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Beacon-Based Fuzzy Indoor Tracking at Airports †

Josué Toledo-Castro *, Pino Caballero-Gil *, Nayra Rodríguez-Pérez, Iván Santos-González and Candelaria Hernández-Goya

Department of Computer Engineering and Systems, University of La Laguna, La Laguna, 38200 Tenerife, Spain; mrodripe@ull.edu.es (N.R.-P.); jsantosg@ull.edu.es (I.S.-G.); mchgoya@ull.edu.es (C.H.-G.)

* Correspondence: jtoledoc@ull.edu.es (J.T.-C.); pcaballe@ull.edu.es (P.C.-G.)

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Abstract: An application of Bluetooth beacons is here proposed to perform real-time tracking of the locations and movements of airport staff through different monitored airport infrastructure elements, such as rooms, terminals or boarding gates. With respect to this, the aim is to provide an efficient location service of airport workers and users through an indoor tracking controller based on fuzzy logic. For this purpose, a mobile application and a Web service have been implemented. This location knowledge may be decisive while performing common airport procedures or managing airport resources, staff or emergency situations aiming at ensuring a short response time. Likewise, the proposed system integrates an operational module of coordination to facilitate the communications of users at the airport. Besides, particular attention has been paid to the security of communication between mobile devices and the Web service, both regarding secure authentication of users and protection of confidentiality of information exchanged between airport staff.

Keywords: beacons; indoor tracking; fuzzy logic; real-time operations; airports; emergency situations

1. Introduction

Nowadays, the coordination and management of team workers in particular infrastructures such as airports may suppose the difference between offering a good or a bad service to clients and users. As a consequence of the huge amount of continuous airport procedures in charge of organising departures and arrivals of flights and the transit of passengers in airport terminals, the response time of airport workers while performing their tasks directly affects the quality of service. To this respect, the real-time knowledge of the locations of airport staff in addition to the possibility of establishing communications quickly with airport coordination headquarters may help reducing this response time considerably.

Real-time knowledge of airport staff locations may be also decisive when an emergency situation happens. With respect to this, staff evacuation strategies, the reduction of damage and material losses or the reorganisation of airport resources and workers aiming at improving the performance of certain airport procedures can be managed more effectively when the location of staff is known. Likewise, it can be useful for monitoring staff entry and exit times during the period of working day, detecting unauthorised access to certain rooms or other elements of airport infrastructure and analysing the airport staff involved in a certain incident.

In the recent times, several systems for tracking location based on networks of beacons have been proposed. These devices are low-power consumption devices able to send broadcast signals through Bluetooth Low Energy (BLE). Thus, they are mainly used for sending messages or warnings or for detecting the close presence of any particular user.

The proposed system has been developed with the aim of performing a real-time indoor tracking of airport workers through different infrastructure elements, such as access doors, rooms, grounds, boarding gates, etc., at airport terminals. For this purpose, a fuzzy-based indoor tracking controller has been implemented to analyse Bluetooth signals scanned by a mobile application and generated as a consequence of the proximity to Bluetooth beacons distributed throughout airport terminals. In addition to this, a Web service has been also implemented in order to represent in detail the movements of airport staff together and coordinate their tasks aiming at enhancing the management of airport resources and staff by ensuring their location during working times and especially in emergency situations. Security mechanisms have been implemented to provide a robust authentication scheme and secure communications jointly with ensuring the confidentiality of information.

This work is organised as follows. In Section 2, some concepts, terms and related works of the discussed topic are mentioned. Then, the proposed system is detailed in Section 3. The indoor tracking controller based on fuzzy logic is explained in Section 4. Finally, the system security is detailed in Section 5. Finally, some conclusions and future research lines are included in Section 6.

2. Background

In the Internet of Things (IoT) [1], beacons and Bluetooth technology currently play an important role in multiple systems. Some of them use beacon technology through Wi-Fi networks for indoor tracking. An example of this is presented in the work [2], based on using a technique that calculates the location of a mobile device through positioning software. In that way, it is possible to get the current location through Wi-Fi access points. On the other hand, hybrid studies have been also carried out for location calculation using Bluetooth and Wi-Fi. The system [3] uses both technologies to provide an asset positioning method. Other works study the optimization of beacon resources. For example, the work [4] analyses how the nodes must be placed effectively in order to cover as much space as possible, using triangulation for determining locations. Likewise, authors in [5] propose a method for choosing beacon locations taking into account several factors such as obstacles, building materials or interferences caused by other devices that may affect signal propagation in indoor environments.

