Journal of the Brazilian Computer Society, 2022, 28:1, doi: 10.5753/jbcs.2022.2210

Helix Project: Exploring the Social Internet of Things (SIoT) in Care of Blind People

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Received: 14 September 2021 • **Accepted:** 21 November 2022 • **Published:** 26 December 2022

Abstract The wide variety of available mobile devices, associated with the increase in wireless communication network availability, enables an increasing offer of mobile and ubiquitous technologies. In this sense, this article proposes an approach called Helix-SIoT, which explores the Social Internet of Things concepts to support Blind People (BP). The objective is to enhance the treatment of the different sensors that integrate the assistance of these people with SIoT use. For this, the proposal employs Context Awareness and Multiple Criteria Decision Analysis, helping people's autonomy in terms of mobility, response times, and the choice of the Caregiver in the most transparent way possible. The functional architecture of the Helix approach operates integrated with the Adaptation and Context Recognition Subsystem of the EXEHDA middleware, which provides support for the acquisition, storage, and processing of context information used by the mobile Helix-SIoT applications.

Keywords: Social Internet of Things, Context and Situation Awareness, Multiple Criteria Decision Analysis, Helix Project

1 Introduction

Accessibility encompasses both physical and digital aspects, being conceptualized as the condition and possibility of reaching for the use, with autonomy and safety, of spaces, urban equipment, furniture, transport, buildings, systems, and means of communication per person with reduced mobility or with a disability.

The last Demographic Census [IBGE, 2010] points out that around 29 million people in Brazil have some visual impairment, about 6 million have significant visual impairment, and approximately 500,000 cannot see. With the reduction or loss of the ability to perform everyday tasks, these people face countless difficulties in their daily lives due to the lack of resources for accessibility, needing considering this situation, support to exercise full citizenship effectively.

The Internet of Things (IoT) is a paradigm that aims to extend Internet connectivity to a diverse range of devices, often called intelligent objects. With this, IoT has been considered the new paradigm of Internet evolution [Aldelaimi *et al.*, 2020].

A new proposal for the social organization of objects has been gaining dimension in the literature, called the Social Internet of Things (SIoT). Smart objects are devices with some Internet access technology in their physical hardware and offer functionalities for interaction with their owners. With these characteristics, SIoT evolves from the Internet of Things idea, proposing functionalities for creating exclusive relationships between these intelligent objects [Atzori *et al.*, 2014; Perera *et al.*, 2014a].

In the Social Internet of Things, networked objects can provide services by exploring the social relationship between humans and objects, humans and humans, and objects and object [Hülür and Macdonald, 2020; Bouazza *et al.*, 2022].

Thus, in a social network, a thing with server functionalities can be responsible for inferring situations in other entities and articulating relationships, employing Context Awareness mechanisms [Shamszaman and Ali, 2018].

Context Awareness enhances the relationships between systems, applications, and their users. Contextual information is obtained from the physical or logical world through data collected by sensors. Context-Aware computer systems must be flexible, adaptive, and able to help the user automatically in carrying out their activities [Sarker *et al.*, 2020].

The Multiple Criteria Decision Analysis (MCDA) is intended to assist decision-making according to a set of elaborated criteria, thus estimating importance and establishing the best possible value for each criterion. In addition to being a set of techniques and methodologies, MCDA also brings a specific perspective to decision-making problems [Greco *et al.*, 2016b].

This work's approach is based on [Garcia, 2017], which proposed the Helix Project's architectural organization. As the main contribution, it adds features that explore the use of Social IoT. In this sense, it is called Helix-SIoT.

The Helix-SIoT approach contributes to the Helix Project in managing interactions between BP and Caregivers, exploring a social network of objects in the IoT, helping BP in their autonomy, optimizing response times, and selecting the Caregiver who has the highest trust level for care at any given time.

This new concept integrates a SIoT in treating different sensors associated with Blind People (BP) and their Caregivers. Therefore, it employs Context Awareness and MCDA in managing interactions involving BP and Caregivers. With this, the expectation is to increase trust in the care of the selected Caregiver for a specific space-time circumstance.

Helix-SIoT incorporates functionalities into the Adaptation and Context Recognition Subsystem of EXEHDA middleware [da Silva Machado *et al*., 2017]. EXEHDA, as middleware for IoT, provides support for the acquisition, storage, and processing of context information necessary for the different functionalities offered by the proposed approach.

The article is structured as follows: Section 2 deals with the theoretical background, addressing aspects of the Social Internet of Things, Context Awareness, and Multiple Criteria Decision Analysis. Section 3 presents the literature review carried out. Section 4 shows a discussion about the EXEHDA middleware and its subsystems. The Helix-SIoT approach and its functionalities are presented in section 5. Section 6 highlights usage scenarios. Finally, Section 7 presents the final considerations.

2 Background

This section introduces the theoretical background considered when proposing the Helix-SIoT approach.

2.1 Social Internet of Things

The Social Internet of Things is an emerging paradigm in which different devices interact and establish relationships to achieve a common goal. SIoT explores, in essence, variants of a service-oriented architecture, where heterogeneous devices can autonomously offer or request such services. In SIoT, objects can also establish, alter, and terminate social relations [Wei *et al*., 2018; Roopa *et al*., 2021]. Thus, there is an improvement in network interoperability, as well as in the composition of new services, everything promoted by the social interaction between the devices, which establishes collaborations on behalf of their owners based on their habits and interests [Khelloufi *et al*., 2020].

The convergence of social-centric computing and communication will allow IoT devices to take advantage of the social context to optimize services offered and customize deliverables [Dhelim *et al*., 2021]. However, for this optimization to occur in the provision of services between objects, some premises must be met, including trust, accuracy, and precision [Khelloufi *et al*., 2020; Afzal *et al*., 2019].

From the perspective of real-time applications aimed at SIoT, considering relationships, the following challenges are still highlighted as not surpassed: (i) the high complexity that comes with the combined use of a social network and IoT in the mapping of temporal social relationships between people, objects and places; (ii) the feasibility of proactive and autonomous behavior in the shift from bright things to social things [Kumaran and Sridhar, 2020]. In addition to the challenges widely addressed in IoT, such as scalability in the localization of objects and the trust established between them [Rajendran and Jebakumar, 2021].

