Semantically Enriched Augmented Reality Applications: A Proposed System Architecture and a Case Study

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Abstract—With a view to creating a mixed reality that combines coexisting real and virtual objects and to providing users with real-time access to information in an interactive manner, augmented reality enriches users' physical environment by incorporating digital and real objects and rendering them in the physical environment in the proper time and spatial framework. Due to its nature, augmented reality can be combined with and exploit other innovative technologies in order to improve its efficiency and potentials. Some such technologies are semantic web, knowledge graphs and deep learning. The study main purpose and contribution is to showcase the benefits of developing semantically enriched augmented reality applications and to present a system architecture for developing such applications as well as to showcase and assess an augmented reality application developed following the proposed architecture. The specific application aims at facilitating end-users' day-to-day activities, enhancing the learning and informing process and increasing user experience (UX). The results of this study showcase that such applications have the potential to be applied and positively affect various sectors and that they can be a useful, flexible, interactive and informative tool for end-users.

Keywords—augmented reality, cross reality, deep learning, human computer interaction, immersive technologies, mobile augmented reality, machine learning, semantic web, extended reality, case study

1 Introduction

Nowadays societies experience rapid growth due to the advent of the information era which has brought about the need for real-time interactive access to dynamically changing information and data. Additionally, the digitalization of everyday life and the adoption of smart devices and technologies have led to the generation of heterogeneous data which increases exponentially. Due to technological advancements, computer systems and smart devices have more processing power along with more intelligent and powerful sensors and actuators [1]. As a result, these interconnected and intelligent devices have the capability of interacting and communicating over the Internet and consequently they are able to rapidly retrieve, store, process and display large volumes of heterogeneous data [2].

Augmented reality is a contemporary technology which in order to meet users' new requirements aims at exploiting these technological developments and the increased volume of data to create more interactive and powerful ways of environment modification, interaction and augmentation. In addition, augmented reality provides access to the rapidly flowing information which is integrated into the proper time and spatial framework and becomes "alive" and meaningful [3]. Therefore, augmented reality provides users with new ways to experience a mixed reality world in which they are able to simultaneously interact with real objects and digital content in real time while also offering them smart solutions to facilitate their daily tasks and everyday life. Due to its nature, augmented reality can be combined with and exploit other innovative technologies in order to improve the efficiency and potentials of its applications. Particularly, the integration of semantic web, knowledge graphs and deep learning into augmented reality leads to successfully meeting the need for more robust, adjustable and customized technological applications [4].

Presenting a novel system architecture for developing semantically enriched augmented reality applications as well as showcasing and assessing an augmented reality application which was developed following the proposed architecture are the main contribution and purpose of this study. Particularly, by offering new ways for users to interact with the virtual and real environments, this application aims at enhancing the learning and informing process, facilitating their everyday life as well as increasing the user experience (UX). Therefore, this study goes over the technologies of augmented reality, semantic web, knowledge graphs and deep learning as well as other related studies. Moreover, it showcases a suggested system architecture for developing semantically enriched augmented reality applications and describes an augmented reality application along with its development and implementation processes. In addition, it presents the results of an experiment which was conducted in order to assess the usability and functionality of the application. Finally, it highlights the main points of the study and discusses potential future work.

2 Technologies used

2.1 Augmented reality

Augmented reality utilizes contemporary applications and computer units in order to provide real-time immersive and interactive experiences and to enhance users' perception by enriching the real environment with virtual objects and content that co-exist with those of the physical one and are customized to their surrounding environment [5][6][7][8][9]. The combination and harmonization of real and virtual objects along with the novel ways to interact with them can be regarded as the main features of augmented reality [10]. By creating a three-dimensional (3D) overlay of dynamic and interactive data that is being registered on the suitable time and spatial framework, augmented reality renders the creation of a mixed reality feasible. More particularly, a mixed reality environment constitutes a space in which both real and virtual objects co-exist and are presented in a unified depiction in the real world, as it is perceived by the users through their senses, and in between the "reality—virtuality continuum", which has augmented reality at one end and augmented virtuality at the other [3][11].

