Towards an intelligent and supportive environment for people with physical or cognitive restrictions

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ABSTRACT

AmbienNet environment has been developed with the aim of demonstrating the feasibility of accessible intelligent environments designed to support people with disabilities and older persons living independently. Its main purpose is to examine in depth the advantages and disadvantages of pervasive supporting systems based on the paradigm of Ambient Intelligence for people with sensory, physical or cognitive limitations. Hence diverse supporting technologies and applications have been designed in order to test their accessibility, ease of use and validity. This paper presents the architecture of AmbienNet intelligent environment and an intelligent application to support indoors navigation for smart wheelchairs designed for validation purposes.

Keywords

Ambient Intelligence, Ambient Supported Living, Smart Homes.

1. INTRODUCTION

The advancements in diverse technological areas, namely computing, networking and sensing, allowed the creation of places where intelligent applications –running over embedded computers, collecting environmental data by means of sensors, and communicating between them by means of wired and wireless networks– are able to provide smart services in order to support people in their everyday activity. This picture, frequently called Ambient Assisted Living, acquires it maximum interest when the users are people with sensorial, physical or cognitive restrictions due to disability or aging. Obviously these users can highly benefit from intelligent environments if –and only if– they satisfy their accessibility requirements. Since accessibility is deeply rooted in the supporting technology Ambient Assisted Living is only possible if the whole design is deep-seated in sound accessibility criteria.

One of the key issues to achieve accessibility is the adequate design of the user interface. In the intelligent environments a large number of supporting activities are carried out by the system without having the awareness of the user. For instance, the system can tune some environmental parameters such as lights, temperature, etc., to the user's likes. But the design of accessible and adaptive interfaces is crucial when the interaction between the environment and the user is necessary. That happens when the user issues explicit commands or poses questions, or when the system provides information to the user or asks for required data. Our previous experiences shown that the design of accessible interfaces can be made difficult or even impeded by the barriers embedded in the supporting technology. For this reason, one of the aims of AmbienNet was to build an adequate infrastructure that allows the design of a supportive accessible environment.

This infrastructure is arranged in four levels: Hardware and Networks, Middleware, Intelligent Services Context and User Support Applications (figure 1). A number of heterogeneous wired and wireless networks and sensor networks are interconnected by means of the Middleware. This level also allows the registering and discovering of mobile processors. The Intelligent Context Services level serves to the applications the structured information received form the sensors, acting as a distributed intelligent repository. In this way the applications in the User Support Applications level can share advanced information (such as user or context models) without having to repeat the processing of raw data coming from sensors. AmbienNet's structure will be described in section 3.

For validation we have designed a navigation support system for smart wheelchairs. This application allows sharing the driving task with the control unit of the wheelchair. The information used for navigation comes from the wheelchair's own range sensors, the environment location sensors, and from its user interface. We also plan to develop a guiding application for people with mild cognitive restrictions using a PDA.

The remainder of the paper is structured as follows. First, a review of existing indoors localization technologies and middleware infrastructures is presented. After that, we discuss the specific developments made within AmbienNet project and the development of an application for validation. Finally, we examine the contributions and future works of the project.
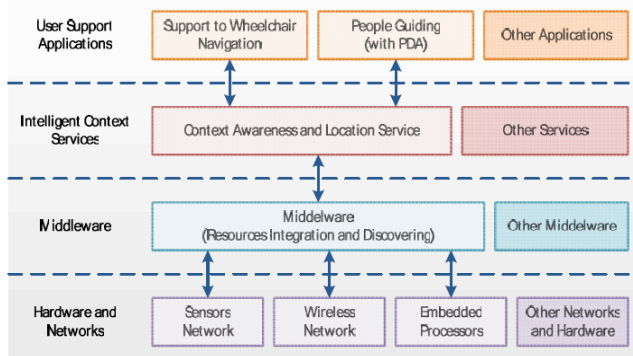

Fig. 1: AmbienNet infrastructure model.