In addition, Bluetooth technology is also commonly used for advertising and marketing purposes. In that case, notifications with advertising messages are sent to users near the beacon area in order to provide users with information about offers or specific products depending on their location [6].

Differently from the techniques and functionalities proposed in the aforementioned papers, the system proposed in this work offers a real-time tracking of locations and movements of airport staff through Bluetooth beacons integrated in access doors, and an indoor tracking controller based on fuzzy logic. Regarding the purpose of providing an enhancement in the management of airport resources, staff and emergency situations, a mobile application able to scan beacons and a Web service in charge of representing in detail the locations of airport staff through particular airport maps have been implemented too.

3. Proposed System

The proposal is based on a distributed network of Bluetooth beacons through different elements of the airport infraestructure (rooms, terminals, boarding gates or airport warehouses) intended to provide a service of indoor location tracking. With respect to this, the main objective consists on analysing the locations and movements of airport staff through access doors that have integrated control tracking Bluetooth beacons. To this end, an indoor tracking controller based on fuzzy logic has been developed aiming at analysing the locations and proximity of airport workers with respect to monitored access doors, in order to determine if they are outside or inside the corresponding airport rooms. To this respect, a mobile application and a Web service in charge of scanning Bluetooth beacons and representing in detail and real-time the movements of users through different maps of the airport infrastructure have been implemented (see Figure 1).

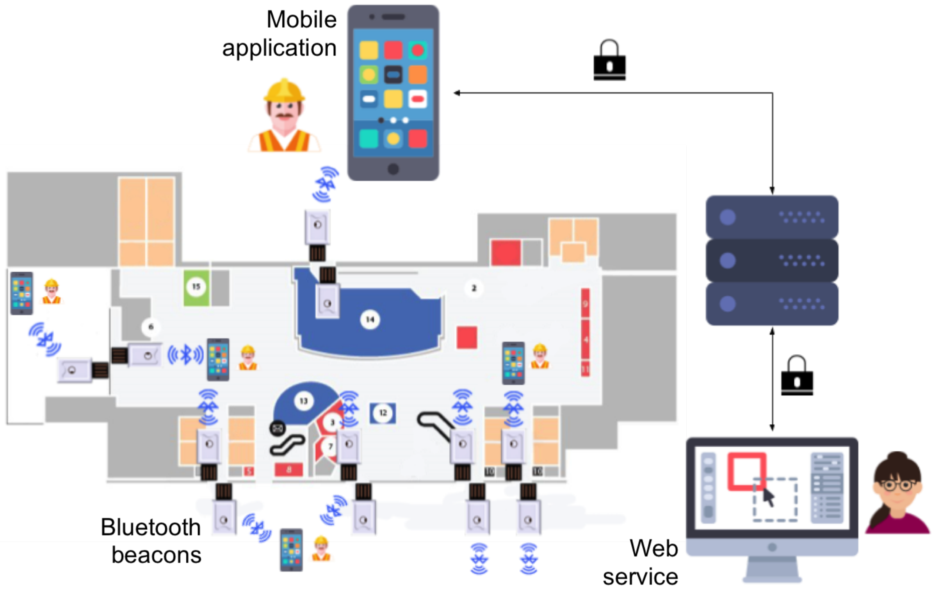

Figure 1. Proposed System

Two control tracking beacons are integrated in each monitored access door in order to detect the proximity of an airport worker from outside and from inside the corresponding airport room. When the mobile application scans close Bluetooth beacons, the proposed fuzzy logic-based indoor tracking controller is used to determine whether the user is outside or inside that room, or intending to cross its access door. After determining the location of the airport staff, the Web service updates automatically the airport maps shown on its interface in real-time.

Several Firebase services such as Realtime Database or Cloud Messaging are used in order to ensure a real-time management of location data, in addition to allow sending notifications to users through the mobile application.

3.1. Mobile Application

The mobile application is responsible for performing a continuous real-time scanning of Bluetooth beacons distributed around the access doors of airport terminal rooms and buildings. Every time new control tracking beacons are detected, the indoor tracking controller based on fuzzy logic analyses the power of the Bluetooth signals as input variables in order to determine the location of that user with respect to the access door whose integrated control tracking beacons have been detected. These Bluetooth signals are more powerful when the user is increasingly closer to the control tracking beacons of a particular access door.