2.2 Context Awareness

Context is any information that can be used to characterize the situation of an entity (person, place, or object) considered relevant to the interaction between user and application, including the user and the application [Khattak *et al*., 2014]. Context Awareness is the ability of a system to use context to provide relevant information and services to the user [Dey, 2001; Knappmeyer *et al*., 2013].

Some motivations for the application of Context Awareness in computational systems are: assisting in the understanding of reality; facilitating the adaptation of systems; contributing to the process of transforming data into information; supporting the comprehension of events; helping the identification of interest situations [Adams *et al*., 2017; Lopes, 2016].

The process involved in the construction of a context-aware system occurs mainly through four steps [Perera *et al*., 2014b; Li *et al*., 2015]:

- acquisition: it refers to monitoring and capturing contextual information. This step aims at abstracting from context-aware applications the complexity of data collection, enabling the reuse of sensors and the separation between obtaining and using contextual information [Alegre *et al*., 2016];
- modeling: it refers to designing a model of real-world entities, their properties, the state of their environment, and situations. The purpose of creating a context model is to provide a uniform, machine-processable context representation scheme, facilitating context sharing and interoperability between different applications. The uniformity of the model between acquisition, reasoning, and utilization of context information is considered vital [Knappmeyer *et al*., 2013];
- distribution: it refers to the step that allows the injection of context into the context-aware application and its delivery to all entities that have expressed any form of interest in this data [Bellavista *et al*., 2012];
- reasoning: it can be defined as a method of deducing new knowledge, and better understanding, based on the available context. It can also be explained as a process of providing knowledge deduction from a set of contexts [Bikakis *et al*., 2008].

In addition to the four steps, we highlight storage and view layers. Context storage is responsible for storing the acquired context data and the contextual information that was inferred by the reasoning step. Context view provides data visualization methods to facilitate access from the context-aware applications to captured data and detected situations [Temdee and Prasad, 2018].

Regarding the reasoning step, in the literature can be found different strategies for context reasoning, which have advantages and disadvantages considering the distinct domains of application [Sezer *et al.*, 2018]. Among these strategies, we highlight the rule-based, which is the most used strategy to perform the context reasoning in IoT applications [Perera *et al.*, 2014b].

2.3 Multiple Criteria Decision Analysis

Multiple Criteria Decision Analysis is used in decision-making in the presence of multiple criteria, often conflicting. In order to assist in the judgment of decision-making using a set of objectives and criteria, establishing the contribution of each option concerning each performance criterion and estimating their relative importance weights. According to the seminal article of Figueira *et al.* [2005], MCDA is a specific perspective for dealing with decision-making problems and not just a set of theories, methodologies, and techniques.

Considering this, MCDA can be viewed as a general framework for supporting complex decision-making situations with multiple and often conflicting objectives that stakeholders groups or decision-makers value differently [Greco *et al.*, 2016a].

MCDA is a general term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter [Belton and Stewart, 2002].

It is rooted in operational research and support for single decision-makers [Mendoza and Martins, 2006]. Recently the emphasis has shifted towards multi-stakeholder processes to structure decision alternatives and their consequences, to facilitate dialogue on the relative merits of alternative courses of action, thereby enhancing procedural quality in the decision-making process [Fish *et al.*, 2011].

The basic idea of MCDA methods is to evaluate the performance of alternative courses of action (e.g., management or policy options) concerning criteria that capture the key dimensions of the decision-making problem, involving human judgment and preferences.

MCDA methods are evaluation methods in that they combine information about the performance of the alternatives concerning the criteria (scoring) with subjective judgments about the relative importance of the evaluation criteria in the particular decision-making context (weighting).

MCDA literature often assumes that the performance scores are determined based on objective expert evaluation. At the same time the relative importance of the criteria, the weighs, is derived from subjective value judgments by decision-makers or participants [Li and Thomas, 2014].

3 Literature Review

Several works were identified in the literature review. This section covers those whose research theme is closest to the approach proposed in this article, which focuses on using a SIoT to assist in the interaction between users carrying smart objects, operating with the standard technologies of the Internet of Things.

Kowshalya and Valarmathi [2017] propose a Trust Management scheme for SIoT, where trust between objects is calculated based on metrics from the literature. In this way, all objects willing to collaborate need to calculate the trust among their peers to create a reliable SIoT about the success of the advancement of interactions. When an object provides a service as requested, it is rewarded with a score corresponding to it. In case of not meeting requests for services offered, the object will be penalized. The greater the number of times an object is penalized, the greater are the chances that it will be considered malicious, lowering its trust level.

Lin and Dong [2017] suggest a model of trust in SIoT, in which trust is a process that is not limited to an evaluation of another SIoT agent but considers behavioral aspects in decision-making. Each user has a goal, their own need, and attitude toward other users. A user trusts the action of another user to achieve a goal and meet their own needs. Users assess trust with other objects and thus decide whether these will act as solution providers for their demands. Therefore, managing agents trust creditors about their behavior considering a specific context. If the context changes, the admin agent's decision may differ. Context is based on two components, a kind of task and environment.

Wang *et al.* [2016] present a reliability model for SIoT to discover services and resources. The cloud provides computing and storage functions and works as a service provider to connect end-user objects with sensory entities. Sensory Entities receive tasks and rewards from a service provider and feed them back with data. The exchange of messages between objects participating in the SIoT explores the links with relevant social data from other devices. The proposal mainly consists of three basic entities: social cloud, end users, and sensory entities.

Nitti *et al.* [2013] addresses the problem of how the information provided by members of a SIoT should be processed to create a trusted system. Information is produced from the behavioral patterns of objects. Two reliability management models are defined: (i) in the subjective model, each node calculates the reliability of its friends based on its own experience and the opinion of mutual friends with potential service providers; (ii) in the objective model, information about each node is distributed and stored using a Distributed Hash Table, so that any node can make use of the information. However, it is virtually immune to typical social media behaviors where a malicious person modifies their actions based on relationships. On the contrary, the objective approach suffers from this type of behavior, since the reliability of a node is global for the entire network.