2.2 Semantic web

Semantic web extends the World Wide Web (WWW) and as it constitutes an actionable information web that is "*information derived from data through a semantic theory in order to interpret the symbols*" [12, p. 96] and by capitalizing on the semantic theory, it enhances the data retrieval, processing, sharing and reusability as it allows computers to understand the data content and the semantics [12][13][14]. Semantics offers syntax rules, facilitates the interpretation process and gives meaning to each language. Hence, having access to structured data and inference rules sets is a prerequisite for computers to autonomously use semantic reasoning [14]. It is worth noting that the use of open data is imperative for the semantic web realization. Nonetheless, due to the nature of open data, certain privacy and security issues and challenges may arise [15]. Semantic web achieves the semantic modeling of knowledge through the ontologies which are being used as knowledge bases [16] and can be defined as "*an explicit specification of a conceptualization*" [17, p. 908] and particularly, as "*a formal, explicit specification of a shared conceptualization that is characterized by high semantic expressiveness*" [18, p. 15]. Additionally, ontologies use inference rules as well as taxonomies and identify the relations among terms and knowledge structures to enhance the accuracy and effectiveness of search engines [14]. Semantic search engines and assessment systems which focus on the contextual meaning of the search query and users' intention in order to provide more relevant and accurate results can be created through the use of semantic web [19][20].

2.3 Knowledge graphs

The creation of extensive knowledge graphs was the result of the increased number of data models which are highly normalized, are characterized by their variety and simplicity and derive from diverse sources [21]. Within the context of knowledge graphs, contextual information is used to enrich data connectivity and for the knowledge representation, the concept of nodes (entities) and their interrelation and interconnection (edges) are used [22][23]. Through the interconnection of concepts and entities, knowledge repositories which support data related processes (e.g. retrieval, monitoring, analysis, management etc.) are being generated [24]. In particular edges refer to the semantic relationships while entities to the object categorization [24]. Furthermore, knowledge graphs utilize unambiguous identifiers, denotations and statements in order to create labeled links between entities (vertices) and since meaning is encoded within its graphical structure, only a specific number of relation types and direct assertion provenance are included [25][26][27]. Therefore, a knowledge graph can be regarded as "*a graph of data with the intent to compose knowledge*" [25, p. 76]. Knowledge graphs can be used in several fields as they are able to define, classify and interrelate arbitrary and real-world entities within a knowledge schema in a form of a graph regardless of their context [23]. Due to this fact, and as they extend pure knowledge-based systems and build up functionality, such as the ability to interact within several external sources, knowledge graphs are distinguished from other collections of knowledge [16][23]. Furthermore, knowledge graphs "*acquire and integrate information into an ontology and apply a reasoner to derive new knowledge*" [16, p. 3] and as a result, they constitute a form of semantically enriched graphs and are connected with the technology of semantic web [28]. Owing to its ability to dynamically crawl the web, a knowledge graph constitutes a self-contained semantic web, thus the most comprehensive knowledge graph is the semantic web in itself [16].

2.4 Deep learning

Deep learning constitutes a novel sub-field of machine learning that exploits the significant increase in computational power and in data volume and can be integrated into several domains as it offers customized and intelligent solutions. Deep learning models "*learn to represent the real world as nested hierarchies of concepts with each individual concept being defined as a result of other simpler and more abstract concepts and representations*" [4, p. 34]. Particularly, they are characterized by high levels of flexibility and extensibility as they learn through examples that is, mimicking the way humans learn. Moreover, deep learning enables "*computational models that are composed of multiple processing layers to learn representations of data with multiple levels of abstraction*" [29, p. 436]. It is worth mentioning that the term "deep" refers to the multitude of layers through which the data is transformed. Due to the high levels of complexity and with a view to finding out intricate structure in high-dimensional data and large data sets, the backpropagation algorithm is used to define how the internal model paraments should be configured [29]. Additionally, deep learning models facilitate the creation of advanced decision-making systems and improve the performance of the systems in which they are applied to as they autonomously detect and utilize the most optimal combinations of perplexed input data [30].

