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AmbienNet
Ambient Intelligence Supporting Navigation for People with Disabilities

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Abstract

AmbienNet project aims to demonstrate the viability of navigation systems to assist users with and without disabilities supported by intelligent environments. In particular, people with sensorial, physical or cognitive disabilities can be highly benefited by the intelligent environments, whenever these satisfy their accessibility requirements. For that, diverse heterogeneous technologies at different levels (network, hardware and middleware) have been developed by AmbienNet, making them interact to each other. Specifically, AmbienNet has developed a multi-cell indoors people localization system, a network of sensors and intelligent wheelchairs (acting like autonomous mobile platforms). The resources management depends on a middleware layer that recognizes high-level dynamic contexts (network scope independent) and provide continuity and high availability. On these elements, a new "context and location services level" is being developed in order to process the data provided by the sensors and the localization system. This level will allow providing abstract information to the services offered by the intelligent environments. As a demonstration, a navigation application to support intelligent wheelchairs for users with disabilities is being developed. In addition we plan to develop a handheld guide application for users without disabilities.

Keywords: Ambient Intelligence; Ubiquitous computing; Assistive Technology.

1 Project Goals

The AmbienNet project aims to demonstrate the feasibility of context aware intelligent applications, such as assisted navigation systems, to support users with disabilities [1]. To do so, different heterogeneous technologies acting at different levels (network, hardware and middleware) and interacting with each other have been developed.

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AmbienNet project has implemented functional prototypes of the diverse technologies involved, namely a set of low-level modules necessary to build up a context aware intelligent environment to support context aware applications (see figure 1). These modules are:

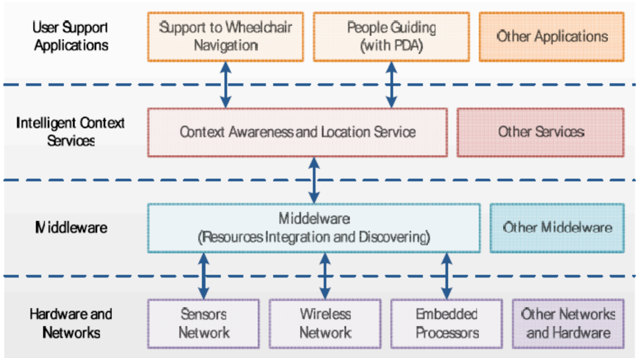

Figure 1. AmbienNet infrastructure model.

- Indoor location system based on sonar and radiofrequency technologies. This module is devoted to locate people and objects indoors, with the possibility of having a number of different rooms (that is, multi-cell).
- Sensors networks to collect and efficiently transmit context information, by means of ZigBee wireless network.
- A middleware layer to ensure seamless communication and interoperability among the previously mentioned modules. This level is includes distributed discovering, dynamically adaptable to high level contexts.
- 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.

Table 1: Project Schedule

WP	First year (2006-2007)	Second year (2007-08)	Third year (2008-09)
1. State of the art in AmI related technologies			
2. Theoretical models to support the development			
3. AmI environment support prototypes			
4. Context service design			
5 Prototypes of navigation support applications			
6. Evaluation, exploitation diffusion			
7. Management and coordination of the project			

A new Context and Location Service is being developed that processes the information collected by sensors and provides abstract information adequately formatted to the intelligent applications. In this way it will offer contextual services resulting of data fusion and spatial data interpretation. This information will be available to context aware user support applications [2, 3]. This level will allow, for instance, the developing of a context modelling 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 is being developed. This 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.

2 Level of Success

At the time of writing this report, the project has consumed 27 months out of its three-year schedule. This section summarizes the main scientific achievements reached so far.

2.1 Ambient intelligence supporting technology

Intelligent environments are able to process contextual information collected by sensors deployed in the ambient [4]. In this line, the current prototype of AmbienNet integrates an indoor location system and a network of video-sensors. They provide context information to any consumer application through the middleware. In addition this information can be directly sent to applications with real-time constrains. Next subsections describe this specific sensors infrastructure connected through the general-purpose middleware layer.