3.1 Discussion of Literature Review

Kowshalya and Valarmathi [2017] propose another trust management system for a SIoT. This management system showed interesting results compared to other approaches, like Nitti *et al.* [2013]. Considering the evaluations carried out by the authors, it is possible to infer that the main reason for this better performance is associated with the sharing of interests by the devices that integrate the SIoT. In turn, trust in the Helix-SIoT is composed by attributes calculated from specifications previously agreed upon by the caregiver network members. This situation proves to be opportune, considering the highly heterogeneous profile of the members.

Lin and Dong [2017] model aims to manage a large number of connected objects, which operate as autonomous agents to provide services to users. In this work, several simulations were performed to validate the proposed trust model when selecting one of these services. An aspect to be highlighted in these evaluations is that the work does not directly address the social factors that influence trust calculation. A strong point is the focus on technological issues related to using the SIoT, despite not prioritizing the users' perception of the associated technologies. In Helix-SIoT, these factors are fully characterized when calculating the MCDA analysis.

In Wang *et al*. [2016], some principles were applied for building a mobile network, with a large involvement of human and mobile devices. The ability of users and their devices to select other devices to exploit their services was addressed using a SIoT. The confidence in device selection employs a reputation-based auction mechanism that selects the winning devices, which will be the service providers. The literature shows that the auction mechanism is associated with aspects related to the participants' privacy, which may be exposed, depending on the service in question. In Helix-SIoT, although it is necessary to qualify the privacy mechanisms, in the future, to preserve the identity of the participants, this aspect has less impact because the SIoT has a Caregiver Network with known members, previously registered by the Main Caregiver together with BP.

The work of Nitti *et al*. [2013] focuses on the management of reliability in a SIoT, proposing subjective and objective approaches for its evaluation. Direct assessment of trust in the quality of services offered in the SIoT and feedback propagation are used to avoid possible self-promotions. The proposal achieves high levels of scalability, through the use of Distributed Hash Table (DHT) to manage the information distributed in the network nodes. With this approach employing DHT, the authors chose to consider a widely distributed environment, which can impact the time window that can be supported and thus introduce some compromise in decision making. The assumptions considered in this work reinforce the decision to employ EXEHDA *middleware* as a strategy for managing the potential scalability of a SIoT.

Most of the related work applies the trust protocols used in traditional social networks, disregarding new structures and restrictions related to SIoT. In this sense, the typical scalability in a SIoT is partially guaranteed, failing to exploit the energy efficiency required for the operation.

The related work focuses on discussing the human-to-human social relationship. However, the connection happens through hardware/software artifacts that articulate the SIoT interoperation with the people involved. Thus, there is little discussion of how the operational dynamics of the artifacts carried by the members affect the different aspects considered by the SIoT to build trust relationships.

In this sense, the advance in the offer of technologies at lower costs enables the composition of SIoTs for specific scenarios, as this article, which focuses on contributing to the synergy of relationships between people with visual impairments and others who are immersed in different routines, presenting the possibility of various levels of involvement throughout the day.

From this scenario, there is a perspective for the discussion of strategies that consider the acquisition of contextual information autonomously, as well as employing multiple criteria in the analysis of alternatives, constituting a promising research front, with different possibilities of unfolding in terms of functionalities and operational profiles.

The discussion of related work was essential for building Helix-SIoT on solid foundations. Although the proposals for exploring SIoT in these works are not specifically aimed at BP, the reliability criteria considered, contemplate the selection of caregivers based on choosing the most reliable caregiver at a given time.

4 EXEHDA Middleware

EXEHDA is a middleware designed to manage distributed, mobile, and context-aware applications, available from anywhere, anytime. The EXEHDA includes in its structure a core and services loaded on demand. The main services provided are organized into subsystems related to Ubiquitous Access, Communication, Distributed Execution, Adaptation and Context Recognition [Souza *et al*., 2018]. In the Figure 1 we highlight the Adaptation and Context Recognition Subsystem, which has greater significance for Helix-SioT.

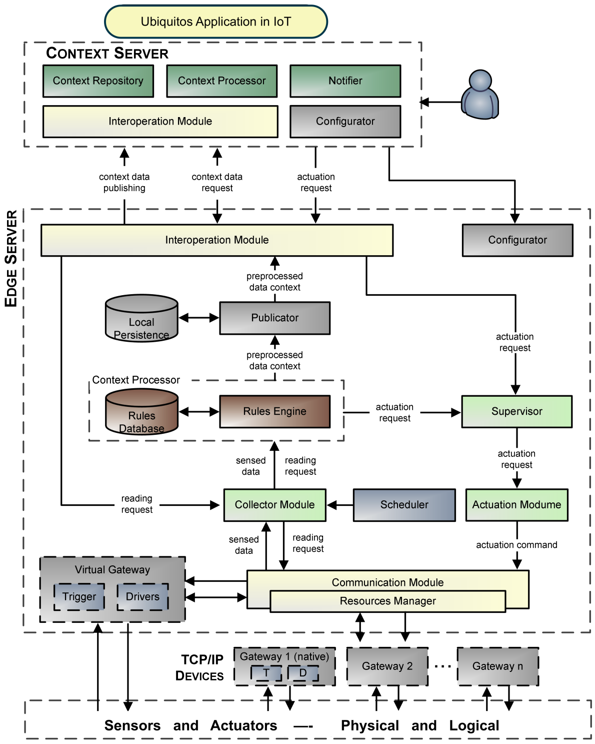

Figure 1. EXEHDA Adaptation and Context Recognition Software Architecture

The IoT environment provided by EXEHDA is formed by multi-institutional equipment, a composite of user devices, and equipment for infrastructure support. Each device is instantiated by its respective execution profile in the middleware, which implies the need to adopt cellular organizational management in this environment, aimed at ensuring the autonomy of the institutions involved [Lopes *et al*., 2014].