Bluetooth beacons scan is performed through the Alt-beacon library [7] that allows detecting and analysing their parameters (power signal, uuid, identification parameters, etc.). Once the location of an airport worker is available, the mobile application adds it together with the corresponding related room identification to the database. In this sense, the database has been structured in order to favour the management of a historical module of the registered locations over every working day, movements and the last known location of every airport worker.

The mobile application has an operational panel as its main interface to allow receiving notifications and tasks to be performed. These tasks are coordinated and assigned from the airport coordination headquarters through the Web service. Notifications are manually generated from the Web service when it is necessary to perform a particular task in a specific airport infrastructure location or when an emergency situation has occurred and the presence of that airport worker is necessary to solve it. On the other hand, notifications are automatically generated and sent to the users as a consequence of a possible unauthorised access. Moreover, the mobile application allows the control of the times of entry and exit of each user during working days, so that notifications are sent if airport staff do not comply with the corresponding working times. These incidences are automatically displayed in the Web service interface.

3.2. Web Service

The Web service is mainly proposed for displaying in detail all the movements and new locations of the airport workers in real-time through different monitored airport rooms, so it is aimed mainly at airport coordination headquarters. To this respect, it is in charge of managing particular airport maps and the location of Bluetooth beacon pairs integrated in the different access doors of the airport elements represented on those maps.

These airport maps are loaded and stored in the database. Once the particular access rooms to be monitored are identified, the Web service allows adding and associating pairs of tracking control beacons to the airport map by clicking on the desired access doors. Regarding each pair of beacons, the first beacon that is located on the airport map is considered as the outside beacon of that access door, while the second is for the inside beacon. To group beacons taking into account different buildings, terminals or other airport infrastructure elements, the Web service allows assigning specific identifiers to the beacons while they are being registered and added to the corresponding map. It is possible to see the last detected location with respect to a specific room. Besides, the Web service allows the airport coordination headquarters to visualize and track all the previous registered movements and locations of the airport worker during the current working day. For that, it is only necessary to select the desired user represented on the visualized airport map.

The main interface of the Web service includes a real-time tracking module that represents the current locations of all airport workers, taking into account a particular loaded airport map. In addition to this, a side information panel has been also included in order to detail the location and last movements, assigned tasks and times of entry and exit of every airport worker. By selecting one of them, all tracks of the current working day are represented in detail on the corresponding airport map. Likewise, the Web service has included an operational panel that allows assigning and coordinating specific operations and tasks that need to be carried out by a specific airport worker. On the other hand, the Web service interface allows airport coordination headquarters to assign unauthorised rooms or buildings to every airport worker. As a consequence, when the system detects unauthorised accesses, a notification is automatically sent to the mobile device of the corresponding airport worker and the incidence is notified to the airport coordination headquarters.

Moreover, the Web service is intended to manage the user accounts of airport workers together with the Firebase Authentication service. In this sense, a user registration and management panel has been integrated in order to allow the system administrator to sign up new user accounts, and update or remove them.

4. Indoor Tracking Controller

The process of analysing and determining when a user is either outside, inside or crossing the access door of a monitored airport element (such as a room or a terminal) through using only Bluetooth signals may not be very easy to perform with complete accuracy. With respect to this, the data obtained by scanning Bluetooth beacons may cause uncertainty in determining the location of the user, due to certain factors such as the existence of obstacles between the mobile device and the beacons. There is not an efficient specific mathematical model related to this process. As a consequence, fuzzy logic [8] has been used in order to develop an indoor tracking controller that allows interpreting the power of BLE signals to determine the proximity and distance between the user and a monitored access door. For this purpose, the proposed method is based on analysing which control tracking beacons are more powerfully detected by the mobile application. In addition to this, the direction of the user movements while accessing or exiting the related monitored airport room can be determined. If the signal power of the beacon outside the room is higher than the scanned Bluetooth signal with respect to the inside beacon, the airport worker may be trying to enter that room. On the other hand, if the beacon inside the room is more powerfully detected than the outside beacon, that user may be trying to exit.