2.1.1 Indoor location system

The system developed for the AmbienNet project used as starting point an indoor localization system previously developed by the University of Zaragoza. The new system is based in ultrasounds —as the previous one— and ZigBee —which replaces Bluetooth as RF technology—. The main advantage of ultrasound technology is that it allows an accurate localization without a high cost (research done with a wired version of the localization system demonstrates suitability of ultrasounds when high spatial accuracy is needed [5, 6], although speed propagation limits refresh rate an must be taken into account for some applications).

ZigBee [7] is a wireless technology designed for sensor networks; therefore 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. In the previous version wireless communication was based in Bluetooth and network management was done from the application level, whereas in the ZigBee-based current implementation, this is integrated within the standard (i.e. it is made by the API provided by the manufacturer) and hence the application must not care about routing or roaming mechanisms. This is particularly interesting for the large area coverage requirement of the localization system, because 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. 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, typically five [8], to enable multilateration and deal with nonlight-of-sight (NLOS) errors, reaching 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 centimetres accuracy. A more detailed description of both localization system and the multilateration algorithm can be found in [9, 10].
The localization system is an important part of the AmbienNet infrastructure, but context awareness also requires 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 other elements —the research team as developed also a fall detector [11] and a time orientation device [12] which communicates using the same network— can be integrated (see figure 2).

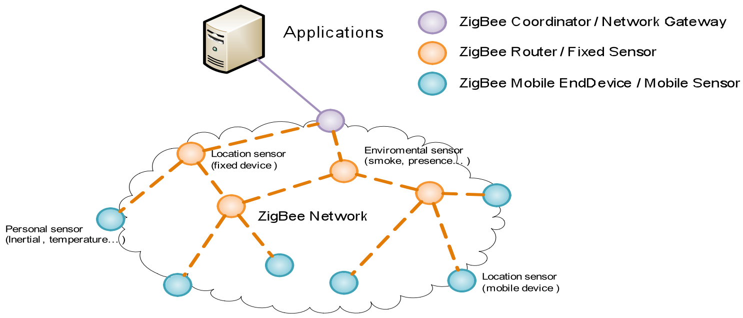

Figure 2. ZigBee sensor network

The indoor localization system developed fulfils the following requirements: it is able to precisely locate a device within a mean error of few centimetres and covering a large enough area to providing an absolute location within the entire application scenario. The refresh rate of the location is highly dependant on the setup: if the location is only required in one room and one mobile device, several times per second can be reached; nevertheless with large areas or high amount of mobile devices, refresh rate can go various hundreds of milliseconds. The biggest drawback is the location data latency. Since we are using a ZigBee mesh network as unique medium to transport data, delays inherent to the mesh network are unavoidable. The main implication is that the location information has few seconds of validity; which hinders indoor guidance and navigation. Scalability, easiness of installation and maintaining are not operational requirements, but definitely contribute to the feasibility of the system [8], as well as cost also must be as lower as possible in order to be approachable and have a realistic application.

2.1.2 Sensors Network

The AmI system includes a Wireless Sensor Network (WSN) that is the base to support communications among sensors that provide context guidance to the wheelchair. Zigbee is the wireless technology chosen. An indoor navigation aid system based on Zigbee benefits from advantages such as low power consumption (mainly important for the mobile devices-wheelchair, hand-held devices, etc.), large number of devices, low installation cost, easiness to move and reconfigure public buildings with relatively frequent repartitioning of space (commercial buildings, hospitals, residences), etc.
AmbienNet project uses sensors that are external to the wheelchair, that is, they are part of the environment. These sensors perform detection and tracking of a mobile object (the wheelchair),