Figure 2 shows the IoT environment managed by EXEHDA, wherein each cell, related to the provision of Context

Awareness, is formed by a server Context Server and by various Edge Servers and Gateways.

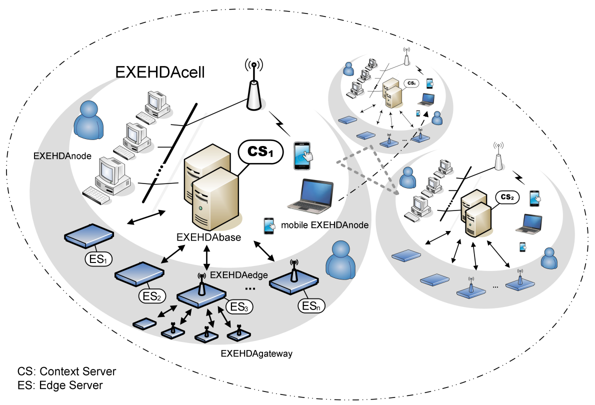

Figure 2. IoT environment provided by EXEHDA

The gateways collect contextual information from physical or logical sensors. They aim to treat the heterogeneity of the various types of sensors in aspects of both hardware and protocol. The gateways transfer the collected data in a standard way to the Edge Servers.

In EXEHDA, the processing of contextual information is distributed, remaining a part with the Edge Server and another with the Context Server. The data received by the several Edge Servers are transmitted to the Context Server that manages them and performs the storage and contextual processing steps. Context Server can combine the data from the Edge Servers with historical information, which is recorded in the Context Information Repository. A broader discussion about the different functionalities of both the Gateway and the Edge Servers is available in Souza *et al*. [2018]. In turn, an approach of the different capabilities of the Context Server can be found in Lopes *et al*. [2014].

5 Helix-SIoT: Proposed Approach

The central issue at Helix-SIoT is caring for people with visual impairments, having as design assumptions: enhancing autonomy, minimizing configuration efforts, and promoting an operation as transparent as possible for the BP. Therefore, the approach explores Context Awareness in the IoT with mobile computing resources, constituting a SIoT, where IoT smart objects can interoperate, seeking a better synergy. Considering these aspects, the functionalities of Helix-SIoT were conceived. Figure 3 shows an overview of Helix-SIoT.

BP and their Caregivers must use smartphones with GPS capability (Global Positioning System) on which Helix-SIoT mobile applications are installed. One of the caregivers, named Main Caregiver, is responsible for configuring the different parameters to Helix-SIoT operation.

BP and his family choose the main Caregiver. He can configure the parameters that define the behavior of the different services in the architecture. Two other types of caregivers are: Corporate, provided by a partner company, and Helix Caregiver, which presents itself as an alternative when all other caregivers of a BP do not respond.

The Mobile Accessibility Assistant (MAA) is the application installed on the smartphone that owns BP. This application directly supports getting contextual information. The MAA also has a Panic Button, which, once activated, sends a help request to the Helix-SIoT Server, with the current position of the BP.

The MAA periodically informs the localization of the BP to the Helix-SIoT server. Thus, it is possible to generate security alerts whenever the BP move beyond the specified distance, considering reference points previously registered. The MAA audible feedback uses the same default language selected in the smartphone's settings, so if the user changes the smartphone's native language, the MAA audible language also changes automatically. This feature enhances that user preferences can be considered, as well as contributes to internationalization aspects.

The Mobile Accessibility Monitor (MAM) interacts through a Bot - autonomous application that performs some predetermined task - configured for the Telegram application installed on the BP Caregivers' smartphone (see Figure 4). The MAM objective is to inform BP situations to responsible caregivers through notifications sent by the Helix-SIoT Server. When BP notifies an emergency, MAM users receive, together with a help request, the GPS position of the BP in the form of a link to Google Maps.

The Helix-SIoT Server uses the software infrastructure of the EXEHDA middleware Context Server, particularly the Processing Module [da Silva Machado *et al*., 2017]. ECA (Event-Condition-Action) rules provide Helix's SIoT functionality, combined with Multiple Criteria Decision Analysis (MCDA) [Marttunen *et al*., 2017]. From this perspective, Helix-SIoT gains the ability to assess the impact of a weighted set of alternatives. This weight attributed to the different criteria allows the creation of a scale, called the utility-scale [Whaiduzzaman *et al*., 2014].

Different information about Caregivers is registered at Helix-SIoT through a web application developed specifically for this purpose. Caregivers can be family members or professionals chosen together with the BP. The number of members in a Caregivers Network is flexible, considering the BP family structure. The Main Caregiver is responsible for inserting and updating BP data and registering other Caregivers for the same BP.

Contextual information listed below is collected by the BP MAAs and Caregivers' MAMs and made available for decision-making by Helix-SIoT.

- Activity Beacon: to keep the Helix-SIoT functional, both BP and Caregivers must send information periodically throughout the day, with the time interval pre-configured by the Main Caregiver. This information, called Activity Beacon, determines whether the BP and their respective Caregivers are active on the network. If any Caregiver does not send the Activity Beacon, they will lose points in the Helix-SIoT Caregiver Selection. In the case of BP, if the Activity Beacon is not sent, an alert is generated to the Caregivers Network, with the last localization of the BP available in the Server.
- Battery Level: at each Activity Beacon, the smartphone's battery level is sent, both the BP and the Caregivers. In the case of BP, it is used for the possible triggering of care requests to the Caregivers Network. In