2. STATE OF THE ART OF SPPORTING TECHNOLOGY

The construction of intelligent environments requires studying, modeling, deploying and testing of diverse technologies that have great interaction between them. Some of these technologies are very advanced today (i.e. the hardware for wireless communications), whereas others are still in development (i.e. middleware, discovery systems, etc.). Anyway, the largest difficulty is to make heterogeneous systems to interact in an intelligent way to exchange information and services that give proactive support to the user. The setup of any intelligent, even restricted, environment requires the integration of diverse systems, operating in different abstraction levels, to allow the design and independent implementation of each system and transparent operation to the rest of systems.

The following subsections describe the estate of the art of two technological areas that are vital for the development of AmbienNet intelligent environment.

2.1 Indoor location systems

Location systems are usually classified attending to their application field (indoors, outdoors) and scope (personal, local, global). The indoors location of a mobile target can be done sending and receiving any type of radiation, by means of vision processing or through other sensors. For indoors personal and local location there exist a variety of systems using diverse technologies. Some of them measure the power of an incoming radiofrequency signal. The most popular are based in the IEEE 802.11 standard, such as WHEREMOPS [1], RADAR [2], AeroScout [3] and Ekahau [4], that take profit from the existing wireless networks. Other systems use Bluetooth, [5], or RFId [6, 7]. There are many similar systems that provide a precision of meters and have a high rate among needed infrastructure (that is, cost) and precision. On the other hand, MotionStar Magnetic Tracker [8] is based on the measurement of a magnetic field, with a precision of millimeters and high refresh rate, but at an extremely high price and with very short scope (about 3 meters). Ubisense system [9] obtains a position by measuring the angles of arrival and the time differences of arrival of UWB pulses,

achieving centimeters accuracy and high refresh rates, but also at a high cost.

The best rate scope/precision/cost is obtained by systems using a combination of ultrasounds and radiofrequency. They take profit from the different propagation velocities of both radiations to measure flight times more or less precisely. Active Bat [10], developed by AT&T Laboratories, or Cricket system [11], developed at MIT. The last version of Active Bat [12], allows locating up to 3 mobile targets at a rate of 50 times/sec., with a precision of 3 cm. Both systems have a drawback related to the number of sensors required (one each square meter). For this reason the complexity of the installation and the cost are high and the scalability low. A similar system, DOLPHIN [13], obtains a precision of 15 cm (2D) in 5m^2 environments.

Our research team has long experience in the development of indoors location by means of the combination of ultrasounds and Bluetooth: the BLUPS system (BLuetooth and Ultrasound Positioning System) [14]. This system is able to locate a target in a 100 m^2 space, with a precision of 5 cm. It uses only 6 elements for emission and reception of the signals. The current version has some limitations related to the refresh rate, making it difficult to locate moving targets.

2.2 Middleware for interoperability and seamless operation

Recent years have shown a feedback phenomenon between network technologies on the one hand, and distributed application necessities on the other hand, hence demanding incrementally complex system support for the seamless integration of heterogeneous devices and services. When it comes to ubiquitous computing system support is provided by middleware services, which includes protocols for the register and discovery of services as its most characteristic feature. UPnP [15] and Jini [16] are relevant examples of these protocols.

It is important to note that Ambient Intelligence imposes a redefinition of the concept of scope, which should be associated to real world boundaries or user roles instead to network scope (LAN/WAN). Hence ubiquitous systems should provide an abstraction for "scope" beyond administrative network domains, providing discovery mechanisms capable to adapt the discovery scope to environments which are (dynamically) defined from high-level context information or from the user role.

In general, discovery protocols for ubiquitous system are designed to operate in the scope of local area networks and scalability is not a design topic. Concerning wide area networks, P2P systems make use of discovery and location mechanisms to support high availability and grid services (DHTs, Pastry, Tapestry). In order to provide the above referred scope abstraction, different approaches can be followed.

