Integrating AR and IoT Services into mHealth Applications for Promoting Wellbeing

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By blending real world information with data from digital environments using modern visualizations empowered with augmented reality features, more comprehensive and attractive software solutions can be created. Augmented Realty and Internet of Things are among the state-of-the-art technologies that contribute to the adoption of new, disrupting solutions in the fields of health and urban planning. IoT body sensors can record real-time measurements and offer instant access to users' vital signs while in parallel, environmental IoT sensors record real-time parameters for weather and pollution. In this work we are introducing a prototype application as part of a Nature-based Solution in an urban environment that offers advanced interactivity features with the users and motivates them to increase their physical activity. AR objects are placed at certain locations in the park and present user-specific or location-related information. Modern gamification techniques are also utilized, such as leaderboards and badges with content generated from the users' health data. Furthermore, location-related information is visualized including weather forecasts, environmental data and or briefing and events regarding the intervention in the urban area. The evaluation results of the system in real-world scenarios highlight positive user engagement remarks for promoting mental health and wellbeing in urban environments.

Keywords—Urban Planning, Augmented Reality, Internet of Things, mHealth

I. Introduction

Living in urban areas introduces several challenges for the physical health and the wellbeing of citizens. Finding proper environments for physical activities and workouts in proximity is often difficult due to the structure of modern cities and the limited maintenance of the available areas and facilities. In addition to the sparse availability of facilities, the lifestyle of the citizens also demotivates them from visiting these areas often and from participating in activities that typically improve their physical and mental health. This topic and the related challenges on how to deal with engaging the citizens to be more active physically and ultimately enhance their wellbeing are extensively discussed in literature and have already resulted into several innovative solutions and interventions [1][2]. On one hand, an increasing number of NBS - nature-based solutions are in progress in urban areas which include eco-friendly actions to improve the urban environment by creating sustainable, "green" spaces that have positive effect on citizens' health and engage them to be more active. On the other hand, the abundance of wearable devices, activity trackers and applications that allow users to measure their physical activity has created many opportunities for engaging them to be more active. This is widely referred to as the Quantified-self concept [3] in which the people that intend to measure their daily activity and biosignals are equipped with commodity devices that keep track of their health status, provide reports and valuable insights.

This work proposes a unique approach for combining these two aspects in an innovative mHealth solution by using AR - augmented reality technologies. The number of platforms which exploit the benefits of the related technologies is constantly increasing mainly due to the inherent features of AR to bring together the aspects of the physical and digital worlds. The motivation for this research is to exploit the advantages of AR for creating an ecosystem with elements from the physical and digital world which will further motivate the citizens to visit the NBS areas and become more active. This hybrid system will also include gamification techniques by taking advantage of the different data sources and the ability to present analysis insights and gamifications actions as part of the real-world.

Typically, the NBS interventions include actions to protect, manage and restore natural or modified ecosystems but are also making use of ICT technologies such as IoT sensors for measuring the environmental conditions and digital boards for interacting with the citizens [4]. Such solutions are creating a healthy environment for the citizens with all the positive effects that this has for their physical and mental health. In addition, they also provide them with real-time data about the current and future conditions, and useful information for upcoming activities. One key element of the proposed approach is that it incorporates these aspects into an mHealth application and adds on top of them gamification capabilities to enable further engagement. Another key element of the application is the integration with wearables and activity trackers for acquiring data related to the user's activity and health condition. These data can be used anonymously through analytics and gamification techniques to create challenges for providing incentives to the citizens to adopt a healthier lifestyle. The use of AR to tailor these aspects in a unified environment further facilitates the engagement of the users and boosts the effectiveness of the aforementioned elements.

The rest of the paper is structured as follows. Section II presents the current state of the literature concerning AR and gamification in urban planning and health. The general idea of the proposed solution is described in Section III and the implementation lies in Section IV. Section V presents the system in practice and evaluation results by using real-world scenarios.

