detected from the appropriate sensors without further processing. On the other hand, they can be as for example, a making-a-cup-of-tea activity, which is not directly detectable from sensors, but could be derived by combining different user actions within a particular time frame (i.e. accounting for the process of making tea). Together these semantic symbolic expressions form the main mechanism that provides the ACCOMPANY robot with the contextual information needed for it to perform its tasks. This contextual information can be divided into the following five different categories (i.e. one physical context and four logical contexts) taking inspiration from (Mostefaoui and Hirsbrunner, 2003):

Physical Context: Contexts that can be measured directly from hardware sensor i.e. drawer is open/closed, doorbell is ringing, light, weather, temperature etc.

User Context: User activity, user location, user role, user preferences, user social situation and user permission profile etc.

Robot Context: Robot activity, robot location, robot role.

Time Context: Current time, day, year, month and season etc.

Context History: A time–stamp log of the above contexts which can be used to improve the robot system.

Using the contextual information presented above, the robot could in principle know when to take the initiative in assisting its users as well as taking into account the users' preferences and overall social situations within these interactions. For example, the robot will know when to remind users about their medication, or notify users if someone is at the door or make them aware that the fridge door has been left open for too long.

To make this contextual information available to the robot, the UH robot house is equipped with two commercially available sensor systems, the Green Energy Options (GEO) Trio System and the ZigBee (ZigBee) Sensor Network. This setup provides over 50 sensors, targeting activities at relevant location, such as the Dining Area, Living Room, Kitchen, Bedroom and Bathroom of the UH robot house (see Figure 1).

The GEO System is a real-time electrical device energy monitoring system and is used in the UH robot house to detect the activation and de-activation of specific electrical appliances by the user, such as when the refrigerator is opened, water is boiled in the kettle, or detecting when the doorbell has been pressed in the case of visitors at the door. The Zigbee Sensor Network is a standards-based (Xbee GatewayX4) low-power wireless sensor system. It is used in the UH robot house to detect user activities that cannot be detected by the GEO System, such as the opening and closing of drawers and doors, occupancy of chairs and sofa seat-places, water being run through taps in the kitchen and bathroom etc. The three main sensors types currently installed are Reed Contact Sensors, Pressure Mat Sensors and Temperature Sensors. An Activity Recognition System has been created to interpret these data to convert them into meaningful contextual information. This is described in the next section. Note, the sensor network is a system that has been used and tested extensively in a previous FP7 project (LIREC, 2008-2012). It was used for example in two long-term studies whereby in total 208 one-hour sessions were carried out involving 20 adult participants as part of long-term studies. In ACCOMPANY this system has been extended: a system to recognize human activities as well as context-aware planner have been developed which did not exist in the LIREC research. During the duration of project other sensors and activity recognition processes will be added (output from WP4).

Figure 1 UH Robot House map showing the location of the sensors (numbers).

3 Activity Recognition System

A knowledge-driven, rule-based Activity Recognition System (Duque et al., 2012, submitted) has been developed to derive sensory information from both the GEO System and the Zigbee Sensor Network which are embedded in the UH robot house. This system provides the contextual information necessary to guide the robot's social behaviour.

The reasons for selecting a knowledge-driven approach over probabilistic/machine learning approaches (as they are used in WP4) for the Activity Recognition System were to: a) avoid necessity to collect large amounts of training data from elderly users, b) provide a flexible approach so that the detectable user activities can be easily extended and modified during the development and fine tuning of the context-aware planner and the ACCOMPANY scenario, c) create a system that is easy to install and setup in other similar environments without the necessity of specialised knowledge (since the rules are based on a natural language description and are explicitly represented, rather than the implicitly representation e.g. within a Bayesian network (Tapia, Intille and Larson, 2004; Bao and Intille, 2004) or a Hidden Markov Model implementation (Sanchez, Tentori and Favela, 2008; van Kasteren ea al., 2008)). The Activity Recognition System presented here will complement the work done in WP4 where machine learning approaches have been investigated, cf. (Kasteren, Englebienne and Kröse, 2010). The two approaches will be integrated to exploit the advantages of each.