When more than a pair of control tracking beacons integrated in different monitored access doors are detected by the mobile application, the proposed fuzzy system only analyses the most powerfully detected of them. The rest of detected beacons are disregarded.

In this respect, a Mamdani inference system [9] has been used as inference method. Against classical logic, fuzzy logic allows representing a level of membership (from 0 to 1) between certain input variables (in this case, the power of scanned Bluetooth signals of control tracking beacons) and particular fuzzy sets [10] that are proposed as possible ranges of Bluetooth signal power for reasoning in linguistic terms when Bluetooth signals are weak, strong or very strong (see Figure 2). After that process (Input Variables Fuzzification step), the fuzzified results are evaluated through different proposed inference rules that link input and output variables of this proposed fuzzy-based indoor tracking controller (Evaluation of Inference Rules), to obtain fuzzified outputs that need to be aggregated into a global fuzzified output set (Aggregation of Outputs step). Finally, the resulting output set is defuzzified (Defuzzification process) in order to obtain the location of a user with respect to a particular monitored room (the output variable of the fuzzy logic system).

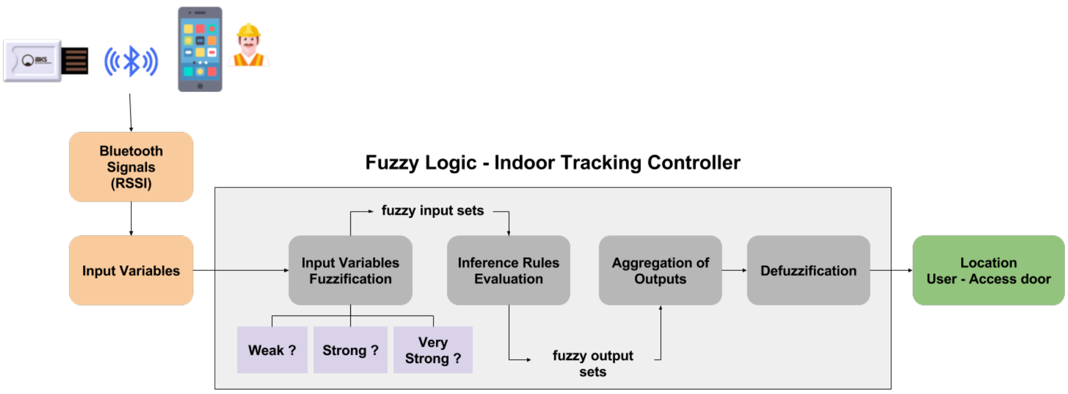

Figure 2. Fuzzy Indoor Tracking Controller

4.1. Input Linguistic Variables

The Bluetooth signals that are the result of the beacon scanning process are here taken as input variables of the proposed fuzzy system. Concretely, the power of Bluetooth signals detected by the mobile application depends on the proximity between an airport worker and beacons. Thus, two input variables are considered, corresponding to each control tracking beacon pair integrated in each monitored access door. On the one hand, the detected Bluetooth signal power between the beacon situated on the outside of the monitored airport room and the mobile application is named BLO (Beacon Located Outside). On the other hand, the detected Bluetooth signal power between the beacon situated on the inside of the room and the mobile application is denoted BLI (Beacon Located Inside).

As discourse of universe of these input variables, the Received Signal Strength Indicator (RSSI) [11] is obtained. It is measured in decibels per milliwatt (dBm) and depends on the distance and the configured transmission power of the beacon (TX). In order to prevent the mobile application detects beacons located more than 3 m from the current airport worker location, the transmission power of Bluetooth beacons has been configured for −30 dBm. According to this transmission power and the characteristics of the used beacons, some particular fuzzy sets have been proposed depending on the detected power of Bluetooth signals: “weak”, “strong” and “very strong” (see Figure 3).