II. Related Work

Urban Planning can be a high complexity process based on the location, the size of the city and the natural characteristics of each area. The urban planning requires a deep analysis of several factors as it can affect several factors, such as the real estate prices, the transportation and the local services, the micro-climate of the city as well as public health and citizens' well-being. During the last decades, the scientific community suggests the inclusion of NBS and Blue-Green Spaces in urban environmental planning. The aim is to redesign and develop healthier cities by following the Healthy Urban Planning (HUP) approach as this has been proposed by WHO [1][2]. Cities from all over the globe seem to understand the necessity and the value of the HUP in order to provide a resilient environment to the citizens [5][6]. According to relative studies, novel urban design strategies can significantly affect the citizens' outdoors physical activity and the cities response to the climate change effects [7][8]. Recent studies propose solutions to increase the citizens' safety and engagement in visiting areas with NBS. These solutions include several sensors and technologies, aiming to provide to citizens' better experiences in a healthy urban environment [9][10][11]. In addition, during the COVID-19 pandemic, the need for a revision on the urban planning methods and approaches has been revealed [12].

Adopting a lifestyle of prosperity by its individuals is vital in a modern society. For this way, eHealth systems that consider changing their users' habits to healthier ones, have to combine easy-to-implement and pleasant-to-use strategies in order to motivate them for achieving specific goals. The use of game mechanics is a technique known as gamification and is adopted as strategy for a variety of purposes in different contexts [13][14][15][16]. Additionally, as it is a widely used and approved mechanism, it can be used in the concept of intelligent guiding in such apps and improve the user's experience. Systems that attempt to highly motivate their users have to implement elements that are deeply integrated in the users' interface while in parallel, the system has to supports these game mechanics and the respective elements by design so that it can be effective. Additionally, applications exploiting the wearable devices and the related technologies include, among others, health monitoring, activity recognition, tracking and localization, safety, and are the perfect candidates for using the gamification elements to enhance the user experience [17].

The most common and historically the traditional form of a gamification approach is the Points - Badges - Leaderboards [18]. Points are used as in-app credits, in order for the user to "unlock" other features, while the Badges are awards that a user wins every time specific actions or quests are accomplished. Leaderboards are visual features which enable users to get informed where they rank in relation to other users. Hanranths 2016 et al. [19] describe a framework based on game elements in learning environments to engage user's motivation.

Ilhan et al. [20] analyzed the gamification methods used in fitness apps such as Samsung Health, Garmin Connect, and Fitbit to motivate their users to adopt more healthy lifestyle habits. Game mechanics like Goals, Points, Levels, Badges, Leaderboards are found to change the user's behavior by motivating and making the activity enjoyable. More specifically, the Leaderboards motivate the user to become better than other users are, while Badges are pleasurable features for users who enjoy getting rewards after a goal completion. Additionally, by using wearables, studies have shown that it may engage the users in a training program on a regular basis which can lead to significant health improvements [21].

AR technology is the ability of the seamlessly integration of already existing environments enriched with computer generated visualized information [22]. User adoption of AR shows high rates in the consumer context and thus results in offering a comprehensive user environment [23]. AR finds application in several fields, from construction and engineering to smart city concepts and wellbeing. Integration with GIS services evaluates the parameters of different features such as performance, usability, effectiveness, and satisfaction of the AR technology [24]. Mobile AR is applicable in campus navigation systems [25] and in real-time location-based advertising platforms [26]. Furthermore, AR shows positive results in the Health and Fitness field. The adoption of such technologies used by mobile and commodity devices in form of exergames results in positive health impact by motivating users to increase their physical activity while at the same time monitor and assess their vital signs [27].

III. The Concept

The proposed platform aims at increasing the user's motivation for visiting a park, in which an urban planning intervention takes place, by utilizing AR, wearable devices and IoT create a unique environment with real-time information and gamification quests. The concept of this application paradigm is illustrated in Fig. 1.

