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AmbLEDs
Collaborative Healthcare 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 propose AmbLEDs, a mobile 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 system for recognizing, informing and alerting home environmental changes and human activities to support continuous proactive care.**

Keywords—Crowdware; Ambient Assisted Living, Smart Light, Internet of Things, Collaborative Systems, Collective Intelligence

I. 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 [1]. 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 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.

This paper is organized as follows. The next section presents some related work. Section III investigates the IoT and Autonomic Computing capabilities to build an intelligent real time monitor and interaction system. Section IV shows how AmbLEDs may be used as input and output devices. Section V illustrates the role of a mobile collaboration tool in data management and monitoring. Section VI describes the AmbLEDs prototypes implementation. Finally, Section VII concludes the paper.

II. RELATED WORK

A. *Activities of Daily Living*

Several articles [2][3][4] 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 [5][6][7]. 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 [4][8][9]. 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. [10], 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 [11], 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.

One advantage to use lights embedded with sensors is that lights are ubiquitous, are installed in all rooms in a house, are connected to power lines, are easy and inexpensive to be installed, positively interfere with the aesthetics of the environment and have been present in everyday life for more than 135 years. Sensors that work in conjunction with LEDs are unobtrusive, invisible and able to contain several features necessary to observe ADLs. Although others have written about the potential of sensor networks [12], 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 (Cloud API, Mobile App) for system setup, configuration, and as an interface for the exchange and analysis of data in a collaborative fashion enabled by IoT and Autonomic Computing to support proactive care for the elderly, sick, convalescent and disabled people and their caregivers.

B. *Activity Recognition*

The goal of activity recognition is to recognize common human activities in real-life settings. Accurate activity recognition is challenging because human activity is complex and highly diverse. Everyday activities in the home roughly break down into two [13]. Some activities require repetitive motion of the human body and are constrained, to a large extent, by the structure of the body. Examples are walking, running, scrubbing, and exercising. These activities are easier to recognize by using on-body sensors (e.g. [11]).

However, a second class of activities is easier to recognize by looking for patterns in how people use things, and not by how they move around [13]. For instance, objects touched by someone while performing activities such as grooming, cooking and socializing may provide more useful information than the way a person moves their limbs.

Homes and their furnishings have highly variable layouts, and individuals perform activities in many different ways. The same activity (e.g. brushing teeth) may result in a significantly different sensor activation profile based upon the habits of the home dweller and the layout of his or her particular home. Successful research, however, has so far focused on recognizing simple human activities. Recognizing complex activities remains a challenging and active area of research. Specifically, the nature of human activities poses the following challenges [14]:

- *Recognizing concurrent activities*. People can perform several activities at the same time, such as watching television while talking to friends.
- *Recognizing interleaved activities*. Certain real-life activities can be interleaved. For instance, if a friend calls while you are cooking, you could talk to your friend while you continue to cook.
- *Ambiguity of interpretation*. Similar situations may be interpreted differently. For example, an open refrigerator may be related to several activities, such as cooking or cleaning.
- *Multiple residents*. More than one resident may be present in many environments. An AAL system needs to recognize the activities residents perform in parallel, even when a group performs them.

Researchers have been using several probability-based algorithms to build activity models for many years. The Hidden Markov Model (HMM) and the Conditional Random Field (CRF) are among the most popular modeling techniques. However, many activities may have non-deterministic natures in practice, where some steps of the activities may be performed in any order or in different time frames due to disability or limitation of each patient. In practice, because many activities are concurrent or interleaved with other activities, HMM and CRF have difficulty in representing multiple interacting activities and are incapable of capturing long-range or transitive dependencies of the observations [15].

To overcome these issues and to embrace the complexity and ambiguity in ADLs, other algorithms like Multi-Layer Neural Network (MLNNK) and Fuzzy Logic (FL) are being used to take advantages of the Autonomic Computing symptoms and activity model databases to be more flexible and efficient. The MLNNK-based algorithm shows better accuracy than both HMM- and CRF-based algorithms. The accuracy of MLNNK is over 23% higher than CRF and about 14.6% higher than HMM [15].