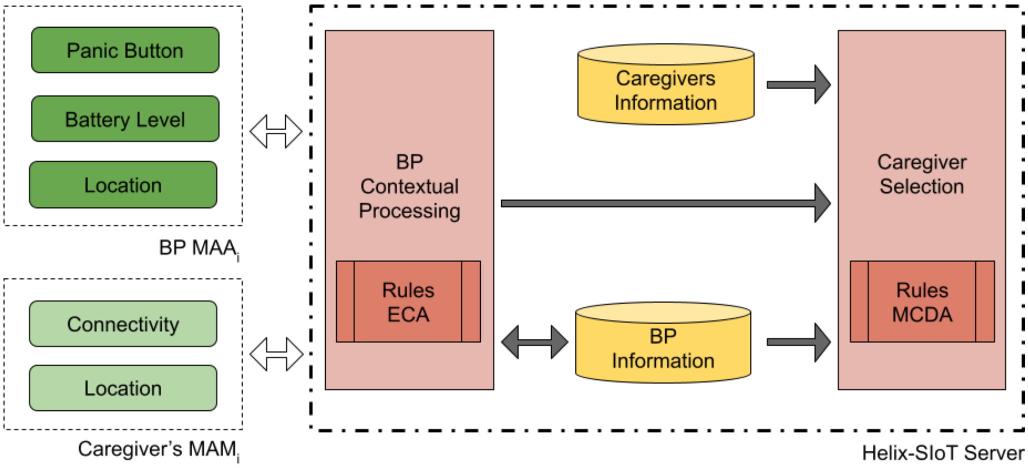

Figure 3. Helix-SIoT Overview

contrast, for Caregivers, it is used as a criterion to avoid sending notifications to Caregivers with a critical battery level. It may therefore have your BP service compromised after accepting the task.

- Localization: smartphones of BP and its Caregivers provide their localizations to the Helix-SIoT Server. The Server considers this information in multicriteria decision-making, thus prioritizing notifying the Caregiver with the shortest path to reach the BP.

In addition, it is also considered as BP contextual information the Panic Button activation, which sends a message with the current localization of the BP to the Helix-SIoT Server. Helix-SIoT by default notifies the closest Caregiver to BP, according to the latest localizations sent. The Main Caregiver can change this notification pattern among the options: Shift Preference, Responsible Caregiver, and Distance.

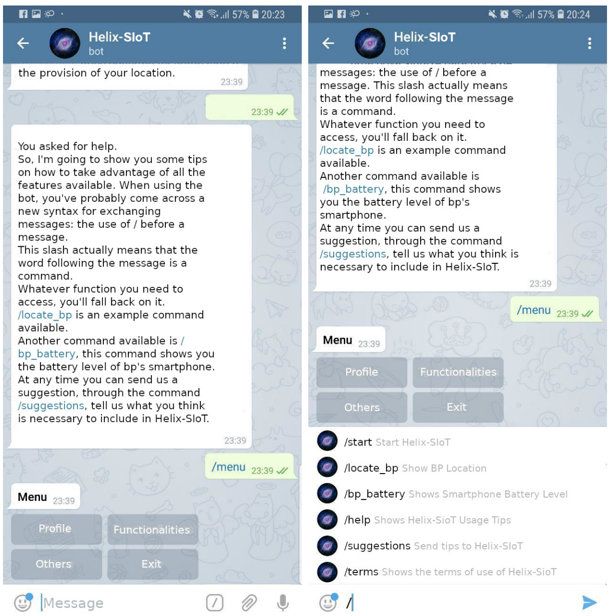

Figure 4. Notifications Sent to BP Caregivers

In turn, Caregivers can choose their preferred shifts to receive notifications, being considered for each day of the week: morning, afternoon, night, and dawn. This preference is divided into four levels: unavailable, low, medium, and high, as shown in Figure 5. Also, Caregivers can choose to leave the Caregiver Network during specific periods. When they return, their profile becomes active again.

Based on contextual information collected from BP, the situations presented below can be identified using ECA rules. ECA rules handle events generated from the following changes in the state of contexts:

- Low Battery Level: Main Caregiver sets the battery levels to be considered and the care priority for each.
- Out of Usual Living Areas: the BP usual living areas are informed in the Helix-SIoT Management Application, through coordinates provided by *Google Maps* [Brown *et al.*, 2018]. Each coordinate must inform a perimeter distance, ensuring that the BP can move without unnecessary notifications.
- Battery Discharge Rate: for each Activity Beacon, the cell phone's current battery level is informed. By default, if there is a discharge level higher than 20%, an alert is generated to the Caregivers Network. The Main Caregiver can change the discharge level to be considered for alerts.

Sending notifications to Caregivers uses the MCDA Simple Additive Weight (SAW) algorithm in decision-making, defining which Caregiver will receive the notifications, taking into account the following aspects, being adopted a weight from 0 to 1, with one decimal place, for each one of them.

- Distance between BP and Caregiver: the server handles the localization information, transforming it into a distance in meters so that the Caregiver with the shortest distance to reach the BP can be identified.
- Availability: availability is calculated taking into account the shift preference specified in the Caregivers register.
- Communicability: the calculation of the communicability potential is performed whenever the battery level of the Caregiver's smartphone falls below a charge level predefined by the Main Caregiver.