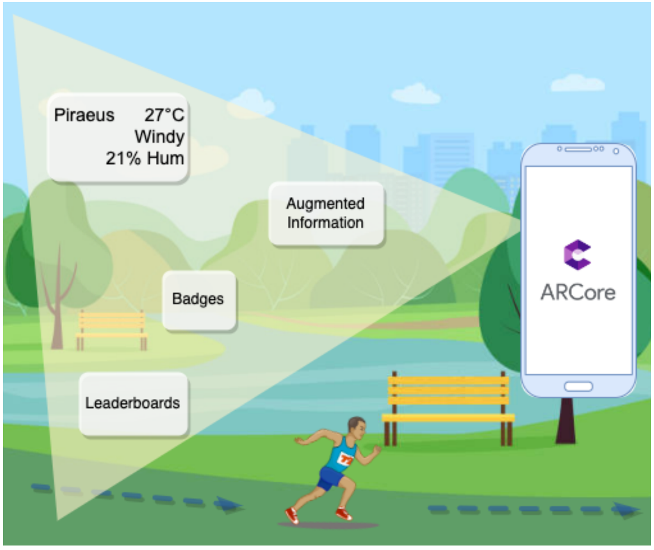

Fig. 1. Concept of the platform.

The system is fed with a variety of data visualized in a way that will increase the user's willingness to visit the park. All data are generated in real-time and can be changed dynamically while a user is in-session. By blending virtual and real world, AR facilitates the user adoption and increases the scopes of the local interventions. Data are divided in two general categories, Location-based information and User-specific information.

A. *Location-based Information*

Location based information are data records which are considered to be useful for the user of nearby attractions or activities. They also include navigation data providing on-screen directions leading the users to either a desired spot or reveal a certain route. Furthermore, weather and environment data retrieved from local IoT sensors are displayed in their precise location and are updated in real-time.

B. *User-specific Information*

User-specific information are personal, health-related data elements that are different for each user and include health and fitness measurements as well as badges and leaderboards in the scope of gamification features of the system.

Gamification elements are the means to motivate users to use their wearables and become more active in their daily lives. In addition, the system encourages users to become more social by rewarding them with badges when they are moving in public spaces such as parks. All data used by the gamification elements are generated by wearables, smartphone devices, or fitness trackers that are compatible with the platform and support direct (via Bluetooth) or indirect (via Cloud) data exchange. The system can recognize the physical activities when the user uses his/her wearable device. Several metrics are used in the system in order to design the gamification elements: 1. total daily steps, 2. distance, 3. duration of physical activities and sleep, event related to user activities or visits to the public space area

Leaderboards are visual representations of users' ranking in certain aspects. Leaderboards can have the form of ranking/scoring tables and every user can view his performance and compare it with performance that other users have. The current study exploits anonymized graphs as Leaderboards that allow the users to view their ranking in the system. Cumulative charts and distribution charts are used for this purpose. In this way the system shows the user's position in the charts, hiding details that are related with other users' personal data.

Badges represent the users' achievements based on the goals completeness. The user interface is designed in order to address the main objective that is to provide feedback on the users' progress and educate them on how to accomplish their goals. Some cases that are used for badge concepts are the total accumulated steps, completing a minimum number of steps each day, visiting a defined public area every day, and others. During the period that the users try to complete their goals, every badge is represented as a widget in the user interface that shows the progress and the effort needed to complete the final goal. Additionally, every time the goal is completed, the user is rewarded with the relevant badge by visiting the park defined by the application.

C. *Data Visualization*

A problem needed solving was the way in which the virtual objects will appear in their correct position within the park for all system users. The technique we used is called SLAM [28], a sort of computer vision technology that identifies and presents objects at precise locations across different devices. Using only the mobile device's camera and IMU sensors, SLAM generates a feature map for each captured area. Then, if an AR object is placed in this area, the feature map along with other metadata (GPS location e.g.) are stored on the Cloud. By opening the camera again, the feature map of an area is identified, and all local objects are presented at their precise location. Taking as example the weather AR label, the label will first be placed using a mobile device. Once the label is attached, the area around it will be converted to hot corners – features and then uploaded to the Cloud. These features can be resembled as a panoramic image of the area around the label. When another user with a different device reaches the same area and opens his mobile device's camera, a computer vision algorithm will try and match the previously recorded features with the front area. If the feature map identifies a known area, the virtual object is automatically attached to the scene and, thus, placed at the precise location it was set. While location selection will be performed once, resolving and attaching procedure can be done from various devices.

IV. Implementation

A. *System Architecture*

The proposed system adapts gamification techniques in order to motivate the users to complete specific goals by combining wearable devices like smartwatches, activity bands, mobile phones, and a sophisticated software architecture. Mobile devices can collect and send data to IoT systems, while the users receive all the information that is generated from these data by utilizing software solutions for better user's experience.