An appealing approach is to take Jini/Java as the base platform to integrate heterogeneous services [17]), and extend the lookup service to provide scalable discovery (JGrid [18]). Jini service attributes could be used to support high-level context information. Anyway, an extensive study of both local-scope and global-scope protocols is required. Finally, security and privacy topics are challenging design topics, as well as fault tolerance.

3. AMBIENNET ARCHITECTURE

AmbienNet project aims to demonstrate the feasibility of intelligent applications, such as assisted navigation systems, to support users with disabilities. To do so, different heterogeneous technologies acting at different levels (network, hardware and middleware) and interacting with each other have been developed. AmbienNet currently consists of an indoors roof located tracking system for individuals, a network of sensors and a number of smart wheelchairs (which act as autonomous mobile platforms). Resource management depends on a middleware layer that recognizes high level dynamic contexts (network scope independent) and provides continuity and high availability.

AmbienNet implemented functional prototypes of the diverse technologies involved (see figure 1). Firstly a set of low level modules necessary to built up a context aware intelligent environment to support context aware application. These modules are:

• Indoor location system based on sonar and radiofrequency. This module is devoted to locate people and objects indoors, with the possibility of having a number of different rooms (multi-cell).

• Smart wheelchairs acting as a mobile platform, with range sensors and embedded processors for guidance control. In addition, each wheelchair is also equipped with a force-feedback joystick as an adaptive user interface for shared navigation tasks

• Vision based sensor network to collect and efficiently transmit context information, by means of ZigBee wireless network.

• A middleware layer has been implemented in order to ensure seamless communication and interoperability among the previously mentioned modules. This level is provided of structured distributed discovering, dynamically adaptable to high level contexts.

The Intelligent Context Service is built on these elements. In this layer a new Context and Location Service has been developed. This application processes the information collected by sensors and provides abstract information adequately formatted to the intelligent applications. In this way it offers contextual services resulting of data fusion and spatial data interpretation. The information is available to context aware user support applications. This layer allows, for instance, the developing of a context modeling system to identify movement patterns relative to persons and/or objects.

In order to verify the validity of this infrastructure an intelligent context aware application to assist people with indoors navigation has been developed. The wheelchair navigation support system uses the information provided by the service of context awareness and location. In addition we plan to develop an indoor guidance system for people with mild cognitive restrictions using a PDA or handheld computer.

3.1 Localization system

For the proposed applications the indoor localization system developed fulfills the following requirements:

• It is able to precisely locate a device with an adequate refresh rate in order to support indoor guidance and navigation aid tasks.

• It covers a large enough area to providing an absolute location within the entire application scenario

Scalability, easiness of installation and maintaining are not operational requirements, but definitely contribute to the feasibility of the system [19], as well as cost also must be as lower as possible in order to be approachable and have a realistic application.

Part of these requirements was already met by the indoor localization system previously developed by our team, which was taken as starting point for the developed localization system. The system developed for AmbienNet project is based in ultrasounds and ZigBee (which replaces Bluetooth as RF technology). Main advantage of ultrasound technology is that it allows an accurate localization without a high cost, although speed propagation limit refresh rate and must be taken into account for some applications.
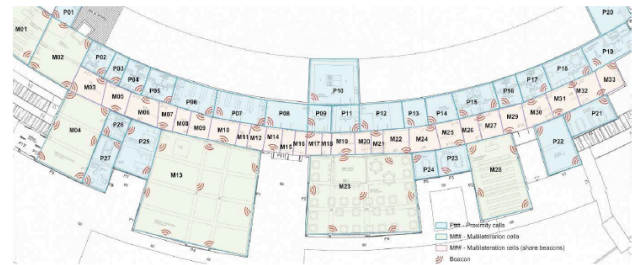

Fig. 2. Beacon deployment in the service floor of the residence. P## are proximity cells, with only one or two beacons, and M## are multilateration cells, with enough beacons to perform multilateration. The areas covered by P-cells and M-cells are 800 and 1200 m² respectively.