3 Related work

With the aim of providing contextual high-quality information about specific points of interest Reynolds et al. [31] went over the impact that linked open data has on augmented reality applications. They suggested that as linked data i) supports dynamic data selection and integration from various sources, ii) enables contextual data to be utilized and iii) provides browsing experience similar to the current Web, it could be used to enhance augmented reality applications. An intelligent augmented reality architecture (i-ARA) that utilized principles of the semantic web technology was proposed by Hervás et al. [32]. This architecture took advantage of the expressiveness of semantic web rule language (SWRL) [33] and web ontology language (OWL) semantic axioms [34]. With the aim of supporting users' daily needs and taking into consideration users' personalization and context-awareness, they emphasized determining mechanisms to deploy augmented reality applications that facilitate the development and implementation of smart decision-making systems. A system, which combined semantic web with augmented reality in order to store context-aware data in a standardized format while also enabling it to be showcased in the real world and linked with other public datasets, was presented by Matuszka and Kiss [35]. Their system allowed users to navigate and explore predefined locations while offering them interactive specifics regarding their characteristics, thus enabling users to acquaint themselves with the locations. With a view to developing an interactive augmented reality application that would support high degree of query expressiveness and which would allow users to search for personnel, students, events and places through a university campus, Contreras et al. [36] utilized augmented reality in combination with semantic web. This specific application followed a client–server architecture with the semantic web module and the searching process being handled by the server side while the augmented reality module by the client side. Their semantic model which was named "University of Cuenca Ontology" and the NeOn methodology proposed by Suárez-Figueroa [37] was applied for its development. Aiming at broadening users' knowledge and awareness, Kim et al. [38] developed a mobile augmented reality application utilizing semantic web technologies that offered relative and useful contextual information regarding specific predefined heritage sites. Furthermore, for the development of their application, they used an information modeling framework which was composed of: (i) heterogeneous cultural heritage data aggregation, (ii) semantic linking web resources and (iii) using the Korean Cultural Heritage Data Model to create a user-centered information ontology. According to their findings, it was evident that their application offered a pleasant and acceptable user experience in relation to efficient, constructional and cognitive features. Flotyński and Walczak [39] provided a comprehensive review regarding the advances in the field of 3D content and object modeling and representation while putting emphasis on the semantic web technologies and going over its specific features and approaches. Rumiński and Walczak [40] presented a client-server framework for developing distributed augmented reality applications and services which was based on Service Oriented Architecture (SOA) paradigm. Their framework supported large-scale semantic modeling and contextual representation. Their findings showcased that semantic web can be used to assist the development of contextual distributed augmented reality environments. Moreover, they highlighted that generating individual knowledge bases with different variations can improve the information searching performance. In their study, Lampropoulos et al. [4] went over the recent literature review about the benefits of using augmented reality in combination with deep learning, semantic web and knowledge graphs to enhance augmented reality application and system functionality and services and to highlight how they can be used in conjunction to provide more intelligent, flexible and user-centered applications. Le et al. [41] suggested using machine learning to overcome some of the image processing challenges in augmented reality. In their study, they developed an augmented reality iOS prototype application that utilized ARKit along with machine learning and incorporated YOLOv3 [42] for object recognition and tracking. In their study, Grandi et al. [43] provided a reference framework that can be used in order to combine augmented reality with model-based design to enhance social sustainability. Based on their suggested framework, they developed a prototype augmented reality application using Vuforia. Moreover, they carried out an experiment in which 10 users participated and conducted a qualitative key performance Indicators (KPI) evaluation.

4 Application description

This study focused on the development of a smart and interactive augmented reality application in which semantic web and deep learning were also incorporated in order to further improve the quality of service (QoS) and the quality of experience (QoE) as well as to enhance the overall UX. The main objectives of this approach were to recognize objects under different conditions, to utilize semantically linked open data [44] to identify and retrieve information which relates to the identified object and to augment it in the physical world in real time so that users would be able to interact with it. Additionally, based on the recognized object, the application provides additional functions such as narrated descriptions, interactive 3D models, related videos and hyperlinks, mapping tools etc.

In order to substantiate the study approach, an augmented reality android application which combines augmented reality, semantic web and deep learning was developed. The application allows users to recognize objects (e.g. cultural heritage monuments, locations, vehicles, plants, animals, food etc.) via their mobile devices and to receive useful information in an interactive way in real time.