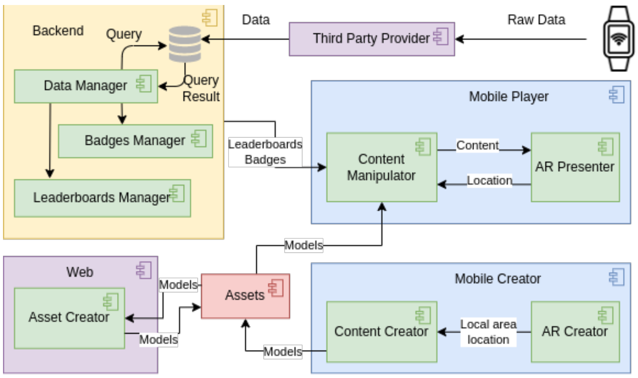

Fig. 2. System Architecture

The system architecture is divided into *Cloud*, *Web* and two *Mobile applications* as presented in the component diagram in Fig. 2. Each application contains components for manipulating the assets, managing content, configuring AR elements and other required procedures.

The *Cloud backend application* is deployed on the Firebase environment and contains serverless functions and NoSQL databases. *Badges Manager* and *Leaderboards*

Manager components are responsible for generating the user-personified leaderboards and badges, managing all the user data retrieved from the database, as demonstrated in Fig. 3 a.

The Web Application is available only to the system administration and manages the AR related content via the *Asset Manager* component. This component manages all content assets, the 3D models, vectors, images, and rich text that will later be presented to the user's application.

Two mobile applications are developed for the purpose of the prototype: *Mobile Creator* and *Mobile Player*. *Mobile Creator* is used only by the system administrators and handles the AR content creation flows. It is responsible for selecting the predefined locations that an AR anchor will be "dropped", defining the content of this anchor, and uploading the information to the *Cloud*. *Mobile Player* is the end-user application that will be available to anyone who wants to visit the park. After authenticating the user, it retrieves health related data, badges, leaderboards and their appropriate AR anchors.

Based on SLAM, locations of the requested anchors are identified, and the results are visualized on the screen presenting a fascinating and comprehensive human-machine interaction experience.

B. Gamification Data Models and Operation

Modelling the gamification elements is a crucial task for the performance and for reusing scopes. A balance between simplicity and effectiveness on the model's design is used in order to perform both efficiency and reuse on those elements. In Fig. 3 b the badge model is illustrated as a composite object of three basic elements, the *BadgeStatus*, the *BadgeConfiguration* and the *BadgeLevel*. The *BadgeConfiguration* object contains the information about badge title, description, and levels. It also has actions to be used for computations. These actions include the metric parameters to be calculated (STEPS, DURATION, LOCATION and other), the period to gather the data (DAILY, WEEKLY) and the calculations to be performed on the collected data for analysing them. Every badge may contain more than one level in order to be marked as completed. Every level has a title, a description and a goal that is described by the min, max or strike elements. The min or the max value is required and specifies the minimum or maximum effort to be performed.

As an example, a goal could be described by setting the min value to 100.000 and metric parameter to STEPS which means that the user has to achieve at least 100.000 steps. If the strike element is set, then defines the times in a row that the user has to achieve a goal. A strike equal to 5 and a min equal to 6.000 for STEPS as the metric, means that the goal is 6.000 steps every day for 5 days in a row. As part of the operation, related queries are predefined and applied during runtime in order to perform efficient data retrieval.

The calculations are performed at certain times every day for all users and are represented in the model as *Action* objects. The objects include information about the type of data to be calculated, the queries, and the period (WEEKLY, DAILY) during which the data should be manipulated. In the next step, the computations are performed according to the definitions that are given by the *BadgeLevel* as described in the previous paragraph. If a Badge contains more than one level, the user must complete all the levels that compose the Badge, in order to set the Badge as completed.

