AmbLEDs: Implicit I/O for AAL Systems

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ABSTRACT
Ambient Assisted Living (AAL) applications aim to allow elderly, sick and disabled people to stay safely at home while collaboratively assisted by their family, friends and medical staff. In principle, AAL amalgamated with Internet of Things introduces a new healthcare connectivity paradigm that interconnects mobile apps and sensors allowing constant monitoring of the patient. By hiding technology into light fixtures, in this paper we present AmbLEDs, a ambient light sensing system, as an alternative to spreading sensors that are perceived as invasive, such as cameras, microphones, microcontrollers, tags or wearables, in order to create a crowdware ubiquitous context-aware implicit interface for recognizing, informing and alerting home environmental changes and human activities to support continuous proactive care.

Author Keywords
Intelligent Interface; Crowdware; Ambient Assisted Living; Smart Light; Internet of Things; Collaborative Systems, Collective Intelligence.

ACM Classification Keywords
H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6).

INTRODUCTION
Driven by an aging population, rising health care costs, lack of professional staff and remote support in most developed countries, there is a growing demand to provide a better delivery of health and social care services for elderly, sick, convalescent and disabled people. Ambient Assisted Living (AAL) is a field of research focusing on IT support for healthcare, comfort and control applications for home environments. AAL facilities often require sensors, actuators and wearable devices, and generally require easy installation and low energy consumption. Current developments in wireless and mobile communications integrated with advances in pervasive and wearable technologies have a radical impact on healthcare delivery systems. Currently, the patients' continuous monitoring is considered the most relevant aspect in healthcare.

This paper aims to study how the Internet of Things (IoT), Autonomic Computing and Smart Lights may be used to provide a novel interface to provide ubiquitous connectivity with Visible Light Communication (VLC) while collect and analyze data for deciding and acting in AAL. This information is stored in the cloud and is accessed in a mobile collaborative environment used by patients and caregivers, to feed and train the system database and algorithms, to perform as a distributed task service to help divide caring responsibilities and training the system's automation. This new collaborative crowdware environment is called AmbLEDs. It is a new intelligent interface to detect activities of daily living (ADLs) and to trigger implicit interaction in AAL. Its technology is based on sensors and actuators embedded into LEDs fixtures shipped with code and enough processing power to make them autonomic based on situational context and connected to a collaborative system.

RELATED WORK
Several articles [1][2][3] show that healthcare professionals understand that the best way for detecting emerging medical conditions before they become critical is to look for changes in activities of daily living (ADLs). These routine activities comprise eating, getting in and out of the house, getting in and out of bed, using the toilet, bathing, dressing, using the phone, shopping, preparing meals, housekeeping, washing clothes and administering proper medications. For tracking the ADLs a distributed mobile infrastructure composed of sensors, actuators, microcontrollers, communication networks must be installed in the patients' homes.

A number of approaches to recognize ADLs in AAL have been considered in several papers [4][5][6]. One is the setup of a large and invisible infrastructure of sensors such as cameras and hidden microphones, presence sensors embedded into walls and ceilings, water pipes sensors and strain sensors under floorboards. Although this approach provides access to a wide variety of information, the cost of installing and maintaining it is usually very high.

Another approach is to use multiple low-cost sensors that cheapen the implementation and facilitate the setup throughout the home [3][7][8]. The disadvantage of this approach is that these sensors are obtrusive and ask for regular maintenance, like battery changes or corrections in their positions (e.g., sensors fixed on the doors of medicine cabinets, kitchen, refrigerator, walls, doors, etc.). According to Fogarty et al. [9], the elderly reject such sensors because they interfere with the look of their homes or create feelings of embarrassment or loss of privacy related to a need for assistance. A third approach is to use wearable devices [10], taking into account that the elderly, sick or convalescent may opt to avoid using such devices, by forgetting to use them every day or being unable to use them due to their health condition or disability.

Although others have written about the potential of sensor networks [11], we are unaware of work where the focus was on answering whether it is possible to recognize activities in diverse home settings using sensors embedded in light fixtures to be ubiquitous and pervasive to detect activities of daily living supported by a crowdware platform for system setup, configuration, and as an intelligent interface for the exchange and analysis of data in a collaborative fashion enabled by IoT, Autonomic Computing and VLC.