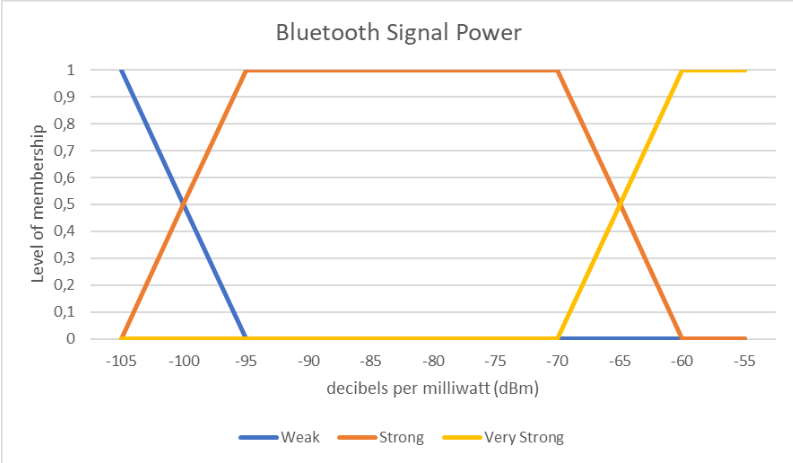

Figure 3. Fuzzy Sets Defined with Bluetooth Signals

All measurements of Bluetooth signal power close to -60 dBm present higher levels of membership with very strong Bluetooth signals fuzzy set. In this case, the scanned signal is really powerful so it is associated with distances close to 0 m, as the user may be a few centimetres away from the beacon. Depending on whether that close beacon is located inside or outside the corresponding room, the user may be trying to exit or to access that room, respectively. If scanned Bluetooth signals are less powerful, until around -99 dBm, higher levels of membership with strong Bluetooth signals fuzzy set are concluded. In this case, the user is not so close as the prior case although he or she is also near the corresponding beacon. Regarding this situation, the user may be around 1 metre away from that beacon. Finally, scanned Bluetooth signals that are around -102 dBm of power present higher levels of membership with weak Bluetooth signals, so the user may be located around 3 m away from that beacon. These specific mentioned distances depend mainly on the transmission power that has been configured in the distributed beacons. If the TX power increases, the relationship between distance and the power of Bluetooth signals change, and the distance to detect beacons increases too [12].

4.2. Inference Rules Evaluation

The evaluation process has as its main objective to assess the proposed inference rules, taking into account all fuzzified values as results of the previous Input Variables Fuzzification step. In this case, the inference rules directly relate the signal power differences between BLO and BLI with respect to the corresponding monitored airport element (room, terminal, etc.), with the fact that the user is outside, inside or crossing it.

For example, if the scanned Bluetooth signal of beacon BLO is strong and the scanned Bluetooth signal of beacon BLI is weak, the user may be close to that access door and outside that room due to the power of Bluetooth signal with respect to the first beacon is stronger than the second. If the opposite situation occurs and the Bluetooth signal related to BLI is more powerful than the scanned Bluetooth signal with respect to BLO, the user is close to the access door but inside the room.

As a consequence, a Fuzzy Associative Memory (FAM) [13] has been used to represent inference rules that are evaluated taking as variables the fuzzified input variables. Regarding the input variables (BLO and BLI), Table 1 shows the possible location of the user (LU) with respect to that room (output linguistic variable). In this sense, the user could be outside (LUO) or inside (LUI) that room, or in the middle of the access door (LUM). In this latter case, taking into account the possibility that scanned Bluetooth signals from both beacons have a similar power (mainly weak and null Bluetooth signals), the indoor tracking controller could only determine if the user is outside or inside that room through the prior and posterior measurements of Bluetooth signals for each beacon.

Table 1. Fuzzy Associative Memory

BLO / BLI	Very Strong	Strong	Weak	Null
Very Strong	LUM	LUO	LUO	LUO
Strong	LUI	LUM	LUO	LUO
Weak	LUI	LUI	-	LUO
Null	LUI	LUI	LUI	-

4.3. Output Linguistic Variables

Finally, the output variable of this indoor tracking controller based on fuzzy logic represents the location of a user with respect to the access door of a monitored airport element (room, terminal, boarding gate, etc.) through a pair of integrated control tracking beacons. As discourse of universe, the metres is used as measurement unit for representing an approximate distance between the user and the access door. As a consequence of the Bluetooth beacon configuration based on a transmission power of −30 dBm, the beacons can be detected from shorter than 3 m with respect to the mobile application of an airport worker. In this sense, possible detections of the user outside of the monitored room are represented taking into account the distance range between −3 m and 0 m, considering 0 m as the centre of the access door and an intermediate state of the user location between being located outside and inside of the corresponding room. Likewise, if the user may be located inside the room, all its possible detections are represented between 0 m and 3 m (see Figure 4). When distances are closer to 0 m, the user may be trying to cross the access door in order to enter or exit the room.