Fuzzy Logic shows improved recognition accuracy compared to MLNNK. Fuzzy-logic-based algorithm shows an 11% improvement in the recognition accuracy of time slice activities. When algorithms utilize activity and symptoms knowledge base, both MLNNK and fuzzy logic show at least 27% improvement in activity recognition accuracy [15], showing the importance to have a collaborative analysis and decision database to share as much as possible how, when and where an activity can be started, paused or finished.

III. AUTONOMIC COMPUTING AND IOT

The AmbLEDs objectives in AAL are to achieve benefits for all the stakeholders, especially the patient (increasing his or her safety, independence and well-being), economy (increasing effectiveness with limited resources) and consequently to improve society living condition [16]. The proposed technologies in AmbLEDs will leverage the selective collection of information based on the connected sensors to provide data to the collaborative system in order to make possible the semiautomatic decision-making and information delivery anytime and anywhere for caregivers and medical staff. This enables the elderly, sick, convalescent and disabled people to live independently for longer and reduce the need for long-term care in hospitals.

Through the IoT, AmbLEDs appropriates identification tags, beacons, sensors, actuators and connectivity to collect data in order to classify and capture ADLs in the AAL using machine learning and collaborative data analysis between medical staff, family members and caregivers. The main IoT technologies considered for prototyping the AmbLEDs in this research comprise infrared, temperature, humidity, ambient light, accelerometer, noise, gas sensors and speakers. 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 [17], 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. Further information on autonomic computing properties can be found in IBM's autonomic manifesto [18].

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 [18]. 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 (Fig. 1).

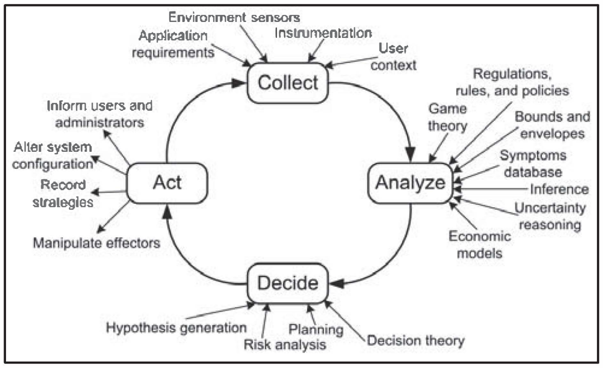

Fig. 1 – Autonomic Feedback Loop

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 [19].

IV. 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 [20].

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 [20]. 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 [21]. They may be configurable in arrays containing many sensors, actuators and microcontrollers at their side, transforming them into a network of ubiquitous and pervasive sensors.

A. *Virtual Lights*

Since smart LED lights are no longer dependent on the bulb/socket paradigm, they may be mounted or fixed anywhere, and not rely on wires or infrastructure, therefore, the switch becomes virtual. The proposal is to abandon the idea that an "ambient light" is just a wall switch that closes the circuit through a wire with a ceiling fixture. The IoT enables rooms to be filled with small lights acting as a virtual swarm lamps with sensors and microcontrollers programmed with events that will set them as desired, in the proportion needed and in many sorts of intensity combinations, color and layout.

Additional intelligent lights may be added to this swarm to fill dark corners without additional wiring or setup. This new approach revolutionizes what we used to think 135 years ago about what a lamp is. One possible consequence of this disruptive idea will be a shift from large light fixtures in the ceiling to a range of smaller LEDs that can be scattered everywhere, placed for example, under a bed or a desk. Besides the change in the number and size of lights, secondary lights will take focus from main lights and will be allocate in furniture, across the floor, footers and will be a secondary cluster that is activated in the middle of the night if any movement is detected or in emergencies for guidance. Virtualization arising from intelligent lights also enables integration with other systems, giving full access to its control and configuration.

B. *LEDs and Sensors*

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.

New infrared sensors are able to detect human presence in the environment even without movement, because of their accuracy and higher range compared with motion sensors based only on ultrasound reflection calculation or passive infrared sensor that only detect any heat energy. They detect occupation through the detection of human body heat. These types of sensor are suitable for AmbLEDs, as well as for capturing the presence of the dweller, enabling people counting, and the detection of position (e.g., lying in bed, sitting in the chair), and body temperature. Such data make it possible to calculate how long a person, not his dog, is standing on one spot, firing alerts for the caregiver's collaborative network if his downtime or his temperatures are off the curve.

