RESIMA: A Smart Multisensor Approach For Indoor AAL

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Abstract This paper deals with a smart multi-sensor system to provide assistance to weak users in indoor environments. A wireless sensor network is used to monitor users position and to detect their inertial status and the environment itself. Advanced computational paradigms process information coming from the sensors to build awareness of the user-environment interaction and user-environment contextualization. Main novelty introduced by the proposed approach is a real time monitoring of user status exploiting a high resolution localization feature. Moreover, the possibility to reconstruct the user-environment relationship allows for the implementation of suitable actions to assist users and to manage alert situations. Activities described in this work are carried out under the RESIMA project - POR- FESR Sicilia 2007-2013.

1 Introduction

Sensor networks have been deeply investigated for applications in both research and industrial contexts. Environmental monitoring, logistics, Ambient Assistive Liv-
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Cognitive Sensor Networks [1-3] and Ambient Intelligent [4] are enabling technologies promoting new directions in the field of Ambient Assistive Living, Home Automation and Advanced Monitoring [5-8].

In [9] a CANBUS sensor network for user-environment perception is presented which can be suitably applied in cases where the user must be aware of surroundings. The system provides support for elderly or impaired people exploring an indoor environment. The aim of the proposed cognitive sensor network is to perceive the user within the environment in order to acquire awareness of User-Environment Interaction (UEI) and to provide the user with useful information for a safe and efficient environment exploitation. The system exploits advanced user localization algorithms and paradigms implementing the UEI functionality.

The WSN discussed in [10] represents an advance as respect to the architecture proposed in [9]. The new sensor platform adopted allows for a distributed monitoring of the environment including the position and the inertial behavior of the user. The main novelty consists in the possibility to build awareness of the User-Environment Contextualization (UEC) which actually defines the user status related to the environment status. Moreover, the use of a WSN conveniently substitutes the CANBUS network.

In this paper a novel WSN for application in AAL context is proposed. Each node of the network is represented by a multisensor architecture aimed at the monitoring of environmental status (environmental node) or user inertial status (user module). Moreover, the system implements a Ultrasound based trilateration system for the sake of user tracking.

Despite the developed architecture implements both the UEI and UEC functionalities, in the following a special focus on the sensing features implemented into the system and the functionalities of the UEC tool will be provided.

Joining the UEI and UEC awareness represents a novel approach to support weak users during site exploration. As an example, typical application contexts could be the exploitation of educational/cultural/job environments by visually impaired people.

Actually, information coming from the UEC and UEI tools could be automatically exploited to build an optimal information for the user and a list of suggested actions to be used by a system supervisor in order to manage hazards or alert situations.

The continuous awareness of the user-environment relationship (contextualization and interaction) leads to the possibility to implement a real time management of the user needs and safety and it can be claimed as the main advantage of the proposed assistive system. The use of low cost hardware, the architecture flexibility, ease of use and implementations represent other fundamental aspects of the system.
In the following, the User-Environment Contextualization feature of the system developed is addressed, with particular regards to the system architecture and solutions adopted for both the environment monitoring and the user inertial behavior assessment.

2 An Overview Of The System Developed

Figure 1 shows a schematization of the system proposed to accomplish indoor AAL activities. The system architecture consists of a wireless sensor network with multi-parametric sensor nodes, a user module, pre-processing algorithms, UEC and UEI paradigms, a DSS, and dedicated User Interface for users and the system supervisor.

The Wireless Sensor Network exploits RF modules “Iris XM2110” provided by Crossbow, equipped with a ATMega1281 microcontroller unit and interfacing facilities. The Wireless Sensor Network is composed by motes spread through the environment and user modules. Environmental nodes, shown in Fig. 2, are equipped with gas sensor (Figaro LPM2610), smoke detectors (FR209) and temperature sensors (LM35).

Figure 1. A schematization of the cognitive Wireless Sensor Network
The user module, shown in Fig. 3, is in charge of estimating heading and inertial status of users through a compensated compass module HMC6343 with a tri-axial integrated accelerometer. The server node is connected to a PC where a LabVIEW™ GUI is used to monitor user/environment status. Network nodes and user module are equipped with ultrasonic transducers adopted to implement user localization.

Pre-processing algorithms use data collected by the WSN for user localization, user inertial status monitoring and environmental status monitoring.
The user localization is performed through trilateration algorithm exploiting distances between the user and the sensor nodes measured by Ultrasound Sensors. The experimental characterization of the system revealed an uncertainty of 2 cm in the estimation of the user coordinates along the x and the y axis.

UEI algorithm combines the positions of obstacles and services in the environment and the user position in order to evaluate possible interactions and generate candidate messages for the user with an appropriate degree of priority.

User posture estimation and UEC functionalities are described in Sec. 2.1. Events generated by the UEI and UEC tools are managed by a decision-making system that operates autonomously by sending appropriate messages to the user and suggesting possible actions to the supervisor.