The suggested system architecture, which this application is based on, is differentiated from applications of other studies as it provides increased flexibility to the development of the augmented reality application and renders the focus on a wide range of object classes and use cases and not only on specific ones feasible. Therefore, this specific application is able to recognize various object classes from 8 broad categories of objects which can be used in numerous application fields. These categories are: Cultural Heritage Monuments, Food, Medical Equipment, Plants—Flowers, Animals, Vehicles, Vegetables and Fruit. Additionally, the information retrieved and displayed as well as the functions offered to the users change dynamically based on the class of the object that is being detected. Thus, the usability, extensibility and interoperability of the overall application are enhanced when compared to other more static applications which were developed only to address specific use cases. Moreover, due to its architecture and design structure, it can be used both indoors and outdoors with or without internet connectivity.

Once an object is identified, the relevant information is retrieved either dynamically by the ontology created and uploaded on the Virtuoso server of the Department of Information and Electronic Engineering of International Hellenic University (IHU), or by the corresponding ontology integrated in the application. A key factor that has led to this particular architectural option is the fact that the application will be used in both internal and external environments. Therefore, in cases where internet connection is not possible, the application automatically searches on the embedded ontology in order to retrieve information. When changes to the ontology uploaded on the Virtuoso server are made, the embedded ontology is automatically updated the moment the device connects to the Internet. By doing so, the retrieved and presented information to users is always up-to-date.

The information retrieval process is followed by the interactive depiction of data on users' device screen in real time. The interaction between users and digital information of the virtual world is accomplished through augmented reality. In order to render the interaction with real and virtual environments and objects feasible in a novel way, to increase end-users' experience and enhance their learning and informing process, the application provides additional functionalities based on the recognized object. Therefore, besides the retrieval and display of the related to the recognized object information, users also have the ability to search for related images, videos and be redirected to useful websites. Moreover, the application offers narrated descriptions and information about objects as well as interactive 3D representations. When the recognized object is a monument or a location, users are also able to search for its specific coordinates and find the shortest route to it. Figure 1 depicts examples of the application functionality.

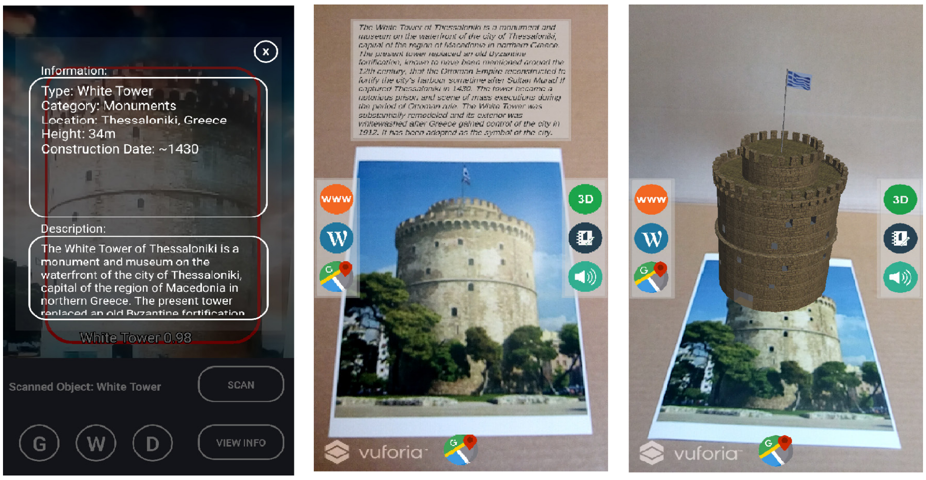

Fig. 1. Examples of the augmented reality application

5 Implementation—methodology

The tools selected for the application development were open-source whenever possible. This specific choice was based on the fact that open-source tools, software and platforms promote and enhance cooperation and knowledge sharing, improve systems control, security, availability and stability, facilitate the integration with other software and offer more flexibility to the confrontation and management of future changes. The processes implemented in this specific approach and consequently in the development of the augmented reality application can be grouped in four (4) categories, which are analyzed further below.

5.1 Data collection, pre-processing and data creation

Initially, for the development of a new dataset, the following eight (8) broad categories of objects were selected: Monuments, Food, Medical Tools, Plants Flowers, Animals, Vehicles, Vegetables and Fruit. Thereafter, for each category, three (3) individual objects were selected and 350 images were collected for each of them. In order for the learning process of object basic features to be enhanced in the subsequent stages, each image depicted the object from different angles and in different conditions (e.g. weather, lighting etc.). However, in order for the dataset to be used for training a deep learning model, it was necessary to pre-process the data. In particular, the dimensions of each image were changed to 300 × 300. Additionally, for each object depicted in an image, the class label and the bounding box coordinates were manually determined through annotations. Afterwards, the individual identifying features of the images were saved in Extensible Markup Language (XML) files. Figure 2 shows the pre-processing procedure concisely. The final dataset, which was created and utilized, consisted of 8,400 different images which presented twenty-four (24) different object classes from eight (8) broad categories, as well as 8,400 XML files with the image annotations.

