

Augmented Reality Geovisualisation for Underground Utilities

E. Stylianidis¹ · E. Valari¹ · A. Pagani² · I. Carrillo³ · A. Kounoudes⁴ · K. Michail⁴ · K. Smagas⁵

© Deutsche Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation (DGPF) e.V. 2020

Abstract

Prior to an excavation for a construction project, fieldwork is necessary to identify the location of all underground utilities. There is a demand for identifying the accurate positioning of the underground utilities, in order to support the contractors in avoiding damages to existing underground infrastructures. Such damages could cost thousands of euros, needless to underline the danger in human lives, in the presence of gas and electricity. There is a concrete market request for solutions that are able to effectively handle underground utilities' data and function in support to the fieldwork. The fusion of technologies such as global navigation satellite systems (GNSS), sensors, geographic information systems (GIS) and geodatabases, augmented and virtual reality (AR/VR) can lead to products and services for monitoring, documenting and managing the utility-based geospatial data. The LARA project, a H2020 co-funded project by the European Commission (EC), embraced these needs and developed a software and hardware (S/H) system. The LARA hand-held and mobile device involves state-of-the-art technologies in the domain of positioning and sensors, AR and 3D GIS geodatabases and aids the users in "seeing" beneath the ground by rendering the complexity of the 3D utilities' models. The visualization of underground utilities is made using a mixed reality paradigm, where the user can see at the same time the surroundings and the utilities rendered at their exact location in 3D. In order to cope with the end-users expectations, two types of visualizations have been implemented and tested. LARA system tested in two case studies during the project lifetime and the results are promising.

Keywords Augmented reality · Virtual reality · GIS · Underground utilities · Visualization

Zusammenfassung

Augmented-Reality – Visualisierung unterirdischer Versorgungsleitungen. Bei der Durchführung von Bauprojekten ist es im Vorfeld einer Aufgrabung wichtig, die genaue Lage aller unterirdischen Versorgungsleitungen zu kennen. Dadurch können Baufirmen die Beschädigung der bestehenden unterirdischen Infrastruktur vermeiden. Anderenfalls können leicht Schäden von mehreren Tausend Euro entstehen oder durch eine mögliche Beschädigung von Gas- und Elektrizitätsleitungen Menschenleben gefährdet werden. Der Markt fordert daher konkrete Lösungen, die in der Lage sind, die Daten der unterirdischen Versorgungsleitungen effizient zu verarbeiten. Eine mögliche Lösung für die Überwachung, Dokumentation und Verwaltung der Versorgungsleitungen besteht in der Verknüpfung von Daten aus globalen Satellitennavigationssystemen (GNSS), anderen Sensoren, Geoinformationssystemen (GIS) und Geodatenbanken, sowie Augmented und Virtual Reality (AR/VR).

✉ E. Stylianidis
sstyl@auth.gr

E. Valari
evalarig@auth.gr

A. Pagani
alain.pagani@dfki.de

I. Carrillo
ivan.carrillo@iso.in.es

A. Kounoudes
tasos@signalgenerix.com

K. Michail
k.michail@signalgenerix.com

K. Smagas
kostas@geoimaging.com.cy

¹ School of Spatial Planning and Development, Faculty of Engineering, Aristotle University of Thessaloniki (AUTH), Thessaloniki, Greece

² German Research Center for Artificial Intelligence (DFKI), Kaiserslautern, Germany

³ Ingeniera y Soluciones Informáticas S.L., Seville, Spain

⁴ SignalGenerix Ltd, Limassol, Cyprus

⁵ Geoimaging Ltd, Nicosia, Cyprus

Das von der Europäischen Kommission kofinanzierte Horizon-2020-Projekt LARA widmet sich dieser Aufgabe und hat ein kombiniertes Software- und Hardwaresystem entwickelt. Das tragbare LARA-Gerät enthält modernste Technologien im Bereich der Positionierung und Sensorik, sowie der AR- und 3D-GIS-Geodatenbanken, und hilft den Benutzern dabei, unter die Erde zu "sehen", indem es die komplexe Struktur der unterirdischen Leitungen dreidimensional darstellt. Die Visualisierung erfolgt nach dem Mixed-Reality-Paradigma, bei dem der Benutzer gleichzeitig die reale Umgebung und den berechneten Verlauf der Versorgungsleitungen sehen kann. Das LARA-System wurde während der Projektlaufzeit in zwei Fallstudien mit vielversprechenden Ergebnissen getestet.