As well as temperature sensors, humidity sensors combined with infrared sensor and noise sensors are able to mount humidity and noise pollution environment maps, to detect possible water leaks, factors that provide mold and excessive noise that will disturb the health of the inhabitant. Noise sensors are programmed to detect distress signals or shouts and trigger emergency alarms for caregivers.

Noise and motion sensors may trigger the lights. For example, when detecting a baby crying, LEDs underneath a baby cot will turn on; when getting out of bed in the middle the night, the lights under the bed will turn on to show the way; and when detecting the sound of a phone, the lights of the room or in the entire house will flash and the ring sound may be replicate by the LEDs speakers (warnings for deaf dwellers). The gas sensors (carbon monoxide, methane and propane) are used as fire alarm, cigarette or other smoking control for patients with restrictions and warn about gas leaks. Patients with Alzheimer's or other degenerative diseases often forget ovens or stoves on [8]. AmbLEDs has also an embedded speaker to give audio feedback in emergencies or to play an ambient music paired with color changes in the light for therapeutic purposes.

C. Light as a Service

Since LED lights operate as a virtual swarm, you can fragment the idea of a single light source to a combination of various lights in the environment. New services and APIs can allow other devices receive the same lighting commands: 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.

Virtualization and sensors embedded into LEDs enable a pervasive output through the light as a source of information and ambiance, not only as lighting. The 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. If there is music in the room, a small subset of lights can pulse at the same beat of the sound. At bedtime, lights may induce sleep or help awaken with a subset of color variations and intensities (chromotherapy). Color variations may also 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 flash red, 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.

V. Collaboration in AmbLEDs Systems

According to Chen et al. [22], 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 [22]. 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.

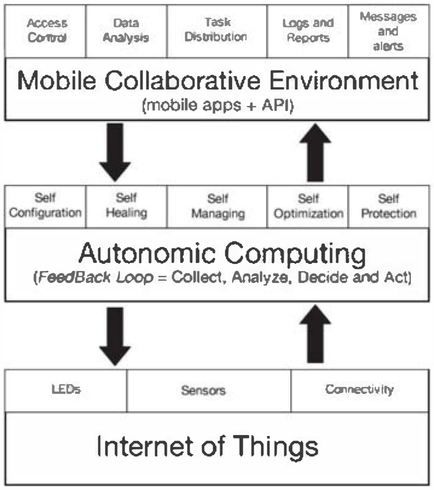

Fig. 2 – AAL Interaction Technology Layers

This research proposes the development of a crowdware environment not only to provide a means of communication, coordination and cooperation among caregivers, but also to provide data and information to feed the symptoms and ADLs classification databases of patients in the autonomic layer (Fig. 2). The autonomic system, fed with the data captured by the sensors provided by the IoT, supports activities in the collaborative environment [23], 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 mobile collaborative environment serves as a repository of real-time information collected from AmbLEDs to be remotely accessed by caregivers and keep them informed. 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, what happens when they are trained with the features and particularities of only a few patients and environments.

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. In order to accomplish these goals, AmbLEDs has also an embedded speaker to play an ambient music with color changes in the light to trigger implicit interaction based on situational context (e.g. play music and change to a specific color to remenber the medicine intake time).

VI. PROTOTYPE AND ONGOING WORK

The prototypes in development for this work are being built to be a full substitute for a common light fixture and as a medications consumption monitor. In this first phase the system is testing if colors changes and sounds will implicit influence the medicine intake at the right time and if the mobile collaborative application is reporting properly the family and caregivers about lack of use, consumer abuse or wrong medication consumption. The prototype is a table lamp with three drawers to keep three different medicines (Fig. 3).

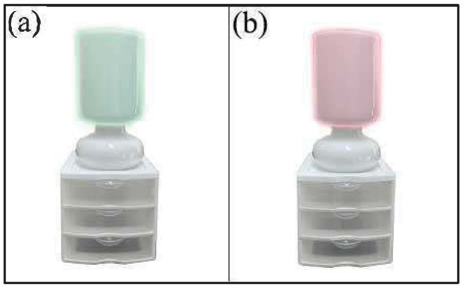

Fig. 3 – Table lamp with drawers for medication consumption monitor

The fixture will blink green and play a cheerful sound if it is the right time and if it is the right drug (drawer) (Fig. 3a). It will blink red and play an annoying sound if the medicine is not being taking at the right time or if the wrong drawer with the wrong drug was open instead of the right one (Fig. 3b).