User notifications will be delivered through the message center managing the user interface. User skill is a key factor for the decision-making system in order to make the most appropriate choices.

Routing algorithms are also implemented to drive the user on user-demand or in case of dangerous event.

![Data flow representation of user posture algorithm](image_url)
2.1 The UEC tool

The user posture is estimated by exploiting information provided by the inertial sensor embedded in the user module, following direction schematized in Fig. 4.

Algorithm for posture estimation classifies 6 different well defined postures: Erect (ER), Bowed (BO), Sitting (SI), Lie Down Prone (LP), Lie Down Supine (LS), Lie Down Lateral (LL). Algorithms individuates also 4 different undetermined condition: Erect/Bowed (ERBO), Erect/Sitting (ERSI), Sitting/Lie Down (SILD) and Bowed/Lie Down (BOLD), these conditions are necessary to avoid fluctuations between 6 postures.

Several tests have been implemented to assess performances of the user posture tool. Three people, in good health, aged over 30 years were recruited to evaluate algorithm in a supervised mode. Users have been chosen with different heights and body styles.

![Diagram](image-url)

**Figure 5.** Data flow representation of UEC algorithm.
Table 1. Experimental results of the user posture tool

<table>
<thead>
<tr>
<th>POSTURE MEASURED</th>
<th>ER</th>
<th>BO</th>
<th>SI</th>
<th>LP</th>
<th>LS</th>
<th>LL</th>
<th>ERBO</th>
<th>ERSI</th>
<th>SILD</th>
<th>BOLD</th>
<th>SENS.</th>
<th>SPEC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSTURE EXPECTED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ER</td>
<td>289</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.96</td>
<td>0.98</td>
</tr>
<tr>
<td>BO</td>
<td>2</td>
<td>273</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.91</td>
<td>0.99</td>
</tr>
<tr>
<td>SI</td>
<td>17</td>
<td>0</td>
<td>234</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>45</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>0.78</td>
<td>0.99</td>
</tr>
<tr>
<td>LP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>225</td>
<td>0</td>
<td>75</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.75</td>
<td>1</td>
</tr>
<tr>
<td>LS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>207</td>
<td>48</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>45</td>
<td>0.69</td>
<td>0.99</td>
</tr>
<tr>
<td>LL</td>
<td>8</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>285</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0.95</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Each experiment was repeated 100 times for each posture to be recognized. Users have been requested to behave in a natural way. In particular, erected posture was performed in static and walking condition. Obtained experimental results are given in Table 1 in terms of number false and positive recognitions. Sensitivity and specificity, reported in Table 2, have been estimated by the following relationships:

\[
Sensitivity = \frac{TP}{TP + FN} \quad (1)
\]

\[
Specificity = \frac{TN}{TN + FP} \quad (2)
\]

where TP = True Positives, FN = False Negatives, TN = True Negatives, FP = False Positives.

All postures are in general well recognized and in particular warning conditions like lie down or bowed postures are correctly identified. Moreover, it must be considered that for practical applications a light statistic approach can help to reduce false positive.

The UEC tool exploits data coming from both environment and user inertial behavior monitoring to provide the supervisor with awareness of the user status as respect to the environment status and to generate candidates messages for the user with an assigned priority. Figure 5 gives a general schematization of the UEC tool data flow where each condition (combination of user status and environment status) is associated to an Identification Number, ID_UEC, and its priority, UEC Priority. Typical user status considered in above described experiments have been used to simulate the UEC tool operation for different environmental status. UEC outputs in terms of candidate user messages and indications for the supervisor are given in Table 2. Measured performances of user posture tool, trilateration algorithms and UEC/UEI tools promise good capability of the developed system to provide a reliable form of assistance to weak users.
Table 2. UEC outputs in terms of user messages and indications for the supervisor

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Erect</td>
<td>0</td>
<td>0</td>
<td>Instructions to drive the user to the emergency exit</td>
<td>Call fire department for gas leakage</td>
<td>Instructions to drive the user to the emergency exit</td>
<td>Call fire department for fire</td>
</tr>
<tr>
<td>Bowed</td>
<td>Courtesy message</td>
<td>Send assistance to the user</td>
<td>Call fire department for gas leakage, Send assistance to the user</td>
<td>Courtesy message</td>
<td>Call fire department for fire, Send assistance to the user</td>
<td></td>
</tr>
<tr>
<td>Sitting</td>
<td>0</td>
<td>0</td>
<td>Instructions to drive the user to the emergency exit</td>
<td>Call fire department for gas leakage</td>
<td>Instructions to drive the user to the emergency exit</td>
<td>Call fire department for fire</td>
</tr>
<tr>
<td>Lie Down</td>
<td>Courtesy message</td>
<td>Call ambulance, Send assistance to the user</td>
<td>Call fire department for gas leakage, Call ambulance, Send assistance to the user</td>
<td>Courtesy message</td>
<td>Call fire department for fire, Call ambulance, Send assistance to the user</td>
<td></td>
</tr>
</tbody>
</table>

References