Schlüsselwörter Augmented reality · Virtual reality · GIS · Visualisierung von unterirdischen Versorgungsleitungen

1 Introduction

AR and VR refer to the use of computer-generated images (computer graphics) for representing data which are usually a rendered 3D scene. When using VR, the overall representation is synthetic, and there is no direct link of the VR user to the real environment. On the other hand, in AR, which has a history of more than 60 years (Van Krevelen and Poelman 2010), the link with the real environment is not broken. In this case the user can visualize at the same time the real world and virtual objects unambiguously linked to the real world at the same time (Pagani 2014). The use of rendering technologies, such as programmable pipelines and shaders, allows the creation of digital, physically based materials that closely match real-life counterparts in the way light interacts and reflects from the virtual objects. Thanks to the improved performance and parallelism of new GPUs (graphics processing units), these digital materials can be applied and assessed in real time. The light conditions of the real world can also be explored and used as input to such digital materials, as to nearly replicate the real light conditions (Debevec et al. 2012). This is necessary to create AR virtual objects that augment the real world without looking out of place and this way break the immersion.

There are many application areas for AR/VR. AR and VR captured the attention of both the research community and industry in many application domains, such as education, cultural heritage, awareness, visualization, and many others. Focusing on the architecture, engineering and construction (ACE) sector, Shin and Dunston (2008) presented eight work tasks, i.e., layout, excavation, positioning, inspection, coordination, supervision, commenting and strategising that AR can extensively contribute to. Research projects like VISTA¹, MTU² and VIDENTE (Schall et al. (2010, 2013)) are examining the use of digital technology and the coupling of existing underground utilities data with AR techniques and methods. These projects target the creation of integrated 3D underground models and use automated recognition for several modelling tasks. The main aim of all these attempts

was to facilitate “X-ray” viewing of the underground utilities, either for collision avoidance, or monitoring, or for supporting the field workers in the real environment. Most of this work has been generated by applications and devices developed in the framework of experimental research projects, tackling specific user needs and improving accuracy, usability and reliability of technology.

One important component in such projects is the GIS technology. It is used to achieve the underground utilities representation. GIS is a powerful tool for managing and visualizing geospatial data. 3D GIS-based registration mechanisms can be used for outdoor AR systems (Huang et al. 2016). In addition to that, a current trend in geographic information sciences is the development of integrated geospatial data infrastructures, which unite geographically and semantically disperse national geodatabases. The INSPIRE³ initiative is the European Union’s (EU) directive, aiming at the unification and interoperability of national geospatial data infrastructures across Europe. The EU-funded pilot project HUMBOLDT⁴ is a real test implementation of the standards defined in this directive.

Mobile GIS pushes technology to go one step further; from the office to the field by incorporating various technologies such as mobile and tablet devices, wireless communication and positioning, orientation and imaging sensors. It also enables on-site capturing, storing, processing, analysis and representation of geospatial data. These capabilities reinforce public participation in GIS within the field of mobile-based applications (Brovelli et al. 2016). Furthermore, mobile AR extends traditional 2D or 3D visualizations by overlaying registered visualisations over video footages. In addition, there are also mobile AR systems which are using high-precision real-time kinematic (RTK) GNSS and often use bulky hardware with limited sensor fusion. The next generation of the mobile AR is the integration of RTK GNSS receiver and performing sensor fusion with inertial measurement units (IMUs). This is necessary for providing a highly qualitative and functional AR experience.

¹ <http://goo.gl/YoD5uS>.

² <http://www.mappingtheunderworld.ac.uk/introduction.html>.

³ <http://inspire.jrc.ec.europa.eu>.

⁴ <http://www.esdi-humboldt.eu>.