Currently, the Activity Recognition System is able to detect user activities directly from single sensor data (without the need to fuse data from different sensors), or predict user activities attached through a knowledge-driven approach that combines contextual information (based on sequences of activities, or activities performed concurrently by the user or the robot) and sensor data. Rules for detecting each user activity can be set up by filling in the required conditions in the appropriate field in the rule file. A skeleton rule file is shown in Figure 2.

```
<Activity Name="">
  <Duration></Duration>
  <Location="">
  <Contexts>
    <Context Interval="" Status=""> </Context>
  </Contexts>
  <Sensors Threshold="">
    <Sensor Status="" NotLatching="" Weight=""> </Sensor>
  </Sensors>
</Activity>
```

Figure 2 A skeleton xml descriptor for defining the user activity detection rules.

The rules for detecting activities are defined using the following tags:

Activity Name – the name of the *New Activity* this rule file is for.

Duration – the duration that the *New Activity* remains activated for, after it is detected. This only applies to activities for which the system cannot detect deactivation. Activities such as *Using_Computer_Dining_Area* or *Sitting_Living_Room* do not require this tag as the system is able to detect the deactivation of these activities via their associated sensors or contextual activities.

Location – the name of the location where the *New Activity* will take place.

Contexts – contains a list of contextual activities that have to be fulfilled before the *New Activity* can be considered as detected or considered as one of the candidates for the detected activity. Activities such as *Sitting_Living_Room* do not required any contextual activities associated with them as they can be directly detected from the sensory networks.

Context – the contextual activity relevant for the detection of the New Activity.

Interval – is the time window which a context activity state remains valid/relevant for the detection of the new activity.

Status – defined the required context activity's state.

Sensors – contains a list of the sensors conditions to be satisfied before the New Activity can be considered as detected.

Threshold – minimum accumulated sensor weights needed for the activation of this new activity.

Sensor – the sensor relevant for the detection of the New Activity.

Status – define the required sensor's state.

Weight – define how important this particular sensor state is for the detection of the *New Activity*.

NotLatching – (true) the sensor weight will only be added to the accumulated weight while it remains on, (false) the sensor weight is added once it's on regardless of its state after.

Figure 3 shows an example of the rules that define user activity based solely on sensory data. The *Sitting_Living_Room* activity is associated with the sensors attached to the sofa in the living room. In this example, the Sensors' *Threshold* tag is set to 0.2, and each sensor has a weight of 0.2 when they get turned on (i.e. when the user sits on it). If the sensor turns on, this user activity *Sitting_Living_Room* is detected. Note that *NotLatching* tag is set to true since we want to deactivate this activity as soon as the user is no longer sitting on the sofa. The *Duration* tag is set to nil as it is not needed for this activity, since the deactivation of the associated sensors can be detected directly to deactivate the activity.

```
<Activity Name="Sitting_Living_Room">
  <Duration>Nil</Duration>
    <Location>Living_Room</Location>
    <Contexts></Contexts>
    <Sensors Threshold="0.2">
      <Sensor Status="on" NotLatching="true" Weight="20"> Sofa seatplace 0</Sensor>
      <Sensor Status="on" NotLatching="true" Weight="20"> Sofa seatplace 1</Sensor>
      <Sensor Status="on" NotLatching="true" Weight="20"> Sofa seatplace 2</Sensor>
      <Sensor Status="on" NotLatching="true" Weight="20"> Sofa seatplace 3</Sensor>
      <Sensor Status="on" NotLatching="true" Weight="20"> Sofa seatplace 4</Sensor>
    </Sensors>
</Activity>
```

Figure 3 Example of Sitting_Living_Room rule file.

Figure 4 shows an example rule set that define a user's activity based on contextual information. The *Using_Computer_Dining_Area* activity depends only on *Sitting_Dining_Area* and *Computer_On* activities to be activate. Therefore the Sensors tag does not contain any conditions and the *Threshold* tag is set to 0.0. The *Duration* tag is not needed for this activity and is set to Nil.

```
<Activity Name="Using_Computer_Dining_Area">
  <Duration>Nil</Duration>
  <Location="Dining_Area">
  <Contexts>
    <Context Interval="0" Status="activated"> Sitting_Dining_Area </Context>
    <Context Interval="0" Status="activated"> Computer_ON </Context>
  </Contexts>
  <Sensors Threshold="0.0"></Sensors>
</Activity>
```

Figure 4 Example of Using_Computer_Dining_Area activity rule file.