taking into account possible obstacles. Wheelchair position detection can be obtained from many different positioning systems. In this project, the advanced positioning system will be used to locate the wheelchair. In addition, this information is complemented through the analysis of video images from cameras situated on the ceiling or on shelves near the ceiling. In this way, wheelchair's position and approximate speed, as well as obstacles, can be obtained from the ceiling cameras in order to perform a "local" navigation (avoiding obstacles and allowing reaching specific goals). Furthermore, from the information obtained from the cameras a "global" navigation aid can also be implemented, for instance proposing alternative trajectories in case of crowded corridors, closed doors, dangerous zones, etc. However, this global navigation would require the use of additional information from other environmental sensors such as for example thermal sensors. These kinds of sensors are adequate to detect human presence in rooms or corridors. They can also help video images to distinguish human obstacles from other inert obstacles. We have included in our prototype a thermal array TPA81 device (a technical report about it is being written).

We use a simple array of colour LEDs to locate the wheelchair (and to distinguish it from other objects) until the localization sub-system is available. For this purpose, we have developed a new library with algorithms targeted to our application [13]. In order to detect obstacles, we have worked on several variations of the Polly algorithm [14]. This algorithm looks for free space in front of the wheelchair and is very suitable to this application since it requires few resources. However, a new version is needed because the original algorithm uses an on-board camera instead of external cameras.

Other interesting issues are addressed in [15] For instance, the question of how many cameras are needed and where these cameras should be positioned, also known as the "coverage problem". As a result, the ceiling cameras are able to compute a grid map of the room with cells (corresponding to small areas, between 10 and 20 cm) that may have two possible values: "free" and "occupied". The "occupied" cells correspond to obstacles as detected by the image processing algorithms and the "free" cells represent the space where the wheelchair can move. The wheelchair's position and orientation as detected by the camera are also sent as an additional message after the grid map. In this way, only two possible values are required for every cell and thus only one bit per cell is needed.

Since we are interested in a semiautomatic navigation system we have integrated this information from the environment with user's intentions. We perform this integration by making obstacles become repulsive virtual potentials, while targets (pointed by the joystick: doors, desks) may become attractive potentials or a mix of attractive/repulsive potentials depending on the situation, a solution we have used in previous projects [16]. 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 modelled as the sum of these single-cells potential fields.

Therefore, the wheelchair has to follow the trajectory imposed by the "virtual lanes" obtained from the ambient intelligent environment. The complexity of wheelchair dynamics has impelled us to investigate a different tracking method that reduces convergence problems when several unmodelled dynamics appear. These difficulties include: variable inertia (e.g., if the user moves her/his position or carries a load), perturbations with respect to the model (the most typical for mobile robots occurs when castor wheels change their orientation brusquely due to a direction change), etc. As a result, we have adapted a new tracking method that we call "error adaptive tracking" (EAT) [17, 18]. In contrast to the classic trajectory tracking approach, EAT reduces tracking errors when the system model is not accurate enough.

The computer and communications architecture of our system obviously has temporal requirements, since our objective is the real-time navigation assistance of a wheelchair. For instance, on detection of environmental changes it is required that a timely reaction takes place. A Time-Triggered (TT) architecture is an interesting alternative: it is based on a synchronous design, with each task and message planned a priori in a static schedule. This approach has several advantages: it provides temporal predictability, allows an easy verification of the timing constraints, facilitates fault-tolerance, etc. Furthermore, it makes it easier to implement the periodic measurements required by any multi-sensor fusion approach. From the point of view of a WSN, the power consumption may be reduced since it avoids idle listening, collisions, etc.

A distributed TT architecture needs a common time base shared by all the nodes. For this purpose, together with Prof. M.S. Obaidat (Monmouth Univ., NJ, USA), we have developed a new synchronization protocol well suited for Wireless Sensor Networks: the Multi-hop Broadcast Synchronization (MBS) protocol [19, 20, 21]. Such a protocol maintains the nodes (cameras, other sensors, wheelchair) synchronized so that the external sensors can periodically send the grid map to the wheelchair. This solution could be implemented using the beacon-less Zigbee mode, although there are still some open questions to be investigated. Due to these unsolved questions, in our prototype (limited number of cameras, static and relatively large obstacles, etc.) we preferred to use a simpler approach.

