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Measurement Technologies to Sense "Users in the Environment" for Ambient Assisted Living

Disability, such as visual impairment, is one of the most important causes of social marginalization. 285 million people worldwide are visually impaired, with 246 million suffering from severe sight insufficiency and 39 million already blind [1]. In Europe alone, about 30 million people suffer from severe sight loss, meaning that 1 in 30 persons are blind or partially sighted [2]. Major causes of visual impairment are related to uncorrected refractive errors, cataracts, and glaucoma [1]. Such alarming data give an idea of the enormous problem to be faced.

In the past, disabled people were often considered a shame to the family. Today, thanks to cultural changes, that mentality has greatly changed. However, physically limited or handicapped individuals still experience discrimination and infringement of their rights on a daily basis at work, trying to find a job, or in going to a café, the supermarket, the hospital, etc. [3]. The best way to help disabled people in the developing world is to give them autonomy and independence and to provide them with a good education, e.g., vocational training, so they can retain their dignity as human beings and acquire the skills needed to lead a full life. This new life concept considers impaired individuals not as different people but as people with different capacities.

The main objective to be achieved for impaired people attending public sites is gaining a ubiquitous and friendly access to information and communications resources and to be able to move safely and autonomously in any environment. To date, such environments are not easily accessible for these people by themselves and without a guide due to communication and structural barriers. When available, existing solutions provide visually impaired people with limited accessibility to information and environments based on *passive tactile aids*, *maps*, and *electronic aids*.

Passive tactile aids and maps suffer from limited accuracy, poor flexibility, low adaptability and re-configurability, encrypted information, vulnerability to damage and vandalism, lack of uniformity in operation and presentation, and poor interactivity which requires expert training. Generally speaking, electronic aids can be used to cope with several needs of daily life involving specific tasks (e.g., color sensing) or certain complex tasks (e.g., mobility in an unfamiliar environment) [4]–[7].

Currently, aiding or assistive systems can be first classified on the basis of the sensory function that is implemented or supplemented, as sketched in Fig. 1:

- sensory enhancement aims to improve functionality of partially depressed perceptors;
- sensory substitution exploits alternative senses to perceive information not achievable by the depressed function; and
- sensory supplementation uses artificial systems to gain information from the environment.

How much information should an assistive system provide to the user? The tendency to feed a rich amount of information can easily confuse the user, especially an inexperienced user, while a simplified form of information could be much more successful. As an example, one of the very first aids for the visually impaired (VI) was the long cane (1950), which allows

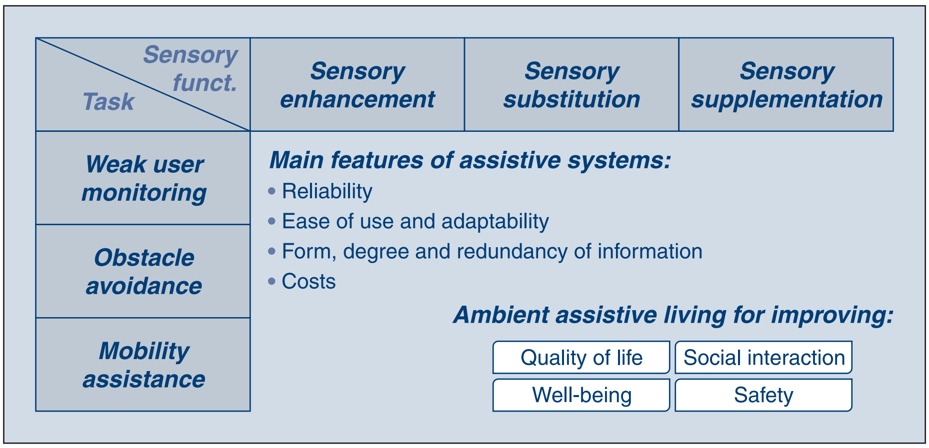

Fig. 1. Classification of aiding systems based on the sensory function they provide.

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detection of obstacles very close to the user and requires instantaneous reaction when an obstacle is encountered. A long cane can provide the VI with a lot of useful information about their surroundings. The optimal feedback for any individual user is determined by his or her skills and abilities, their capability to exploit perceptual and/or cognitive information, and the specific application context. These considerations highlight the complex scenarios routinely encountered by people working in the field of electronic aids for ambient assisted living (AAL).