ZigBee [20] is a wireless technology designed for wireless sensor networks, so it integrates in a native way the development of distributed networks to maintain a node connection and thus making linkages between other network nodes dynamically. This makes ZigBee ideal for the system proposed. Take into account that in the previous version wireless communication was based in Bluetooth, and network management was done from the application level. Whereas in ZigBee, this is integrated within the standard, i.e., it is made by the API provided by the manufacturer, and application must not care about routing or roaming mechanisms.

This is particularly interesting for the large area coverage requirement of the localization system: localization service must care only about localization task, but communication and especially mobility is not a concern.

The purpose of the localization system is to provide coverage in a large area, usually a floor (or several ones) of a building, as shown in figure 2. The area is divided into cells, according to the coverage of the fixed devices that emit ultrasound, named beacons. The system operates in two granularity modes. In the proximity mode, a rough location —typically the stance related to the cell— of the target is computed. This operating mode requires just one or two beacons in every stance from which we want to provide location information, and for the guiding application, the achieved accuracy is enough. The second one is multilateration mode, where location of the target is computed accurately by measuring the ultrasound times of flight. This mode requires some additional beacons to enable multilateration and deal with nonlight- of-sight (NLOS) errors —typically five, up to eight elements on biggest stances.

The multilateration algorithm, based on the Least Median of Squares, can handle up to near a half of the measurements affected by NLOS errors, achieving centimeter accuracy. A more

detailed description of both localization system and the multilateration algorithm can be found in [21, 22].

The localization system is an important part of the AmbienNet infrastructure, but context awareness also requires for a number of sensors deployed into the application scenario which capture relevant data. ZigBee technology is especially suitable to support communication with all of these sensors, shaping an intelligent environment where localization system and sensors are integrated (figure 3).
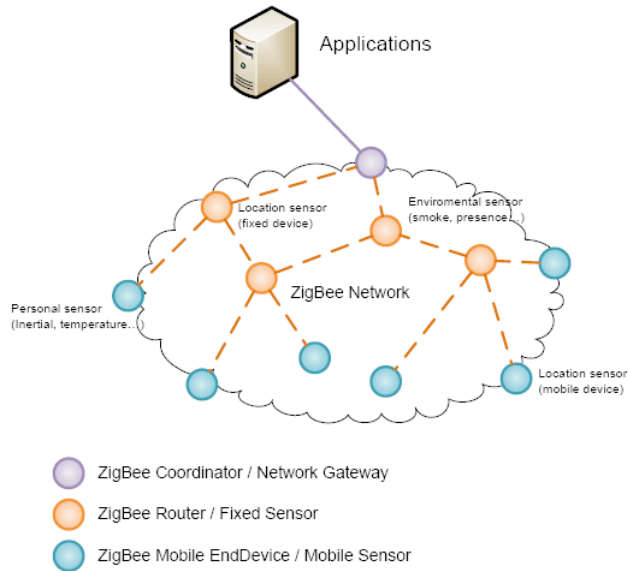

Fig. 3. ZigBee sensor network

Collected information by the sensors along with the localization information is delivered by the middleware to the Intelligent Context Services level, where it is materialized into the context awareness and location services. These services will process the information about location and sensors to extract data of higher level to use it as support for the context applications named before (assistive navigation and guidance). Moreover, it could be proposed other applications to enhance services and allow other services such as pattern recognition or user behaviors, to identify or detect certain situations of risk or alarm.

3.2 Vision-based sensor network

The current availability of inexpensive, low power hardware including CMOS cameras makes it possible to deploy a wireless network with nodes equipped with cameras acting as sensors for a variety of applications. AmbienNet includes a vision-based Wireless Sensor Network (WSN) based on Zigbee wireless technology. This WSN performs detection and tracking of a mobile object taking into account possible obstacles. The speed and position are computed by the micro-controller based camera, a CMUcam3 board with a CMOS camera based on an ARM processor (Philips LPC2106). The CMUCAM3 is an open source programmable embedded color vision platform, whose goal is to provide simple vision capabilities to small embedded systems in the form of an intelligent sensor [23]. The CMUCAM3 (in figure 4) is frequently used in wireless sensor networking applications as a smart sensor (see an example in [24]).