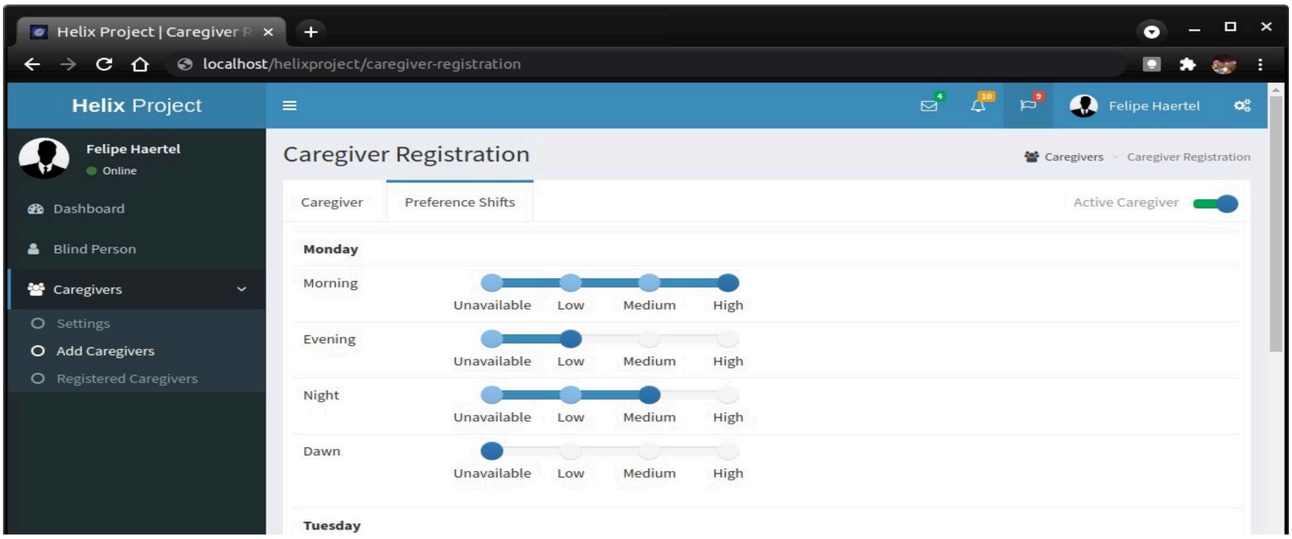

Figure 5. Management of Notifications Sent to Caregivers

- Trust: is calculated based on the Caregiver's availability for the service shift. Also, amortization is used, and calculated based on the history of fulfillment of requests made by BP.

The normalization for the Distance between BP and Caregiver is performed through the SAW algorithm, using the Equation 1, where $\min(dt_j)$ represents the smallest value among all Caregivers in the Network and $dt_{i,j}$ the Caregiver that will be calculated [Tzeng and Huang, 2011].

$$Dt_{i,j} = \left[\frac{min(dt_j) * 100}{dt_{i,j}}\right] \quad (1)$$

The final result of the MCDA is calculated considering the weight defined by the Main Caregiver for each of these aspects, according to Equation 2, where $Dt_{i,j}$ refers to the normalized value of the Distance from Caregiver, Pdt, the weight referring to Distance, $Dp_{i,j}$ the Availability, where Pdp is its weight and $Cb_{i,j}$ represents the Communicability, as well as Pcb its weight, Trust is defined as $Cf_{i,j}$ and its weight as Pcf.

$$MCDA = Dt_{i,j} * Pdt + Dp_{i,j} * Pdp + Cb_{i,j} * Pcb + Cf_{i,j} * Pcf \quad (2)$$

6 Helix-SIoT: Usage Scenarios

The Helix-SIoT evaluation was based on two Usage Scenarios, which include an overview of the main functionalities of the proposed approach. The first scenario is based on the contextual processing of the BP sensors. In turn, the second usage scenario highlights the Caregiver's multicriteria selection.

Considering the need to have different situations to be treated, both from the perspective of BP and Caregivers, the approach used performs a synthetic production of values for the sensors, respecting the usual operating range according to the opinion of the community of Louis Braille School Association[1], which has significant experience in dealing with BP.

[1] https://louisbraille.org.br/

6.1 Scenario 1 - Contextual Processing of BP Sensors

This scenario explores the functionalities of contextual processing of data produced by sensors associated with BP. From these data, the different functionalities of Helix-SIoT were addressed individually, and the interoperation of the other architectural components was performed.

The data used, synthetically produced, referring to the sensing of BP, were delivered using the standard API of the Helix-SIoT architecture, emulating the behavior of real sensors. This scenario considers the Battery Level, localization, and Activity Beacon sensors.

The Main Caregiver parameterized some information to carry out the emulations (see Figure 6): (i) battery levels lower than 20% and higher than 15%, with low priority, less than 15% and greater than 5% with medium priority and less than 5% with high priority; (ii) Activity Beacon sent every 30 minutes, with 10 minutes tolerance.

Both the interval for sending the Beacons, as the tolerance period, can be configured considering the particular interests of each BP. In this sense, shorter intervals for sending the Beacons increase the monitoring accuracy. However, they introduce a higher cost of battery and network.

Thus, sending a BP Activity Beacon may produce a situational information event of low battery level, distance from the expected living regions, and battery discharge rate, requesting the selection of a Caregiver to meet these demands. Likewise, not sending the Beacon will also produce an event featuring BP smartphone inactivity.

In this scenario, 1008 Activity Beacons were generated with information about the considered sensors, with a simulated Beacon sent every 30 minutes for three weeks.

Associated with the collection of Beacons, ECA rules are used, producing Situational Information from the different states of context. Action triggers may be generated with the Caregivers Network depending on the inferred situations.

A linear decay was adopted to characterize the discharge of smartphones batteries, superimposed on a randomly generated fluctuation with its value ranging between 0% and 10%.