Through the rules file, the Activity Recognition System can easily be updated for different environments, and new user activities can be added as the sensor networks are improved. Table 1 lists some of the activities the system is currently able to detect or predict. Details of the Activity Recognition System design, implementation and evaluation can be found in Duque et. al. (2012, submitted).

Table 1: Example of user activities that can be detected by the Activity Recognition System

Location	**Low Level Activity -** user activities directly detectable from sensory information.	**High Level Activity -** user activities that can be derived from fusion of current sensory information and contextual information from both the user's previous activities or initiated by the robot.
Dining Area	-turning computer on/off -sitting on the chair	-using computer -reading a book/Newspaper -writing letter/birthday card etc. -having meal -cleaning table -playing game
Kitchen	-using microwave -using toaster -using kettle -using dishwasher -using kitchen's taps -opening the fridge -opening the cattery drawer	-preparing food -preparing cold drink -boiling water/making hot drink -cleaning dishes -drinking water or cleaning
Living Room	-turning TV on/off -sitting on the sofa	-watching TV -playing game
Hall	-doorbell ringing	-newspaper delivery

The implementation of the Activity Recognition System in the robot house currently allows the ACCOMPANY robot to take the initiative and therefore is hoped to provide a better interaction experience for the users. Future user studies need to confirm the acceptance of this new feature. A mechanism that allows users to teach the robot to take advantage of the low level activity rules is currently being implemented as part of the work done in WP3.

4 Initial Implementation of Context-aware Planner

The first proof-of-concept prototype context-aware planner presented here aims to improve the robot's social behaviour by adapting its distances and orientation in terms of interpersonal space, based on the user's context (i.e. user's location and activity). Research (Walters et. al., 2005, 2006; Koay et al., 2007; Takayama and Pantofaru, 2009;) has shown that proxemics (how interactants negotiate interpersonal space within an interaction) plays an important role in both human-human interactions as well as those between human and robots. We therefore selected proxemics as the first behaviour to focus on in our implementation of the first proof-of-concept prototype context-aware planner.

The users' proxemic preferences vary depending on situation and interaction context (Walters et. al., 2005, 2006, 2009; Koay et al., 2007). For example, a robot approaching a person who is seated in the living room with the aim of interacting with the user should behave differently depending on what activity the person is engaged in and what the purpose of the interaction is. For example, if a user is watching TV in the living room, they may not want the robot to approach and stop at their preferred (relative) approach position and orientation if it blocks their view of the TV. However, this approach may be appropriate if the robot is presenting information that needs to be acted upon immediately, such as a visitor at the door.

The prototype context-aware planner is implemented using a state-machine approach. It modifies the robot's proxemic behaviour by providing appropriate robot target coordinates (i.e. the robot's pose), which have incorporated findings from human-robot-proxemics research [Walters et. al., 2006; Koay et al., 2007] and the user's context (i.e. the user's pose and activities) to approach the user in a socially acceptable manner for interaction. The appropriate target coordinates are retrieved directly from a proxemics data set stored in the specific user preferences database. In the future, we plan to allow for the robot system adapting these coordinates and parameters to match the user's preferences and requirements, and thus be able to change the motion profile of its navigation system. The functionality of the context-aware planner will also be extended through integrating results from T2.3 to improve the robot's social behaviour with empathetic expressions.

Figure 5 illustrates how the robot task uses the context-aware planner to improve its proxemics behaviour for offering a drink to the user. The context-aware planner is currently being implemented using SMACH (State MACHine) [SMACH], a ROS-independent Python library for building hierarchical state machines. Details of this implementation will be presented in an updated version of this deliverable D2.4b.