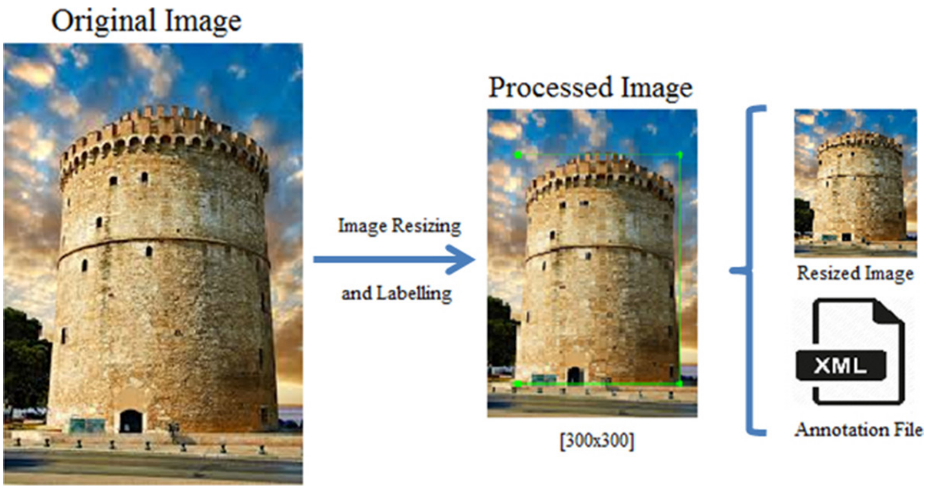

Fig. 2. Data pre-processing procedure

5.2 Development and training of the deep learning model

The creation of the new dataset was followed by the training and development of the deep learning model for the detection and classification of objects. As mentioned above, this specific application is intended for implementation on mobile devices and for use both indoors and outdoors. Therefore, the selected resources and tools favor the use of deep learning models on mobile devices. For the development of the specific model, the software library TensorFlow [45] and in particular the TensorFlow Lite version was used. This version solves many of the limitations and difficulties of on-device machine learning inference and concurrently, it offers many advantages such as enhanced efficiency, higher portability and acceleration rates, shorter latency times, significantly smaller models etc. Its potentials, in combination with the useful tools, libraries and functions it offers, make it ideal for the development and implementation of deep learning models on mobile and embedded devices.

There are several models and architectures for object detection. In this specific implementation, due to its capability of detecting objects very accurately and rapidly, Single Shot Multibox Detector (SSD) [46] was selected as the object and multibox detector and MobileNetV2 [47] as the neural network architecture. More specifically, MobileNetV2 was selected instead of MobileNetV1 [48], as its application is more efficient and effective on mobile devices. SSD, as its name indicates, implements localization and classification procedures in a single forward pass of network. In order to implement bounding box regression, SSD uses the MultiBox technique which is presented in [49]. The network also constitutes an object detector which classifies the detected objects. SSD takes an image and a set of ground truth labels as an input. Then, by extracting the main features of the image through the use of a base network and several extra feature layers, it yields several sets of multi-scale feature maps. With a view to evaluating a small set of default bounding boxes, it uses a set of convolutional filters for each location in each of these feature maps. Concurrently, it predicts both the class probabilities and the bounding box offset for each one of the default boxes. During training, it matches the predicted bounding boxes with the ground truth boxes based on Intersection over Union (IoU). SSD applies Non-Maximum Suppression (NMS) so as to filter and exclude highly-overlapping boxes and redundant results in general.