Measurement Technologies for Developing Assistive Systems

The main tasks performed by electronic aids can range from continuous monitoring of weakened, vulnerable, or incapacitated users to obstacle avoidance and mobility assistance (Fig. 1). Examples of systems for monitoring the activities of individuals with physical infirmities can be found in [8]–[10]. Many assistive systems for AAL are based on the use of ultrasonic or infrared sensors, inertial units, GPS, and CCD cameras. Extensive reviews of the state of the art are found in [4]–[7] and their references.

Fig. 2 proposes a nonexhaustive list of aids for obstacle avoidance and mobility with particular regard to the needs of the blind [11]–[21]. Notable efforts have been dedicated to the development of solutions which transmit some form of remote signal once the user gets within range of the device. The main drawbacks of such systems are related to discontinuous contact with the signal and the sometimes arbitrary forms of information provided.

Inertial tracking systems suffer from cumulative position error and drift. Navigation systems for outdoor environments mainly use GPS systems, GIS (Geographic Information System), and digital maps to locate users in the environment and to provide them with automatic navigation instructions (in the form of a synthesized voice message or other forms of codification). The main drawbacks of these systems are positioning errors from the loss of GPS signals in buildings and urban areas, multi-path effects occurring when GPS signals are reflected off objects (such as tall buildings) before they reach the receiver, and the poor accuracy of suitably small and inexpensive commercially-available GPS units.

Laboratory research in the field of smart sensing approaches for AAL applications at the Department of Electrical and Electronic Measurement (DIEES) of the University of Catania, Italy, has been going on since 2003. The following tools have been developed:

- The very first InfraRed Clear Path Indicator [12] which is a vision system solution for blind people to avoid collisions while walking in a well-defined area [6].
- The PyrUS system assists users in performing tasks requiring urban mobility [16]. PyrUS exploits a multisensor architecture including a sonar module to estimate target distance and velocity and an infrared motion sensor to estimate human presence. Smart paradigms have been developed to perform human detection, specifically while walking in crowded conditions and crossing roads. It uses a *smart step detector* that is intended to provide a blind user with useful information for stair negotiation [7]. The step detector system incorporates an IR coupled device and an inclinometer in a conventional shoe. The addition of a contactless haptic cane provides a user with the same sensation he would have when using a traditional white cane [7]. The contactless cane uses ultrasound sensors for obstacle detection and a set of actuators distributed on the cane's handle for user feedback. The social advantage of this system is the possibility of perceiving the environment without the need for physical contact with objects and other people.
- The SoNaSy system is an indoor navigation solution which is based on a sonar system to localize the user in the environment [6]. The user is required to wear a transmitter unit while a CAN bus sensor network is used to measure distances between the user and the network nodes. The localization algorithm exploits the redundancy given by multiple distance measurements to improve the accuracy of the positioning system. A map containing georeferenced indoor corridors, points of interest, incoming obstacles, hazards, and available services gives weak users more spatially continuous information during mobility

Task \ Sensing meth.	Optical	UltraSound	Inertial & GPS
Obstacle avoidance	LaserCane [11] IR Clear path [12] CamAnCo [6] Step detector [7]	NavBelt [13] Miniguide [14] Mowat [15] PyrUS [16] Haptic cane [7]	
Mobility tasks	Talking Signs [17] Safe free Path [8]	Binaural Sonic Aid [19] SoNaSy [6]	ActiveBelt [20] MoBIC [21] GPS Talk [5] Cognitive WSN [22-23]

Fig. 2. A list of aids for obstacle avoidance and mobility with regard to the needs of the blind.

tasks. It is a type of indoor GPS. This solution overcomes drawbacks of traditional indoor navigation aids, such as the discontinuous form of information. Actually, a user has all of the information necessary to enable his ability to travel, which is especially good during emergencies, and it can reduce the stress of facing unexpected events. At the same time, the autonomous mode of operation can guarantee privacy and can help make users confident in their abilities.

"Sensing the User in the Environment" in AAL

A novel emerging approach in AAL relies on the perception of the user in the context of the environment using paradigms [22]–[23]. The basic idea behind this approach is to estimate user needs and anticipate upcoming emergencies, e.g., the presence of gases, smoke, fires and temperature changes, by perceiving the user within the environment. To do this, several "measurement tasks" must be performed, such as user posture detection, user tracking, and environmental monitoring. User posture estimation can be calculated using inertial measurements which give a sharp classification between standing, bending, or recumbent postures.