We employ a star topology, beacon enabled configuration. It may occur that several nodes try to transmit at the same time when a beacon is sent by the ZC, thus causing collisions. Usually these collisions are avoided using a slotted CSMA/CA mechanism, waiting a random number of *backoff* periods previously to any transmission attempt. However, this mechanism cannot guarantee successful transmissions with upper-bounded delays.

In order to avoid this situation, we implemented a polling scheme as an alternative approach to share the available bandwidth. Of course, the ZC is the best candidate to perform this polling since all communications must go through it. The usual way to send data from a coordinator to a given node requires that first the node transmits a data request message. However, this mechanism does not avoid more than one data requests from several nodes, probably causing collisions. A simple solution is to let the ZC transmit a kind of token to the selected node. This approach works in such a way that only one node (the one that has previously received this virtual token) is allowed to transmit. Details are given in [15]. This research line on real-time systems and architectures has also produced other interesting results that were partially supported by this project [22, 23, 24, 25, 26].

We are currently considering several alternatives to the approach outlined in the previous paragraphs. The point is to have a compromise between computation on the cameras and traffic over the wireless links. If computation of the virtual forces representing obstacles is performed on the cameras (instead of on the wheelchair) then only the final force vectors (instead of the whole grid) must be transmitted through the WSN.

2.1.3 Middleware

We have studied the infrastructural requirements of general pervasive health care applications [27, 28] and identified the specific requirements of applications our system is oriented to:

- Integrating heterogeneous devices. Adopting a layered architecture abstracts device-dependent features and provides a homogeneous interface to the upper layers of the system, minimizing software complexity.
- Providing device discovery mechanisms. Discovery protocols are usually bound to specific devices or hardware manufacturers and share a limited network-level scope. Although different standards have been proposed (e.g., Jini, UPnP), their incompatible nature, together

with the need for higher-level abstractions of discovery (e.g. users searching for useful devices with a particular context), make an integration framework necessary.

- Managing context information. Context in pervasive applications is related to high-level, user-centred information. Since context information is to be extracted from raw sensor data, an efficient software infrastructure will have to elaborate the sensor data and extract higher-level information and make it available to the application level. A flexible and powerful model for context representation is required.

We have designed a middleware layer with two differentiate roles: (1) efficient integration and dynamic management of heterogeneous resources and services; (2) providing developers with a framework to build intelligent applications. The service oriented middleware architecture is based on distributed modules which can be deployed across a network where loose coupling is a key feature and multiple instances of both low level modules and applications can be found. The overhead of locating instances of low level services, managing their state, regulating access to them and granting the general consistency of the distributed system is shared by the main functional modules, and is thus transparent to both applications and low level modules. This way, application developers can concentrate in their applications, and resource driver developers can create efficient hardware drivers without worrying about the inner workings of the middleware.

AmbienNet prototype focuses on the previously mentioned sensor infrastructure, but the middleware layer is abstract enough to support services of diverse nature, for example maps, intranet or Internet access, etc.

Integration architecture

We describe here the system architecture and, specifically, the components we have developed for the integration prototype. As a reference model, we take the system architecture of figure 1. At the bottom end, a middleware layer integrates devices through drivers. A context awareness and location service exports high-level context information to the applications. Some of the applications, however, require a close interaction with sensors in order to provide real-time behaviour. That is the case of wheelchair navigation. Although common middleware services, such as discovery, are also available to this kind of application, specific context information captured by sensors should be processed in real time by the application.

Drivers represent generic services that encapsulate a given hardware, technology or device (e.g., a X10 control driver, a Zigbee context driver or a Pocket PC interaction driver). Driver modules are conceptually grouped according to the nature of the resources they encode, and provide one of three unified interfaces to modules above them. Driver modules can be very specific and therefore contain specific parts of code to access the hardware and control the flow of information between the application and the target resources.