In order to limit the need for high computational power equipment and reduce the time required to train the model, a process called transfer learning was selected. Transfer learning constitues a specialized learning method in which a more complex but successfully pre-trained model is reused to train a potentially new and simpler model through transferring useful knowledge and experiences. The main aim of transfer learning is the enhancement of model overall learning process by exploiting the pre-existing knowledge [50]. Transfer learning facilitates and accelerates the overall development process of deep learning models while requiring less input data [50][51]. For all the above-mentioned reasons, it is also considered to be the future way for the rapid training of new complex models. With the aim of implementing transfer learning in the training process of the model, the pre-trained model "ssd mobilenet v2 coco" was utilized. In particular, the Common Objects in COntext (COCO) dataset [52], which is provided by TensorFlow, was used to train the specific model. After the completion of the multi-stage process of training, the model inference graph was generated. It is worth noting that due to the fact that transfer learning was used and the objects to be recognized were a few and distinct, the performance of the model was high.

5.3 Modeling and development of the semantic ontology

A semantic ontology was used as knowledge base for the semantic representation and the interconnection of the data. This specific ontology was developed using the platform Protégé (https://protege.stanford.edu/) [53] and the knowledge representation language OWL [34]. The information contained in the ontology was collected through several open access databases. Particularly, the ontology contains more general information about the specific attributes of each of the eight (8) main categories as well as additional and more specialized information for each of the twenty-four (24) objects according to their individual characteristic and attributes, type and category.

In order for this specific ontology to connect, to utilize and be utilized by other linked open data, as well as to be able to provide dynamically changing information, it was uploaded on a Virtuoso Server of the Department of Information and Electronic Engineering of IHU. In this way, dynamically changing and interrelated information is offered to users. As the application is intended for both indoor and outdoor use, there may be cases where users will not have access to the Internet. For this reason, an embedded in the application ontology which is utilized when connection to Internet is not feasible was also used. Additionally, the embedded ontology gets updated to the latest version of the online ontology when the application is connected to the Internet. In this way, the information retrieved and presented to the users is always up-to-date and the application can also be used when Internet connection is not available. The application monitors the state of the device and the network and performs accordingly the appropriate SPARQL queries either in the embedded ontology or in the ontology located in the Virtuoso server. Hence, the application robustness in extreme conditions is enhanced, while the potential of providing dynamically changing interconnected information is maintained.

5.4 Application development

The Android Studio SDK (https://developer.android.com/studio) and the Unity Editor (https://unity.com/) were used for the development of the android application. There are several augmented reality frameworks that can be used in order to develop android applications all of which have both advantages and disadvantages [54]. This study utilized the Vuforia SDK (https://developer.vuforia.com/) so as to materialize the development of the augmented reality application. The inference graph of the SSD MobileNetV2 model was used in conjunction with TensorFlow operations to detect and recognize objects in real time. Thereafter, the on-device ontology was embedded into the application to act as a knowledge base from which the relevant information will be retrieved in case the connection to the Internet is not feasible. As it has already been mentioned, the same functionality is also offered through the dynamic ontology uploaded on a Virtuoso Server. Moreover, the interconnection of ontology semantic information with the android application was accomplished through Apache Jena. SPARQL queries were used for the semantic information retrieval. Augmented reality was utilized to display the information in an interactive way in users' physical environment as well as to provide additional functionalities based on the detected object. For example, in the case of monuments, the users are able to interact with 3D models, get additional information in the form of video, text and audio messages, find map instructions on how to get to the specific location etc. It is worth noting that the SSD model is being used to detect each object and its corresponding position and only when the user selects the option for additional information or functionality to be displayed, the augmented digital content is shown through the use of Vuforia as it can be seen in Figure 1.

5.5 Summary of the development process

The above-described approach resulted in the development of a new dataset, ontology and SSD MobileNetV2 model as well as the development of a lightweight mobile augmented reality application. By virtue of its embedded systems, the application can be fully utilized in both indoor and outdoor environments even in adverse conditions. Furthermore, using this application through their mobile device, end-users will be able to detect, track and recognize objects and retrieve useful relevant information in real time. Finally, this information will be augmented to the users' environment and they will be able to fully interact with it and comprehend it in an immersive manner.