The cameras are used to detect objects that are distinguished from the floor, shadows, etc., using simple and well known image processing algorithms. Note that we are not interested in the research on new image processing, contrarily we prefer to use simple solutions that work with off-the-shelves, low-cost hardware.
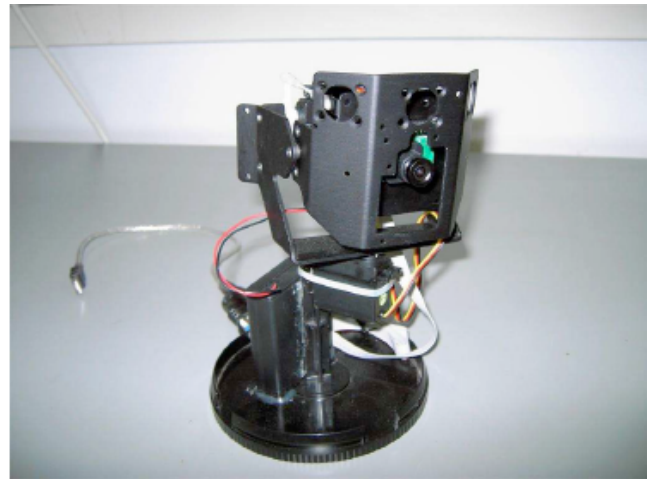

Fig. 4: The CMUCAM3 video camera

Since the camera's position is known in advance, the microcontroller of the CMUcam3 board can compute a grid map of the room with cells corresponding to small areas of 10-20cm. Even if our prototype admits the change of the resolution, the selected values are enough for our purposes, and they keep communication traffic low. These areas may have 2 possible values: "free" and "occupied". The "occupied" cells correspond to obstacles as detected by the image processing algorithms, as well as to the architectural limits defined in a map of the building stored in the wheelchair controller. On the other hand, the "free" cells represent the space where mobile objects and people can move. Note that the use of only two possible values allows us to use only 1 bit per cell.

In order to ensure that the mobile objects are always within the field of view of at least one camera, we worked out how many cameras are needed and where these cameras should be positioned. These questions are related to what is known as the coverage problem in sensor networks [25].

Some of the information provided by this subsystem is redundant with the localization system. This is useful to ensure fault tolerance.

This system will allow us to study in depth further issues, such as the density of information that the context must provide to enable different aid navigation levels, getting probabilistic guarantees (soft real-time) for external sensor information transmission, context information integration in the shared control and the possibility of apply them in bio-inspired navigation algorithms.

3.3 Middleware

It has been defined an environment model independent of the administrative scope of the network, dynamic, and configurable assuming the user role and the context information. Above this environment model it must operate a high level discovery protocol. The protocol is flexible enough, scalable and capable of integrate protocols, devices and heterogeneous services. This needs an exhaustive study of existing protocols for different scopes and the specialization of the high level protocol in terms of a common language. The Jini-JAVA platform was selected for

this purpose. Security and privacy issues will be studied later, because it is not pretended to integrate them into the prototype.

The context information regarded by different sensors can be used by the applications that provide services dependent of context. However, it is not convenient that the applications manipulate data from sensors directly. The context service level takes charge of processing and interpreting that information, in such way that applications can have information of position and localization of higher level. For this, on one hand, it was necessary to design the format in which the context information will be specified, and on the other hand, the processing mode of the large amount of special data provided by sensors. Techniques used in sensor fusion were used for interpreting and classifying this type of information.

4. CONTEXT SUPPORTED NAVIGATION SYSTEM FOR SMART WHEELCHAIRS

In this section an intelligent application to support indoors navigation of smart wheelchairs is described. This application uses information coming from the diverse sets of sensors through the Context Awareness and Location Service. The control of the wheelchair is shared by the user interface and the intelligent application.