Autonomic Computing

To leverage the selective collection of information, AmbLEDs appropriates IoT technologies to provide data to the collaborative system in order to make possible the semiautomatic decision-making and information delivery anytime and anywhere. Caregivers and medical staff use collaborative data analysis to help the machine learning algorithms classify and recognize ADLs in the AAL. The idea of using the concepts of IoT is to provide relevant information in the correct format when and where needed, to establish communication between lights and to bridge the gap between the web and the real world.

However, to gather and access these data require different properties depending on their nature or even the role of the actor who is accessing it. Therefore, AAL may be viewed as a set of environments: hospitals, family homes, etc., each one containing different characteristics and requirements (emergency, security, monitoring, etc.). These characteristics make it necessary to build AmbLEDs applications as autonomic [12], with self-configuration, self-management, self-organization, self-healing and self-protection, to be flexible and adaptable to different environments and needs for users with different expertise and health condition.

Each element in autonomic computing must include sensors and actuators. The sensors responsibilities are to monitor the behavior of the system, while the actuators are used to enable any actions that may be necessary [13]. The process begins with the system collecting data from the sensors and comparing the observed situation in the environment with what it is expected. Then, the system analyzes the data and makes decisions on how to act, apart from medicine prescription. If an action is required, it is performed and its effects are monitored, creating an autonomic feedback control loop (Figure 1).

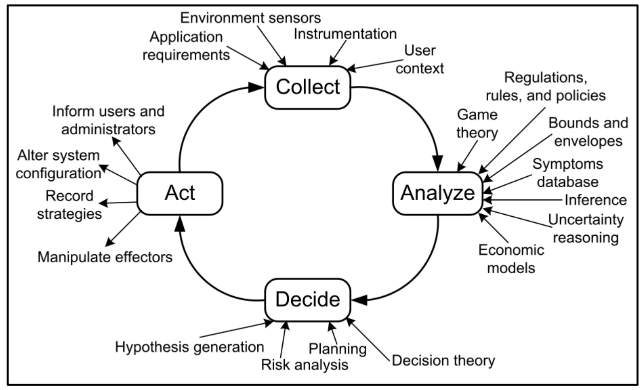

Figure 1 – Autonomic Feedback Loop

Autonomic computing also provides a reference knowledge base containing the system states, symptoms, references, rules and models to compare with the system observed behavior. In AmbLEDs this base is built and enhanced collaboratively by medical staff, families and caregivers, to describe variations and unique circumstances of each patient's condition or environment particularities, in order to build a collective intelligence with which to classify activities and routines [14].

SMART LIGHTS

Smart Lighting comprises a heterogeneous and multi-disciplinary area within illumination management, allowing integrating a wide set of sensor and control technologies, together with information and communication technologies. Its goal is to achieve higher efficiency and lower negative impact derived from the use of energy for illumination, in combination with enhanced intelligent functionalities and interfaces of lighting in the environment [20]. One of the principal Smart Lighting enablers has been the introduction and emergence of semiconductor based digital light sources such as LED (Light Emitting Diode) and next generation LED technologies such as Organic Light Emitting Diodes, also known as OLEDs or Solid State Light (SLL) sources [15].

Besides the advantage of low consumption (range 3-12 volts), LEDs do not depend on the lamp/socket paradigm, are smaller, resistant, and are able to emit different light spectrums to suit the user and lit environments needs, directly affecting the health, humor and productivity [15]. LEDs can also deliver optical and data communications (LiFi) or Visible Light Communication (VLC), and are becoming a new option to scalable and secure wireless communication [16].

LEDs and Sensors

Lights may be configurable in arrays containing many sensors, actuators and microcontrollers at their side, transforming them into a network of ubiquitous and pervasive sensors. For example, lights with moisture, temperature, infrared, noise, and gas sensors (carbon monoxide, butane and propane) enable AmbLEDs to capture useful data ensuring the safety and welfare of the elderly, sick, convalescent and disabled people. Temperature sensors on all light fixtures allow to assemble a thermal map for the whole house, enabling caregivers to remotely monitor the ideal temperature according to each patient's health, and to detect possible problems with the heating or cooling systems. AmbLEDs also come with an embedded speaker and a scent diffuser to give audio and olfactive feedback in order to play an ambient music with a specific scent paired with color changes in the light for therapeutic purposes or to trigger implicit interaction based on situational context.