6 System architecture

The most essential and important entity for each augmented reality application is the physical environment, as augmented reality experiences cannot be created without it. Besides the use of the physical environment, the architecture of this particular application uses the following four (4) modules (Figure 3):

- Augmented reality module: This module comprises the application central module as it communicates and interconnects with the other modules. In particular, it receives input data (images) through sensors (camera) embedded in the users' mobile devices. This data is then processed with a view to being transferred to the next module in the best possible way. Moreover, this module communicates and interconnects with other modules by sending and receiving the necessary for each case information. Therefore, it can be considered as the mediator of the system. The most significant process it performs is to augment the information in the users' physical environment in an interactive way and in real time.
- Object recognition module: This module is responsible for detecting, identifying, defining and classifying objects. Specifically, it receives the pre-processed image as input and then through the SSD MobileNetV2 model is subject to further processes in order to extract its basic characteristics and to be classified in the appropriate class. An additional basic process of this module is the detection and definition of the position of each object depicted within the input image.
- Semantic module: This specific module is responsible for executing SPARQL queries and also for finding, aggregating, retrieving and processing the relevant semantic information. The Semantic Module is directly connected to the embedded ontology and to the remote dynamically changing ontology.
- Remote repositories: In this application, the remote repository is a dynamically changing ontology which was uploaded on a Virtuoso server so as to connect, use and be used by other linked open data.

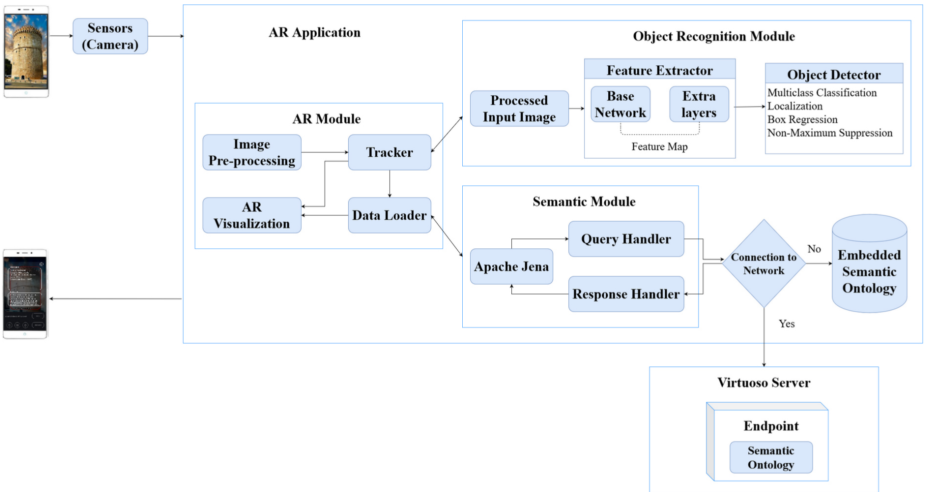

Fig. 3. Application architecture

7 Results and analysis

7.1 Application assessment

Usability is regarded as a major factor in every application. Therefore, in order to assess the usability of the augmented reality application, a study was carried out, in which 17 undergraduate students of the Department of Information and Electronic Engineering of IHU participated voluntarily. More specifically, after the presentation and analysis of the aims and goals of the application, as well as its architecture, modules and individual characteristics, the students used the application in both indoor and outdoor environments so as to detect specific objects and retrieve the related information. After using and interacting the application, the students were requested to fill in a related questionnaire on paper which assessed the overall application usability.

The System Usability Scale (SUS) questionnaire, which gives an overall assessment and a subjective evaluation of the system/application usability through a composite measure called SUS Score, was used [55]. In particular, the specific questionnaire consists of 10 questions, uses a Liker scale and is considered as robust and reliable assessment means, even for studies with a smaller number of participants.

The final SUS Score of the application, which was calculated according to the way described in [55], was 83.2. Table 1 depicts the participants' responses to each question while the mean values and standard deviation are showcased in Table 2. However, the participants' small number (17 individuals) and the fact that most of them, due to their expertise, were acquainted with the usage of mobile devices and applications must be pointed out. According to the analysis of the results, the application was assessed by students as useful and functional, simple and easy to learn and use and mainly effective for their being informed and educated.