4.1 The Smart wheelchair acting as mobile platform

The great majority of commercial electric wheelchairs do not include sensors that could be used in navigation assistance. Furthermore, their controller does not allow the programming of high level tasks, such as the above mentioned navigation assistance. For this reason, the necessity arises to include a set of sensors and embedded controllers linked together through a real-time communications network to convert it into an smart wheelchair.

Due to the design objectives, low cost components are to be used at the expense of loosing precision, so that these drawbacks have to be overcomedby software intelligence. That is, there is no sense in using more precise and expensive devices because, due to the characteristics of the proposed application (mobile platform in unstructured environments) they are intrinsically imprecise and with a high level of uncertainty.

4.2 Smart versus open wheelchairs for context guidance

Several authors have pointed out that most current prototype smart wheelchairs are too complex to be commercially used [29]. The main advantage of the context guidance approach is the simplification of the design of the wheelchair itself.

If most of these sensors are situated in the environment (as part of an Ambient Intelligent system), it is enough to have an open wheelchair controller that could be capable of interoperate with its environment and to receive information relating navigation. Information from the sensors could be used together with the information from the user interface, in what is called "shared control" [30, 31].

To safely navigate through crowded places, wheelchair's incoming information flow needs to be at least 10 times faster than the provided by the current implementation of our intelligent environment can provide. In other words, the localization system's and sensor network's response time do not fulfill the wheelchair's

guidance system time requirements. For this reason the wheelchair is equipped with ranging sensors and well-known robotics algorithms to autonomously navigate (without environment aid) during two consecutive information updates. The wheelchair is provided each information update by the intelligent environment, with the actual and desired next position, along with a local map of its surroundings.

4.3 Environment support for navigation

In most systems described in the literature [26, 27, 28], the sensors used for navigation are incorporated into the wheelchair. Given the recent advances in wireless networks, many of the sensors used to assist navigation (i.e. detection of certain types of obstacles) may be part of the environment (ultrasonic sensors in doors or corridors, cameras on the ceiling, etc.). In other words, the objective is to take advantage of the environment intelligence to assist the wheelchair navigation. This procedure presents several advantages. First, a global view of the whole desired trajectory is obtained. It is possible that some obstacles that cannot be detected locally by the wheelchair, may be detected by the smart environment, including information related to the environment itself like closed doors, broken elevators, dangerous zones, facilities timetable, etc. This type of information is permanently updated to reflect any changes in the environment, as well as the appearance of new obstacles. Another advantage relates to usual problems with mobile sensors, like interferences, shaded areas, non-line-of-sight, etc. Since these sensors are fixed to the roof, they can be positioned and oriented in such a way that these problems are minimized.

The number and type of sensors depends on the desired level of navigability, and also on the environment. Previous works on sensor fusion for navigation [32, 33, 34] have been adapted to this particular problem. Several questions arise from the use of external sensors in the wheelchair navigation, that have to do with the transmission through wireless links (connecting the external sensors with the wheelchair) of information with real-time constraints.

These constraints cannot be considered hard since given the number and variety of sensors there will be a certain level of redundancy. Furthermore, the lost or delay of a certain number of packets can be compensated by the subsequent reception of new values from the sensors. However, in any case it has been necessary to obtain probabilistic guarantees (soft real-time). The effect of interferences due to the use of different wireless technologies have also to be studied: Bluetooth, Wi-Fi, Zigbee, etc. This line of work links with previous results obtained by our research group [17, 35, 36, 37].