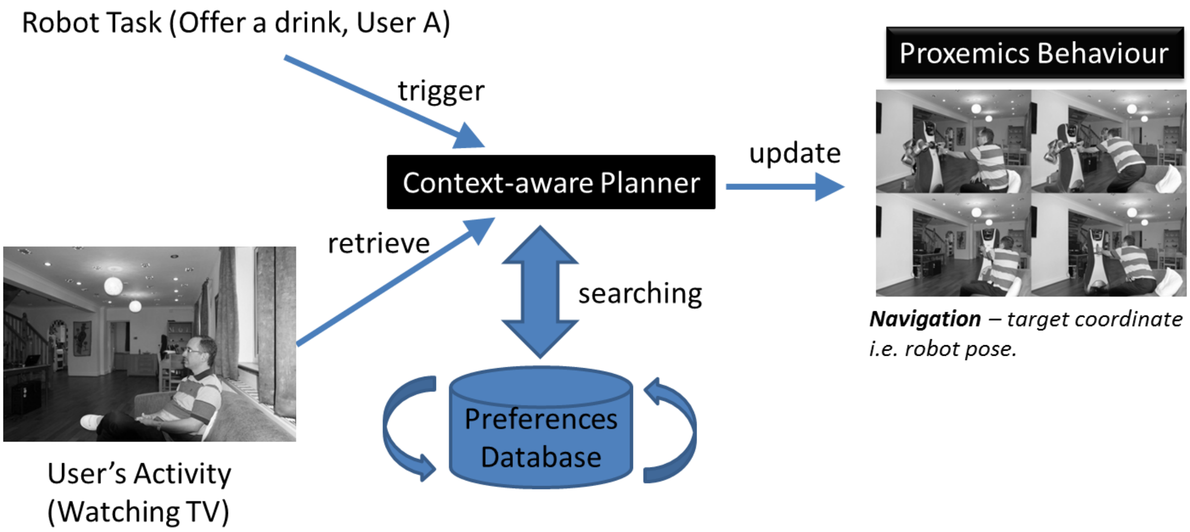

Figure 5 Flow diagram of the context-aware planner

The robot proxemics data set have been obtained from the re-analysis of the data from a Care-O-bot® 3 study (conducted in June-July 2011 as part of the LIREC Project) which focussed on creating a baseline understanding of Human-Robot Proxemics (HRP) for approach directions and distances for a Care-O-bot® 3. Figure 6 shows some of the HRP and handing over configurations tested.

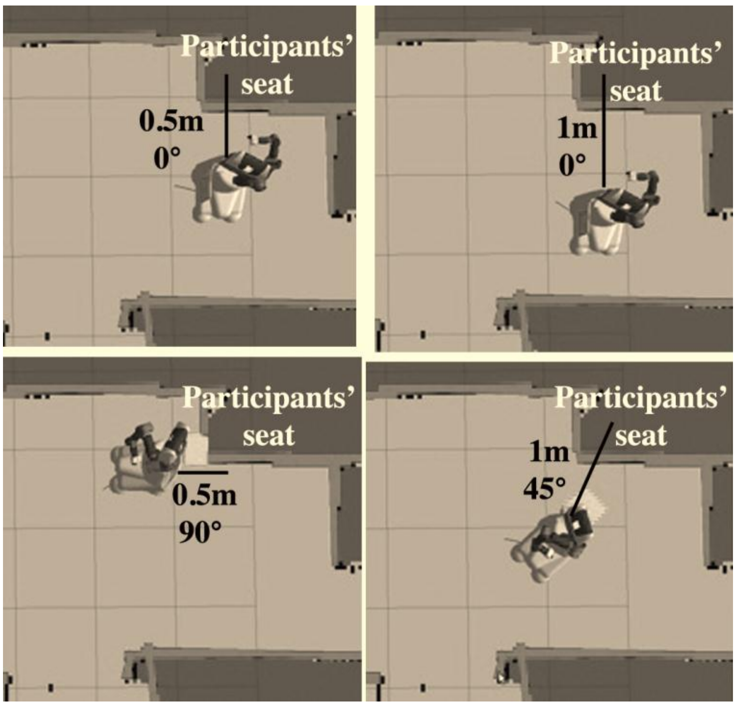

Figure 6 Care-O-bot® 3 stops at the four pre-defined HRP approach positions used in the trial. Counter-clockwise from top is the Front Close, Front Far, Side Far and Side Close HRP approach positions.

5 Conclusion

This deliverable has reported the phase 1 work done for T2.4. This work draws on both the robot task requirements listed in D1.2 and the scenario reported in D1.3. Requirements for the context-aware planner have been developed and used to guide the design and implementation of the context-aware planner. This includes the development and testing of an Activity Recognition System for detecting user Activities of Daily Living. The Activity Recognition System is vital for the design of context-aware planner as currently it is acting as the main source of information regarding the user's physical context for the ACCOMPANY robot.

The context-aware planner is currently being implemented and integrated into the rest of the ACCOMPANY system. Details of the implementation will be available in the updated version of deliverable T2.4b at the end of phase 2. Additional sensors are currently being integrated as part of the WP4 research on activity monitoring.

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