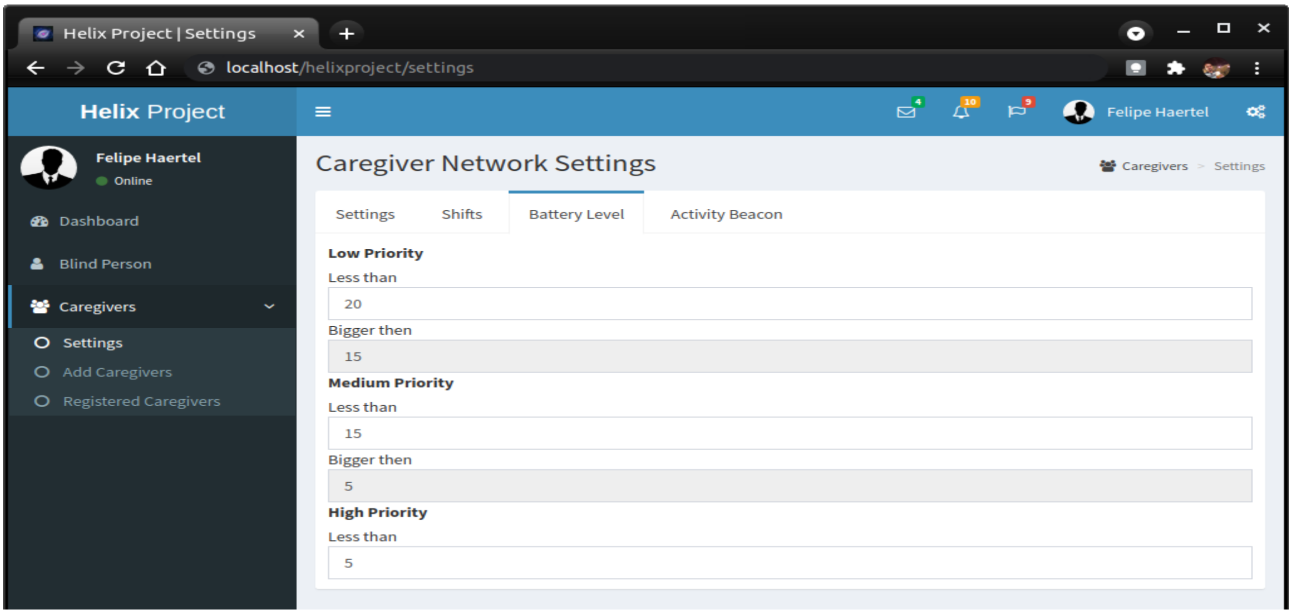

Figure 6. Battery Level Alert Configuration

The battery decay between 0% and 25% was performed randomly, in approximately 10% of cases, causing decays above 20% to be counted for the Battery Discharge Rate index.

Smartphone recharge behavior was performed on approximately 90% of nights and approximately 10% during the day. A recharge percentage was added for daytime recharges, ranging between 30% and 100%.

From the contextual information delivered by the Beacons to Helix-SIoT, referring to the sensors of the BP, situations were identified, whose totals can be seen in Table 1.

For better visualization of the proportionality between the identified situations, in Figure 7 only the conditions that will trigger events in the architectural functions responsible for selecting Caregivers were preserved. These results are consistent with the operational expectations of Helix-SIoT. It is essential to highlight that the Priority of the Situation associated with the Battery Level is passed as a parameter.

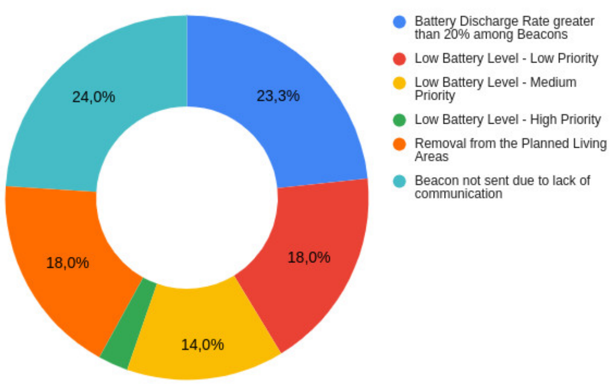

Figure 7. Situations of BP Identified by Helix-SIoT

6.2 Scenario 2 - Multicriteria Caregiver Selection

This scenario explores the use of the SAW algorithm in decision-making based on multiple criteria for selecting Caregivers. This selection considers both: (i) static information configured in the Helix-SIoT; and (ii) information obtained from the MAMs used by Caregivers. This decision is multicriteria and will indicate a Caregiver with more reliability to attend one BP, considering the circumstances involved. The functionality for selecting Caregivers is activated on-demand, based on the identified situations referring to BP.

The Main Caregiver parameterizes some information to carry out the emulations. As for the total number of Caregivers, it was considered a Caregivers Network consisting of four people, one of them being the Main Caregiver. This number of four members for a Caregivers Network is an average value present in the literature, which was also corroborated by professionals working at the Louis Braille School Association in interviews conducted during the development of this work [Iribarren *et al.*, 2018].

Thus, the emulations performed considered a single BP and all four caregivers associated with it. As for the calculation of the MCDA, the following weights were considered: (i) Distance between BP and Caregiver in 0.6; (ii) Availability of the Caregiver at 0.5; (iii) Caregiver Communicability in 0.8; and (iv) Trust in Caregiver Care at 0.7, as shown in Figure 8.

Each of the four Caregivers' availability, seven days a week, is defined by the Main Caregiver, considering four different service shifts. The distance of each of the four Caregivers was calculated, considering their localization about the BP localization. This metric is intended to consider possible displacements of those involved over the different shifts.

For this Scenario, in the synthetic generation of the sensed data, having as a reference the localization of the BP, it was considered that:

- **Caregiver 1**: is at distances between 1 meter and 2 km;
- **Caregiver 2**: is at distances between 1 meter and 5 km;
- **Caregiver 3**: in the morning and afternoon shifts it is between 3 km to 5 km and at night and at dawn between 1 meter and 5 km;

Table 1. Situations Identified by Helix-SIoT

Situations	Totals
Battery Discharge Rate greater than 20% among Beacons	35
Low Battery Level - Low Priority	27
Low Battery Level - Medium Priority	21
Low Battery Level - High Priority	4
Removal from the Planned Living Areas	27
Beacon not sent due to lack of communication	36
No Situation Identified	858