Affordable user tracking and localization involves the use of multiple measurement approaches exploiting multi-sensor data fusion techniques. Ultrasound trilateration, as well as using inertial odometers and compass sensors, are quite common approaches to cope with indoor environments, while the use of GPS is mandatory in outdoor environments. It is worth noting that highly accurate indoor localization systems based on a trilateration approach need structured environments with a number of measurement nodes distributed throughout the environment. In the case of unstructured environments, the localization task must be implemented by exploiting user wearable devices. A large amount of information must be collected, transferred, and manipulated; new enabling technologies will improve such tasks.

Application of wired and wireless sensor networks (WSN) for AAL can provide dense sensing close to physical phenomena, processing and communication of this information, and coordinating actions with other nodes [24].

Different approaches can be adopted for the development of user monitoring (both for tracking and posture estimation), ranging from customized vs. commercial solutions. As an example, the sensing and communication features of smart phones are considered a very promising and enabling technology in AAL. Such solutions are currently under development and represent convenient options to implement user monitoring strategies [25]–[27].

A supervisory system having a simple representation of user/environment status will be able to manage anticipated alert situations. For this to be accomplished, the development of reliable user interfaces that do not mask natural echoes and could exploit natural pathways is mandatory [28].

A Cognitive WSN for AAL Tasks

Fig. 3 shows a schematic of a system developed to assist weak users of AAL applications [22]–[23]. The system architecture is a wireless sensor network with multi-parametric nodes and a wearable user module. The WSN architecture has been developed using commercial off-the-shelf components and adopting a ZigBee-based protocol. Network nodes have been equipped with sensors for environmental monitoring (gas, temperature, humidity, smoke) and ultrasound sensors for user localization. The customized wearable module uses an inertial measurement unit for posture estimation and an ultrasound sensor for localization. Pre-processing algorithms and paradigms have been developed for these functions and the user in context and environment interaction applications [28]. User localization is performed through trilateration algorithms exploiting distances between the user and the sensor nodes.

User-Environment interaction incorporates knowledge of the user's position and the environment itself (obstacles, services) to provide the user with information useful for efficient and safe site exploration. User notifications are delivered through the message center managing the user interface.

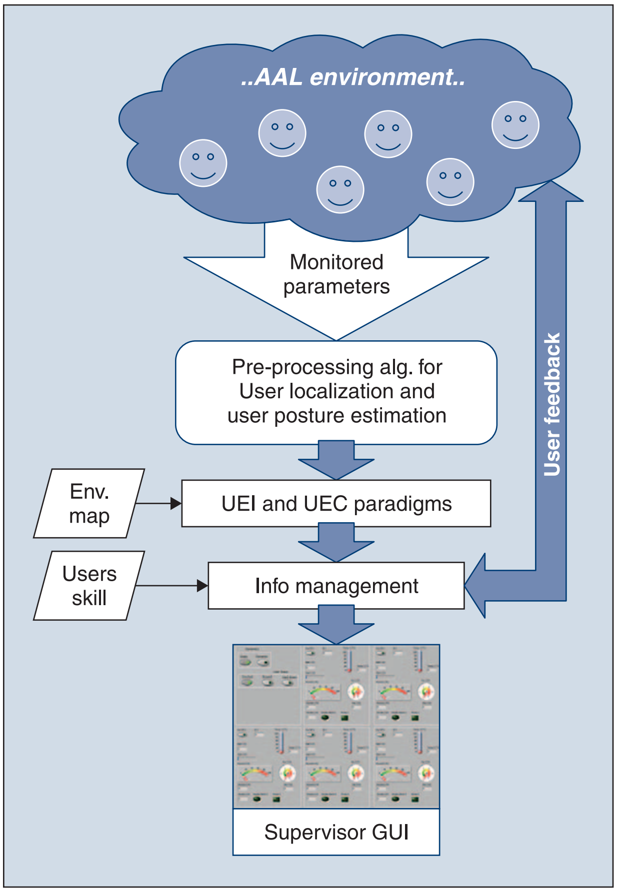

Fig. 3. Schematic of a system developed for an ambient assisted living (AAL) environment.

User-Environment contextualization uses data from the environment monitoring and user modules to provide the system supervisor with a descriptive awareness of user status with respect to the environment status. The latter is used to conveniently manage emergencies and user needs.

The system graphical user interface provides the supervisor with rough data coming from the sensor network (environmental sensors, inertial sensors in the user module, user distances from the network nodes), information extracted by the user inertial tool (e.g., user posture and user dynamics), the User-Environment Interaction tool (user interaction with obstacles and services), and the User-Environment Contextualization tool (user status with respect to the environment).

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