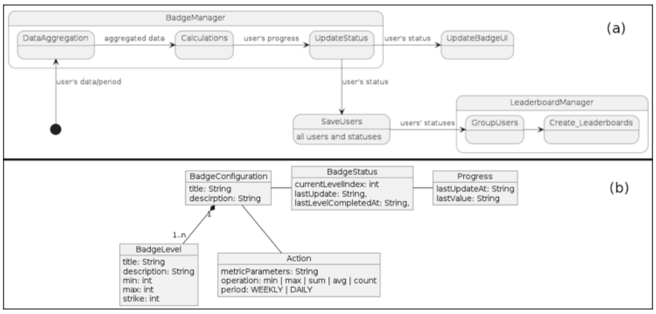

Fig. 3. a. Badge Flow, b. Badge Model

Regarding the generation of the *Leaderboards*, the data are retrieved by queries that are predefined and are configured according to the data types and time periods. As a next step, the data are aggregated and grouped by gender and age category. Several classes are created in order to represent properly the users' achievements according to the different users' groups. Using this model, every user can view the charts related to achievements by his/her category.

C. The Augmented Reality Subsystem

AR for mobile devices is a technology that visualizes the required digital content without losing the user's sense of presence. For this demonstrative example we are using Google's *ARCore* library with support for both iOS and Android. *ARCore's Cloud Anchors API* is utilized for applying SLAM techniques.

In *ARCore*, all AR objects that are present in the environment are called anchors. Anchors are hosted via the *Mobile Creator* application using *Cloud Anchors* hosting functionality. Three objects have been created, as illustrated in Fig. 4, in order to proper display the visualized data at a precise location: *GoogleCloudAnchor*, *LocalizedAnchor* and *VisualizedAnchor*.

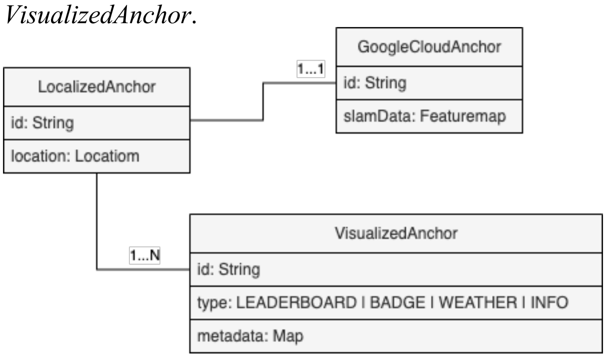

Fig. 4. The AR Anchors Model

GoogleCloudAnchor objects are stored at the Cloud Anchos API and contain the SLAM and feature map related information. *LocalizedAnchor*s are responsible for matching *GoogleCloudAnchors* with coordinates and other location related metadata and, finally, *VizualizedAnchors* contain the content of each anchor that will be displayed to the end user. While *LocalizedAnchors* and *GoogleCloudAnchors* share a one-to-one relation, *VizualizedAnchor* objects are related with more than one *LocalizedAnchors*.

System administrators are responsible for localizing, attaching and hosting the anchors. The content that is contained in an Anchor is different per user and type, thus Anchors are separate from their displayed data. *Mobile Creator* and *Web* apps define which information will be presented at each anchor for each user. *Mobile Player* application uses *ARCore Cloud Anchors* anchor resolving functionality to download and localize the precise locations of the retrieved anchors. Appropriate information is retrieved from the cloud and visualized as an AR anchor on the screen.

V. System In Practice and Evaluation

A. Real-world usage scenarios

The developed prototype was tested in real-world usage scenarios by introducing AR objects for both Location-based and User-specific data categories. The precise locations of the objects were defined by the *Creator* application while the data are presented dynamically.

Internal validation activities took place in the context of the project which focused on the technical aspects. The usability and the overall effectiveness will be assessed in pilot deployments in three cities which implemented NBS. The prototype will be available to the project participants and it is currently closed source, however after the assessment, the delivery of a public version will be considered.

For Location-Based AR objects, indicators providing places for outdoor gym as well as weather-related information are displayed, as presented in Fig. 5. These objects have a location-based content, meaning that they are visible to all users and their goal is to notify, inform and help.