Visible Light Communication

LEDs provide an almost ideal platform for VLC. An LED can emit and receive light at the same time (with multiplexing) [17]. In this research we propose to use the AmbLEDs as a LED-to-LED communication system for VLC. Such system can modulate light intensity with high frequencies so that the human eye is not affected by the light communication [17]. Light communication has several advantages: it is visible (in contrast to invisible radio communication), so it is easy to determine who can listen to (or receive) a message and will be used as a communication means between the lights themselves. In the midst of an emergency, if wireless communication is interrupted, lights with gas sensors will use the VLC, passing the command to the other lights that do not have such sensors to also blink red, and like a swarm, the information will pass on until all are flashing with the same color to warn the dweller.

Since AmbLEDs can operate as a virtual swarm, we can fragment the idea of a single light source. New services and APIs can use VLC to allow other devices receive the same lighting commands to overcome configuration overload and multi-device interactions: TVs, furniture, digital picture frames, refrigerators, etc. If someone gets into a room at night, not only will the secondary lights illuminate in the wall footers, but the TV could environmentally glow as well. Moreover, lights can ripple or flash in series across the room, when necessary to convey an idea of conduction to somewhere, for example, an individual route towards the kitchen to remind you to drink water or towards the apartment door at exercise time.

COLLABORATION IN AMBLEDS SYSTEMS

According to Chen et al. [18], we should consider the impact on patients and caregivers as part of AAL systems. By studying ADLs, we must not only address the physical, social and emotional needs of patients but also of their caregivers. Considering the caregivers' needs is especially important, since the burden of care may negatively impact their health and well being, leading to anxiety, stress or even death [18]. This same reasoning applies to the family, medical, social service, etc. Hence the collaborative environment is not only for the patient but also for the network that surrounds him.

The mobile collaborative environment serves as a repository of real-time information collected from AmbLEDs to provide data and information to feed the symptoms and ADLs classification databases of patients in the autonomic layer. The autonomic system, fed with the data captured by the sensors, supports activities in the collaborative environment, such as automatic alerts (with several risk levels) promoting communication, task distribution and its coordination, thus dividing the burden on all stakeholders involved in the process. The system also enables the exchange of experience among the community, providing psychological support among individuals who are experiencing the same difficulty, comparison of treatments, symptoms and experiences. This data exchange records the collaboration group's collective intelligence to feed the autonomic system database. This enables the algorithms training and fine-tuning for analysis and decision-making, based on the experiences and activities of hundreds or thousands of AmbLEDs, hence decreasing the chance of overtraining algorithms.

The collaborative environment is also used to investigate how the information captured by AmbLEDs can be worked in to provide the elderly, sick and disabled people, to be in touch with their families, relatives, and neighbors and meet some of their basic needs while respecting heir privacy and wishes more generally to be respected and not overtaken by well-meaning family members, social services or medical teams. The collaborative environment should provide some sort of self-help and a more formal external support, given that the system can also inform patients where their caregivers and family members are. The environment should also provide integration with the neighborhood and the local community to promote digital and social integration.

CONCLUSION

AmbLEDs provide a realistic solution to the problems expected as a result of the increase and population aging in all developed countries. At the center of these environments, the IoT is the layer that supports sensors' and objects' connectivity to the Internet, in order to monitor patient's daily lives activities. Autonomic computing offers intermediation for environments with self-management and self-adaptation to provide trust and security through the Autonomic Feedback Loop; and the mobile collaborative environment brings the collective intelligence of medical staff, family members and caregivers to the system algorithms, to support tasks distribution and provide awareness and context to the Autonomic layer.

Currently we are prototyping AmbLEDs with sensor integration and communication between devices with VLC and Internet connectivity. The second phase is the agent modeling and the Feedback Loop for the autonomic computing. The third phase is the modeling of the collaborative environment that will manage and store the data from the first and second phases, supporting collaboration, tasks distribution and building the caregiver's community collective intelligence. The fourth phase is the machine learning algorithms and classification tasks in the knowledge base from second and third phases. Finally, the fifth phase is the evaluation of the impacts of this new approach on real environments for the patients and caregivers.

The contribution of this work is to show how it is possible to assemble assisted environments that support not only the safety and independence of elderly, sick, convalescent and disabled people as well as relieve caregivers of stress and work overload. This work can be replicated to other areas that require monitoring and distribution of tasks, such as smart cities and factories, which also make intensive use of lights that can be used to control other activities, as well as a user intelligent interface and data collector.

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