The board used in the current prototype is a BeagleBone Black (BBB). BBB is a low-cost Sitara Cortex A8 ARM processor from Texas Instrument with 512MB SDRAM and 4GB onboard Flash (Fig. 4a). This community-supported development platform has enough power to run Linux (Debian), a Node.JS Server and MongoDB (NoSQL database).

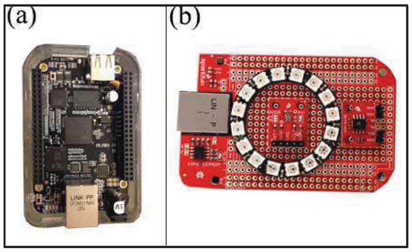

Fig. 4 - Beagle Bone Black and Proto Cape with Sensors and LEDS

The BBB was setup with a protoboard shield (Proto Cape) design specific for it, with access to all gpio pins available on the BBB. The Proto Cape fits on top of the BBB and gives a large prototyping area, two red LEDs and access to a blank EEPROM for storing pin configuration data. The LEDs (NeoPixel RGB LED ring) and all the sensors (temperature, humidity, RGB light and gas) and a speaker are mounted over the protoboard (Fig. 4b). Magnetic sensors were fixed inside the drawers to inform if it is open or close, it communicates wireless it's status to the AmbLED.

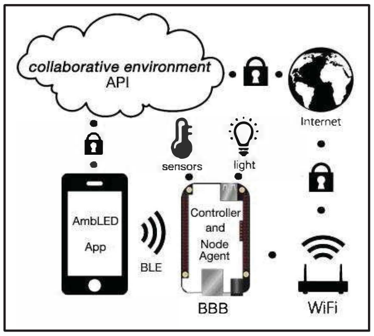

Fig. 5 - BBB AmbLEDs Architecture

The AmbLEDs prototype architecture (Fig. 5) can embrace the whole system in a single board: the LEDs, all the code (server agent and database), sensors, and BlueTooth Low Energy (BLE) dongle. The user can setup the AmbLED informing the medicine schedule in each drawer via mobile app and it has to inform in which room it is installed. If the prototype loses Internet connectivity, it has all the power, sensors, code, models and data to run the Autonomic Feedback Loop and act by itself to inform the right medicine consumption. When the Internet connective is restored, the system synchronizes its data with the collaborative environment API. Communication with other AmbLEDs can be made by BLE Personal Area Network (PAN), Visible Light Communication or through the Internet.

VII. 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.

This new proposed architecture for AmbLEDs takes advantage of collaborative multitude of hundreds of lights in a residence to carry out a substantial amount of storage (rather than stored primarily in cloud data centers), communication (rather than routed over backbone networks), and control, configuration, measurement and management (rather than controlled primarily by network gateways). It uses data science to reshape the "balance of power" in a fog-networking ecosystem, it also leverages a strategic and prime locations for data capture to monitor ADLs and energy source.

Currently we are prototyping AmbLEDs with sensor integration and communication protocols between devices (Bluetooth, VLC) and Internet connectivity. We are also modeling the Feedback Loop for the autonomic computing and testing the collaborative environment for medicine consumption reports. At the second phases we will implement the tasks distribution and the caregiver's community collective intelligence database. The third phase is the machine learning algorithms and classification tasks. Finally, the fourth phase is the evaluation of the impacts of this new approach on real environments for the patients and caregivers. In each phase we will change the activity that we want to monitor (administering proper medications, getting in and out of the house, getting in and out of bed, using the toilet, bathing, using the phone, preparing meals, housekeeping and washing clothes) and if we are really influence it with colors changes, sounds and the remote collaboration with the family 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 individuals as well as relieve caregivers of stress and work overload. The system takes care of the tasks distribution and provides a mobile app with information about the health of their families using computer models and technologies available and accessible to all. 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.

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