Table 1. System usability scale (SUS) questionnaire—responses

No.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Raw Score	SUS Score
1	4	1	4	1	5	1	4	1	4	1	36	90
2	4	1	5	1	5	1	5	1	5	2	38	95
3	4	2	4	2	4	2	5	1	4	2	32	80
4	4	1	5	2	5	1	5	1	5	1	38	95
5	4	1	5	1	4	1	5	2	4	1	36	90
6	4	1	5	2	5	1	5	1	5	1	38	95
7	4	3	4	2	4	2	4	2	3	2	28	70
8	4	2	5	1	5	3	5	1	4	1	35	87.5
9	4	1	5	1	4	2	5	2	4	1	35	87.5
10	4	2	5	1	4	2	5	1	4	2	34	85
11	3	1	5	2	4	2	3	2	4	1	31	77.5
12	3	2	5	2	4	1	5	2	4	1	33	82.5
13	3	2	4	1	3	1	4	1	3	2	30	75
14	3	1	5	1	3	2	4	2	4	2	31	77.5
15	2	1	5	1	3	3	3	2	3	1	28	70
16	2	2	5	1	3	3	5	1	2	1	29	72.5
17	4	1	5	1	2	1	4	1	4	1	34	85

Table 2. System usability scale (SUS) questionnaire—mean values and standard deviation

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Raw Score	SUS Score
Mean	3.5	1.5	4.8	1.4	3.9	1.7	4.5	1.4	3.9	1.4	33.3	83.2
SD	0.7	0.6	0.4	0.5	0.9	0.8	0.7	0.5	0.8	0.5	3.4	8.5

7.2 Analysis

Augmented reality constitutes a state-of-the-art technology that aims at creating a mixed reality in which the co-existence of both real and virtual objects is feasible. Moreover, it offers new ways to interact with physical and virtual objects and environments and provides them with real-time access to dynamic information in a user-friendly way. Due to its nature and with a view to further enhancing the efficiency and effectiveness of its applications and services, augmented reality can be used and combined with various advanced technologies to capitalize on their individual potentials.

The presented system architecture, which was used to develop the augmented reality application, demonstrated the potentials and benefits of combining augmented reality with semantic web, knowledge graphs and deep learning in order to improve the overall UX. Moreover, it is a flexible and extensible architecture, as the remote repositories, the information sources and even the deep learning model can easily be replaced to better suit each use case.

Furthermore, the specific augmented reality application, which was developed following the aforementioned methodology and was based on the proposed system architecture, was evaluated by university students. The results showcased that when compared to conventional applications, the particular application had increased usability and learnability and improved their interactivity, engagement and knowledge acquisition. Based on these findings, it can be said that when combined with other technologies, augmented reality can yield numerous merits to the end-users.

Particularly, based on the results of Table 1 and Table 2, it can be said that the students felt very confident while using the application and characterized it as simple, consistent and easy to learn and use as well as something that they would frequently use it in their everyday life. Moreover, according to the final SUS score and the students' results, the application successfully fulfilled its goals while also remaining user-friendly. Nonetheless, there is still room for improvement.

8 Conclusions

With a view to offering new interactive and immersive experiences as well as to offer access to rapidly changing digital information in real time, augmented reality depicts additional interactive information and digital objects in the physical environment so as to meet users' new requirements. It is worth noting that this information is being rendered in the appropriate time and spatial framework. Moreover, augmented reality is a flexible and extensible technology which can be enhanced and enriched when it is combined with other contemporary technologies.

With the aim of providing users with a more interactive way to be informed and educated, this study presented a system architecture for developing semantically enriched augmented reality applications as well as an augmented reality application which implemented the proposed system architecture. Therefore, it went over the specific technologies that were used, namely augmented reality, semantic web, knowledge graphs and deep learning, as well as other related studies. Furthermore, it analyzed the application along with its development and implementation processes and presented a system architecture for developing semantically enriched augmented reality applications. Finally, it presented the results of an experiment carried out so as to assess the application usability and functionality.

Based on the results of this study, it can be concluded that augmented reality can further enhance its functions and processes when used in conjunction with other novel technologies. Moreover, due to the nature of augmented reality, this combinational use of technologies can be really flexible and extensible. Having a user-centered development approach, simple and easy to use applications that facilitate users' everyday life and improve the way in which they receive and absorb information can be created. As devices become more powerful and more applications are being developed to meet specific needs and cases, the adoption of augmented reality in several domains is inevitable.

Future work will concentrate on improving the augmented reality application to enhance its functionality and on implementing it in specific use cases and various application domains to assess the benefits it could yield in each case while exploiting semantically linked open data and the interactivity that augmented reality provides. Moreover, emphasis will be put on further evaluating and improving the overall UX.

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