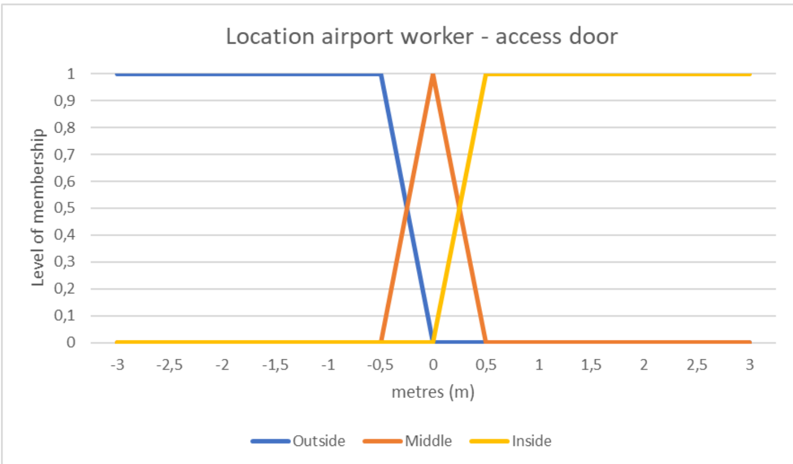

Figure 4. Fuzzy Sets Location Airport Staff

Three fuzzy sets have been considered to express the location of the user with respect to an access door: outside, inside, and crossing or in the middle of it. If the output set presents higher levels of membership with distances lower than −1 m, the user may be outside that room. If the opposite situation occurs and the output set presents levels of membership with longer distances than 1 m with respect to the 0 m reference, it is more probable that the user may be inside that room (especially when the distances are getting larger).

5. Security

The system security scheme that has been implemented includes three main fields: security of communications, secure authentication of users, and protection of confidentiality of the information exchanged between airport workers.

On the one hand, all communications between the mobile application, the Web service and the Firebase platform are performed through HTTPS. On the other hand, the Open Web Application Security Project (OWASP) [14] authentication guidelines have been used for ensuring authentication processes. These guidelines have as main objective to protect insecure software against different attacks. One of the most relevant OWASP authentication guidelines is the use of authentication tokens through the Json Web Token library (JWT) [15]. When a new user logs in, a specific custom token is generated taking into account the Firebase authentication service that is in charge of verifying user credentials. This token allows the user to access the system, receive notifications from the Web service and airport coordination headquarters, and update every new location detections in the real-time database. In addition to this, authentication tokens are very useful to avoid the use of cookies as user information storing method, so particular attacks such as Cross-Site Request Forgery (CSRF) [16] can be detected and managed. Other important applied security guidelines are based on forcing all authentication processes to be performed on the server (never on the client), encrypting all used API keys, or analysing all metadata related to a possible detected system attack for future security audits.

6. Conclusions and Future Works

This paper includes the proposal of an indoor tracking controller based on fuzzy logic that allows performing real-time monitoring of the locations and movements of airport workers. This proposal can be used for the management of airport staff and users both under normal circumstances and in emergency situations. Multiple challenges have been taken into account during the development of the proposal, such as the integration of innovative Bluetooth beacon technologies together with the development of a mobile application and a Web service in charge of scanning Bluetooth signals, for the analysis of the location and movements of airport staff, and their representation in interactive airport maps in real-time. On the other hand, particular attention has been paid to the system security in the form of the establishment of secure communications, secure authentication and protection of information exchanged between airport staff.

Since this proposal is a work in progress, several research lines are still open. To analyse and improve the accuracy of the proposed fuzzy-based indoor tracking controller, experimental testing in different scenarios is being performed on the basis of a data set composed of Bluetooth signals from different beacons scanned by the mobile application of multiple users. In addition to this, it would be interesting to expand the proposed network of distributed beacons around the airport infrastructure for improving and increasing the Bluetooth scanning area, so that the tracking of locations and movements of airport staff may be more efficient. On the other hand, the adaptation of this model to be applied directly to passengers transit may improve their experience through relevant information based on their location and movements (flight and boarding gate warnings, publicity, location of interesting airport services or resources such as boarding gates, etc.).

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Conflicts of Interest: The authors declare no conflict of interest.

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