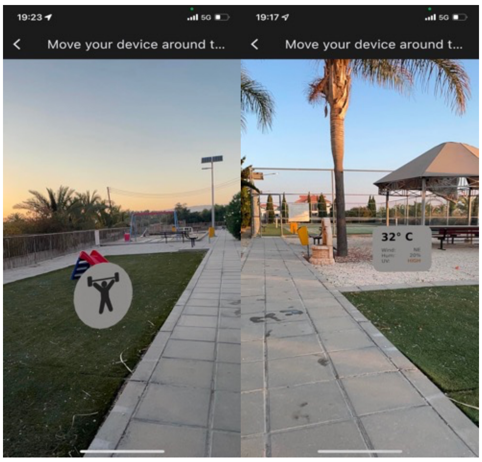

Fig. 5. Location-based AR objects

Concerning the User-specific information, as demonstrated in Fig. 6, data from leaderboards and badges are generated and visualized. The leaderboard ranks the current user compared to all others (anonymously) while the user's current badge can also be found in the park. Although the location of such objects is predefined by the creator, the content is different for each user.

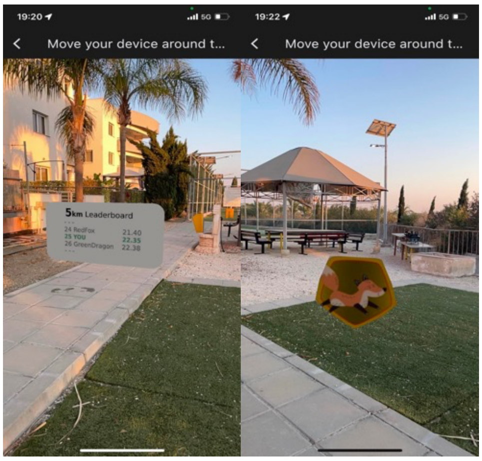

Fig. 6. User-specific AR objects

B. Performance

Performance metrics were captured in order to provide a clear view of how the system interacts with the users in the context of human-machine interaction principles. Tests were performed for various devices concerning loading times, FPS, MB consumed, and battery drain as metric parameters. All devices were tested for a duration of 5 minutes and were set to display 12 anchors each. Each test was repeated for 10 times, resulting in a total of 30 tests. Results of the experiment are presented in the following table.

TABLE I. Performance Results

Device	OS	Loading Time	FPS	Data Usage	Battery Usage
iPhone SE 2020	iOS 15.5	3.1s	48	8.5MB	1.2%
iPhone 12	iOS 15.6	2.9s	53	9.1MB	0.8%
Huawei ANE LX1	Andr oid 9	4.2s	36	7.6MB	1.3%

As shown in TABLE I. , the three hardware ranges of phones that were tested demonstrated a pleasant execution of the prototype application. Although FPS metrics may vary, everything above 30 FPS is considered totally acceptable concerning a user experience in a mobile device.

C. Evaluation

The content of this AR application example in both visual and informative aspects may considerably improve the engagement of the users to visit the park often and which in will have a positive impact on their health. By providing the user with not only his fitness data but also comparisons to other users in the context of a tailor-made gamification scenario, as well as by visualizing the data in a blended with the real environment way, it highly increases their willingness to repeat their visits and achieve a better personal "badge".

Augmented information about the current, previous, or future attractions is another factor that will engage the users to make a visit. Navigation and routing will also help participants to find their paths and all visitors to not miss visiting any important to them space. What makes this approach unique is the requirement of the user presence in order to get access to this information. By requiring presence, motivation to perform a visit in the park is increased.

VI. CONCLUSIONS

The proposed work illustrates a prototype mHealth and AR solution that motivates the users to visit urban sites where Nature-based interventions are taking place in order to increase their physical and mental activity. State-of-the-art technologies are applied and User-specific and location-related information are presented as 3D augmented objects in the user's phone screen. Advanced AR visualizations and access to additional information will only be available if the user is present at the park thus, resulting in engaging the user to visit it. The variety of content and the dynamically updated information offers a comprehensive and pleasant way of exploring and interfering with the environment. Navigation vectors that lead to running routes or physical activity areas are presented as stuck to the ground arrows while the fitness data and rankings are also available as virtual tables and objects. Additional information such as wind, temperature, humidity and air pollution data will offer the user a complete AR experience accommodating the users to be more active, increase their physical activity and have a greater impact on their health.

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