Operational interfaces to services and drivers follow the OSGi (www.osgi.org) specification and system components at any layer are defined as OSGi bundles. Henceforth, hardware components of an eventual production system based on this architecture, as mobile devices, sensor network coordinators and wheelchair controllers, are supposed to be able to support a Java Virtual Machine and the OSGi service framework.

A framework for application development

Middleware offers to the applications an object-oriented interface. Interface functions refer to three differentiate kinds of functional modules, which we call managers: context manager, control manager and interaction manager. As described in [29], managers provide a unified interface to

respectively context, control and interaction drivers. Furthermore, an additional interface is provided to the intelligent context services as explained in the next subsection.
Due to its distributed nature, we initially designed the framework as an extension to the Apache River technology [http://incubator.apache.org/river/], formerly known as Jini Network Technology. Jini is a service oriented architecture that defines a programming model which both exploits and extends Java technology to enable the construction of secure, distributed systems consisting of federations of well-behaved network services and clients. For the current prototype, however, we have followed the OSGi specification. OSGi is oriented towards the implementation of residential gateways and supports the integration and runtime combination of software components (bundles). Like services in Jini, OSGi bundles are invoked as Java interfaces, preserving a programming framework that can be considered as a standard nowadays. The OSGi framework provides bundle installation, management and monitoring functionality. Typically a centralized element is used to house an OSGi framework runtime, and this residential gateway is in charge of integrating all the different devices, services and resources of the whole system, discovering components, checking dependencies, launching bundles on demand, and performing other related tasks. The centralized approach of OSGi could be seen as a drawback when considered as a component of a distributed system. Nevertheless, as Rellermeyer et al [30] have shown, it is feasible to extend the OSGi approach to transparently distribute parts of a service. The extension, named Remote-OSGi or R-OSGi, preserves the OSGi interface to applications, and hence portability, and it is the approach we are following in the deployment of our system.

2.1.4 Intelligent context service

Managing contextual resources poses various challenges to developers of pervasive applications [31]: detection of existing contextual resources, data gathering from those resources, persistence of old contextual information, inference of high-level contextual information from raw readings, and others. The architecture of the Intelligent Context Service is described in [2]. To test the validity of this service an application to support people with mild cognitive restrictions in every day tasks has been designed [32]. In addition, the environment to allow context supported navigation for smart wheelchairs has been setup.
Among the different approaches to the context representation [33], models based on ontologies are nowadays the most powerful and flexible. The intelligent context services module is in charge of managing a persistent ontology database, importing ontological data from the driver modules, and setting up the initial instance of the ontology reasoner, which can be leveraged by applications to produce smart behaviour and proactive interaction with end-users. This functionality is currently being integrated in the prototype. As part of the work developed in the project aimed to provide a model of the context, we have developed a user model for people with disability and elderly people based on population statistic in the EU [34].

3 Achievements indicators

3.1 Level of achievement of goals

AmbienNet project provided advances in middleware design concepts for ubiquitous systems that 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 [35, 36].
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.
Two main contributions are being obtained from this research line. On the one hand, new tracking methods are proposed. They are interesting in order to let the wheelchair follow the trajectory imposed by the "virtual lanes" obtained from the ambient intelligent environment. On the other hand, following previous research results [37], new approaches for real time transmissions in sensor networks are being studied. We focus on synchronous solutions, very well suited for Wireless Sensor Networks, since they avoid collisions and wasting energy idle listening.