4.4 Navigation scheme

During the autonomous period (between two successive updates from the environment) the wheelchair will use the well-known *wavefront path planning algorithm* [38] to set checkpoints (small triangles depicted in the figure 7 between its initial position and the desired one. Due to intrinsically inhered odometric errors, the real position estimation is needed be maintained during the whole autonomous period until the next position update. For that, Adaptive Monte Carlo Localization (AMCL) [39] algorithm was selected due to its great performance. ACML estimates the real position comparing the map given and the one obtained trough sensor readings. For obstacle avoidance, the enhanced Vector Field Histogram (VFH+) [40] algorithm is used.
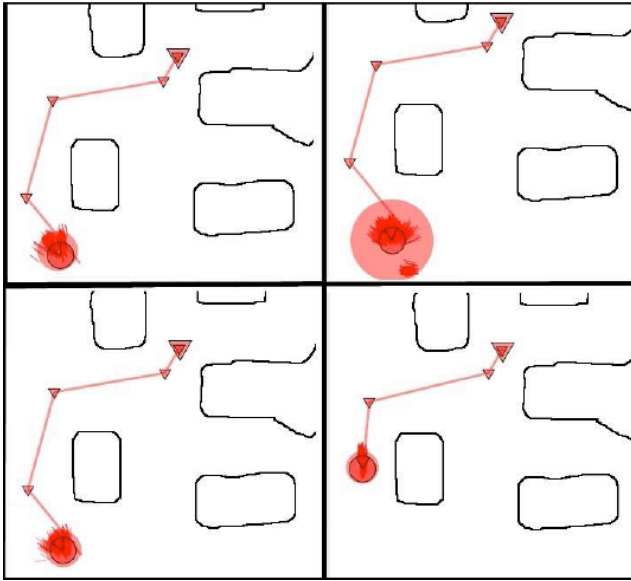
Fig. 7. Route example of shared control obtained from a simulation environment). At the initial state, actual and desired positions, along with a local map, are provided to the wheelchair. It is able to reach the desired goal using Wavefront, ACML and VFH+ algorithms. In the left lower part of the figure, a normal execution is shown.

A typical execution flow could be as follows (shown in figure 7). The user selects the destination goal trough an adaptive user interface and initiates the route by driving the joystick. In this initial state, the actual position (small dark circle) and estimated one (big light circle) are almost the same. In addition, the wheelchair has already planned its path to the goal (big triangle) through a set of 4 checkpoints (small triangles) using the wavefront algorithm. Then, if the user selected path is not close to the planned one (like in the picture, trying to drive backwards), the wheelchair corrects the resulting path and informs the user about that through the Force Feedback mechanism available in the wheelchair's joystick. Due to wheelchair movements and the lost of reference of the map, the actual position estimation uncertainty increase as shown in the figure (big light circle in the upper right part). When wheelchair is again in the correct route, and ACML detects enough environment features to be able to match this new acquired map with the previous stored one, the position estimation uncertainty decrees. If the user path is so close to an obstacle, the VFH+ will take control of the guidance until the risk of collision disappears. In the left lower part of the figure, a normal execution is shown. In the right part, an update has been occurred, and all estimated values are updated according to ones received by the environment. In the right part, an update has been occurred, and all estimated values are updated according to ones received.

In this way, the wheelchair position and approximate speed, as well as obstacles, can be obtained from the ceiling cameras in order to perform a "local" navigation aid (avoiding obstacles and allowing reaching specific goals). Furthermore, from the information obtained from the cameras a "global" navigation aid could also be implemented, for instance: crowded corridors, closed doors, dangerous zones, etc. In the future this global navigation may be enhanced by using information from other environmental sensors.

In order to distinguish the wheelchair from other objects, we simply use an array of color LEDs. This simple solution allows us to detect the wheelchair's orientation and it make easier to extend our system to the case of several wheelchairs in the same area by using different combinations for the LEDS (this approach is similar to that described in [40]).