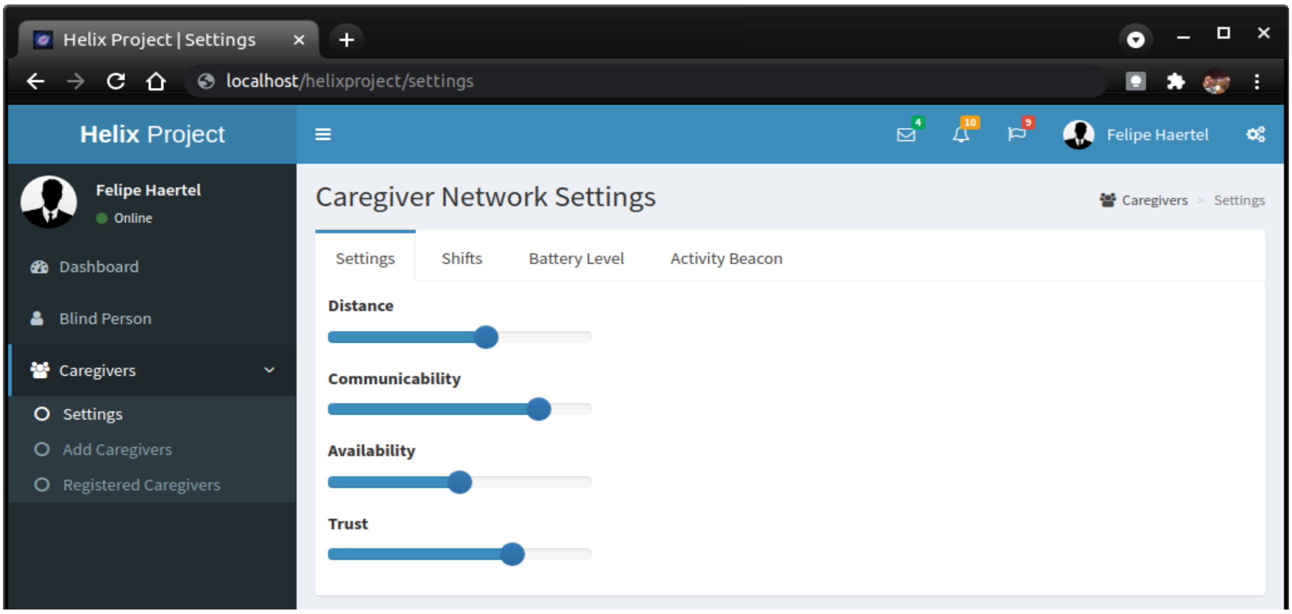

Figure 8. Registration of Pesos for MCDA

- **Caregiver 4**: is at distances between 1 meter and 5 km;

A percentage of communicability above 80% of the cases was considered, causing caregivers without communicability to lose points and thus not being prioritized for care. Based on this, the Caregiver's trust index was evaluated, considering their preference for consideration for that shift. In this way, each Caregiver will have three levels of trust: High, Medium, and Low. This index varies according to the requests and care provided by the Caregiver.

For this scenario, tests of care requests were performed in all registered shifts for the seven days of the week, totaling 28 shifts per week, running for 36 weeks, resulting in 1008 tests. As shown in Figure 9.

In the tests performed, more than 92% of the requests were conducted by one of the four registered Caregivers. Thus totaling 1123 requests and 933 confirmed care, which represent approximately 83%.

7 Final Remarks

The literature review points out that approaches employing the Social Internet of Things usually contemplate many requirements to be met. Thus, its adoption in a specific area must consider the type of user, the services offered, and the functionalities to be provided, ensuring the interactions between objects in the most autonomous way possible.

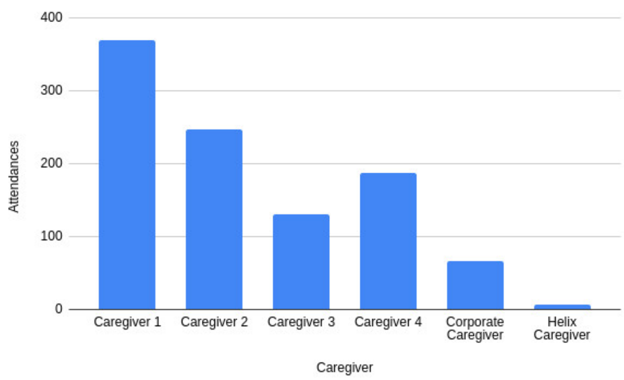

Figure 9. Caregivers Assistance

Among the conclusions arising from work developed, it is understood that this premise of functionalities activated by contextual information, obtained with a minimum of direct intervention from the users involved, is shown as a necessary condition for the success of approaches involving SIoT.

In discussions on the functionalities of the Helix Project with the Louis Braille School community, was explored Technology Acceptance Model (TAM) to identify how users come to accept and use the technologies of Helix, particularly the aspects of Perceived usefulness and Perceived Ease of Use [Garcia, 2017; Okoli, 2015].

The research group carried out this effort with the teachers and specialized staff of Louis Braille School, selected by their expertise and time of experience with BD. The achieved results were promising, characterizing a high acceptance of the Helix proposal by the involved community. Also, as a consequence of this evaluation effort, it was indicated that each BP and their family would have different criteria for selecting Caregivers. Considering this, the use of a methodology that contemplated the treatment of multiple criteria, where each one could have weights of relative importance, proved to be a suitable alternative to Helix-SIoT, leading to the integration of the MCDA analysis in the proposed approach. Considering this, Helix-SIoT preserved the same core functionalities of the project Helix when the TAM evaluations were done, but promoted its personalized treatment by the architecture.

Applications of the Helix-SIoT approach require a distributed operation, with the exchange of contextual information of different natures and a process subject to unforeseen connectivity interruptions. For the treatment of this scenario, the use of middleware stands out. In this sense, the use of EXEHDA middleware proved to be a decision that brought synergy to the research carried out, as it was possible to abstract when designing the approach several aspects that would not contribute to the focus of the study carried out.

It was verified in the literature review efforts in research that adopt the SIoTs. However, although research has been found discussing the exploitation of SIoT in user groups, none is aimed at BP.

Finally, the results point to using a SIoT exploring the Context Awareness to identify BP situations based on MCDA for selecting Caregivers. As discussed in the Usage Scenarios, this can enhance cooperation between users of devices endowed with sensing capabilities and interconnected by the IoT.

In future works, the following fronts of activities stand out: (i) submit a field study of the Helix-SIoT approach to a Research Ethics Committee to carry out tests with BP, considering quantitative and qualitative aspects. We are planning the use again of the TAM, now considering the BP user profile. Relevant to register that the Covid-19 pandemic significantly compromised this evaluation in the last two years; (ii) review the security aspects of the hardware/software infrastructure employed in Helix-SIoT; and (iii) explore the use of historical data to record displacements and also data analysis.

Declarations

Funding

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001

Authors' Contributions

All authors contributed to the writing of this article, read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

Data can be made available upon request.

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