3.2 Scientific and technological production

So far as a result of the AmbienNet research activities the following papers have been published:

Type of publication	Number	References
JCR Journals	4 (+2 Submitted)	[8, 9, 22, 37 (+ 18, 20)]
Other Journals	3	[4, 7, 31]
LNCS	4	[3, 12, 34, 35]
CORE A International Conferences	2	[17, 29]
CORE B International Conferences	2	[10, 19]
CORE C International Conferences	2	[2, 27]
Other International Conferences	13	[1, 5, 6, 11, 15, 17, 21, 23, 25, 26, 28, 32, 36]

3.3 Training in human resources

In December 2007, Álvaro Marco presented his doctoral thesis entitled "Sistema multimodal de localización en interiores multicelda basado en Zigbee y ultrasonidos" under the supervision of Drs. Falcó and Casas. In addition, the following researchers in formation are developing their doctoral work within this project:

- UPV-EHU: Borja Bonail and Jorge Berzosa under the supervision of Dr. Gardeazabal and Zigor Salvador under the supervision of Dr. Lafuente.
- UZ: Rubén Blasco and Ángel Asensio under the supervision of Dr. Casas. Alejandro Ibarz and Victorián Coarasa under the supervision of Dr. Marco. Yolanda Garrido and Héctor Gracia under the supervision of Dr. Falcó.
- US: Juan Luis Font under the supervision of Dr. Sevillano, Carlos Luján under the supervision of Dr. Cascado, and Pablo Iñigo under the supervision of Dr. Vicente.

3.4 Coordination and management

AmbienNet is a project where coordination is strictly necessary because several technological specialities are applied. Each participant research group contribute with the specialities that it

masters. The group from the University of the Basque Country has experience in the application of mobile robotics to smart wheelchairs, the design of human-computer interfaces for people with special needs and the development of middleware for ubiquitous computing. The team in the University of Seville has a long record on robotics and smart wheelchairs, sensor networks and wireless communication systems. The group from the University of Zaragoza focuses its work to indoors location systems and smart home technology. All of them have a common experience in developing technology for people with disabilities and elderly people. In addition they have a long experience of collaboration in previous projects[1]. All these issues make coordination among the three research groups fluid and efficient.
Several remote (via telephone, e-mail or chat) and in place meetings have been held. In order to ensure appropriate development and coordination of the project management it has been designed a website that allows collaborative work between the different members of each team and among the three subprojects [http://www.atc.us.es/ambiennet/]. This website enables the project management information to be developed collaboratively using version control methods.

3.5 Partnerships with other international or European teams

The Technologies for Disability Group from the University of Zaragoza is a partner of the following European Projects:
- MONAMI: Mainstreaming on Ambient Intelligence (2006-2010), [http://www.monami.info/]
- EASYLINE+: Low Cost Advanced White Goods for a Longer Independent Life of Elderly People (2007-2010), [http://www.easylineplus.com/].

The Laboratory of HCI for Special Needs of the University of the Basque Country has been invited to assess the following European Projects:
- ASK-IT: Invited talk "Challenges in the Development of Intelligent Environments for People with Disabilities" at ASK-IT Final Conf. June, 2008. Nuremberg, [http://www.ask-it.org/].
- ACCESSIBLE: Invited as an advisor to the 2nd plenary meeting of the European Project ACCESSIBLE, Genoa (Italy), 14/01/2009, [http://www.accessible-eu.org/].
- Contacts with the i2Home European project [http://www.e2home.org/] to study the applicability to AmbienNet of the URC standard middleware.

The RTCAR group
- Has worked together with Prof. Obaidat (Monmouth University) on several topics related to AmbienNet (for instance, references [19, 20]).
- As held a meeting with researches from Norut (Northern Research Institute) and Tromsø Telemedicine Laboratory (Norway) took place in Sept. 22-23 (2008) in Seville. Several grants and End of Degree projects for students from the University of Seville were proposed by these Norwegian institutions. An application for a joint European Project is currently in preparation too.

[1] The AmbienNet project gives continuity to the research line started with TetraNauta, TER96-2056-C02, 1996-99 (by US, UPV-EHU, Hospital de Parapléjicos de Toledo, Bioingeniería Aragonesa); and continued with Domosilla, 2001-04, (by Bioingeniería Aragonesa, US, UPV-EHU); and Heterorred, TIC2001-1868-C, 2001-06 (by UPV-EHU, US, UZ).

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