4.5 Shared control

Once the wheelchair has received the grid map from the cameras (see also previous section), it is able to identify the obstacles and free paths. In order to implement a semiautomatic navigation system, we have to integrate automatic navigation aids with user's intentions. We perform this integration making obstacles become repulsive (virtual) potentials while targets (doors, desks) become attractive potentials or a mix of attractive/repulsive potentials depending on the situation. For instance, when crossing a door it is useful to make the doorframe become repulsive (figure 5).
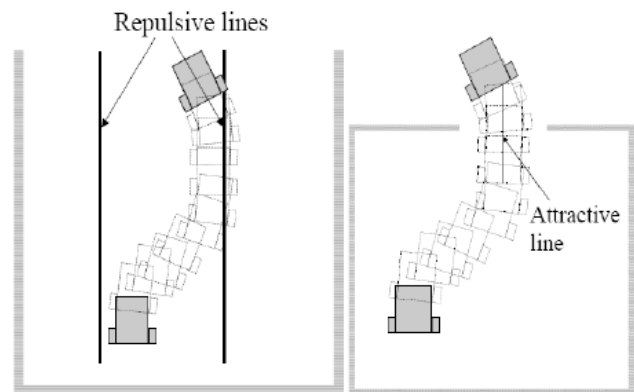

Figure 5: Showing the effect of repulsive and attractive virtual potentials.

Virtual Potential Field (VPF) control techniques, give us a simple and intuitive way to implement the shared control needed for semiautomatic navigation. It is based on the idea that any obstacle generates a virtual potential field that repels the wheelchair (RVPF-repulsive VPF). To reach the desired goal (e.g. a door or a desk) an AVPF (attractive VPF) is used. VPFs generate virtual forces affecting to the wheelchair and guiding its motion. User intentions, taken from the steering device (e.g. joystick), are treated as an additional force by the navigation system for a semiautomatic navigation. "User virtual force" is added to virtual forces generated by VPFs associated to obstacles (occupied cells) and desired goals. The resulting force contains both user and automatic navigation intentions. Note that we focus on a shared control approach because fully automatic controllers are usually rejected by most users (except for people with very severe mobility restrictions) and furthermore they involve in most cases a very complex and/or expensive system.

The wheelchair controller performs the computation of these VPFs using the information sent by the cameras. For every occupied cell (obstacle) a potential field is computed which is inversely proportional to the distance from the wheelchair. Large objects that occupy several cells are modeled as the sum of these single-cells potential fields.

The information from the cameras can be complemented with other sensors (ultrasounds, positioning systems, etc.). The number and type of sensors used depend on the desired level of accuracy.

Information from these heterogeneous multi-sensors should be then combined and integrated.

There are several sensor fusion approaches available well suited for target tracking applications, like for example, Kalman-filter based methods. In our first prototype version, we use a simple approach consisting in the accumulation, for every cell in the grid map, of the information from the external sensors (we follow a similar approach to [42]), with the virtual potential field values depending on these accumulated values. For instance, if the accumulated value exceeds a given threshold then the cells are marked as "occupied" (obstacle) or "free".

5. CONTRIBUTIONS AND FUTURE WORK

AmbienNet project provided advances in middleware design concepts for ubiquitous systems which are supported by heterogeneous "ad hoc" networks. Moreover, it introduced a new context services level that allows the development of advanced user-support applications. This new level perspective is achieved by a semantic interpretation of location and context data obtained through the diverse sets of sensors. Its validity has been verified with the design of an intelligent application for navigation support of smart wheelchairs.

Ambient Intelligent sensor integration for wheelchair navigation where sensors are external to the wheelchair is in itself an interesting and practical contribution. This environment allowed us to discuss how to adapt parameters of the shared control user-automatic system and to provide generic models to determine the type and number of sensors needed for a certain navigation level.

In the near future, a study of the real time transmissions for sensor networks (a recent and promising field [43]) will be possible through the developed infrastructure. AmbienNet will allow the creation of models to determine probabilistic guarantees to soft real time transmission of external sensor information. In addition, it is especially interesting the study of the effect of interferences due to the simultaneous use of a variety of wireless technologies. Previous results are centered in Bluetooth transmissions that would be widened to 802.15.4 standard which probably would be used in the next version of the sensor network.

6. ACKNOWLEDGMENTS

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