This paper aims at describing innovative methods of integrating cutting edge AR technologies which are coupled with other technologies such as GIS and geodatabases, GNSS and positioning sensors into a mobile system. The main focus is given in the AR component, which is the powerful component in visualizing 3D representation in a mixed reality interface. After reviewing the state-of-the-art in AR technologies coupled with GIS systems, we introduce the LARA system. LARA is a software–hardware solution, that is able to help utility networks workers in their everyday professional activity. As we shall see next, the LARA system consists of a hand-held tablet equipped with a GNSS antenna that allows for visualizing any kind of available buried assets such as water pipes, electricity cables, gas pipes, etc., at their real location, using AR. This system integrates GNSS, GIS and AR technology to provide accurate information to field workers working in the underground network utilities sector.

2 State of the Art in AR

The LARA system provides a tool for the direct visualization of hidden objects using AR in the context of location-based application. In this section, we analyse the current competitors for the LARA system submodules, especially for the AR component which is one of the most important pillars of the system.

Competitors providing AR SDKs (software development kit):

- *Wikitude* Wikitude was founded in 2008 as an Austrian-based AR technology provider. Originally the company focused on location-based AR, while Wikitude released an updated AR SDK in 2012 utilising image recognition, 3D scene tracking and geolocation. In January 2017, Wikitude released their latest AR SDK featuring a simultaneous localization and mapping (SLAM) component. Wikitude has positioned itself as a direct competitor to Vuforia, but with its recent SDK release it has provided some competitive advantages over Vuforia, specifically in pricing and license options, but most significantly in the ability to track a scene without the need for a 2D trigger image, more commonly referred to as markerless AR. Wikitude’s geolocation services utilise either the Wi-Fi connection or the device’s GNSS, plus access to any device motion sensors and/or compass.
- *Vuforia* Vuforia’s AR SDK (Kwik and Bahama 2016; Imbert et al. 2012) is probably the most widely used. Vuforia was originally owned by Qualcomm, but in October 2015, was purchased by PTC Inc., with a name originally derived from Parametric Technology Corporation. Vuforia’s extended tracking feature (where the SDK can track the 3D scene using image processing techniques



Fig. 1 GeoBoid on an Android-based tablet (left) and Ingress map on a smartphone (right)

- once a trigger image has been lost from the camera view) is considered to be one of the best that are commercially available. Vuforia offers a range of AR technologies targeting the mobile and tablet market. Vuforia’s SDK includes image recognition, SLAM and options to use the IMU sensors of a device. It also provides 3D object recognition and a range of cloud-based services. In August 2016, Vuforia implemented a new licensing and pricing strategy. This has resulted in significant commercial hurdles for AR app developers. Vuforia’s SDK has punitive fees applicable to any company developing AR applications for use in conjunction with commercially sold physical objects such as books, toys, gaming cards, etc. This change in licensing and fee policy by Vuforia, and its restrictive use of image and object recognition to be locked into SLAM and 3D scene tracking, provides an opportunity for competitors to take market share.
- *Layar* Originally a Dutch-based company, Layar was acquired by Blippar in 2016 and the operation re-located to the UK. Layar’s AR technology is based on what is termed a “browser”. Layar’s browser utilises a range of data sources to provide an AR experience, including the device’s camera, GNSS, compass and accelerometer. The final result is an AR experience that provides location-based information overlaid on top of the device’s camera view.
 - *Apple’s ARKit* In 2017, Apple introduced ARKit as a new framework to allow developers easily create AR experiences for iPhone and iPad. This feature is integrated in iOS 11, but is limited for the use with iPhones and iPads with Apple A9 or A10 processors.
 - *ArCore* ArCore is an AR SDK provided by Google for the Android operating system. It allows the generation of AR experiences by providing positional information inferred from video input and IMU data when available. It incorporates a SLAM module that partially reconstructs the environment to help stabilize the tracking. While ArCore generally provides good results in indoor environments and to a lesser extent in outdoor environments, the drawback is that it does not geolocalise the device in a reference coordinate system. However, it



Fig. 2 Pokémon Go AR view (left) and crowd of Pokémon Go gamers (right)

operates in a local reference system with unknown offset to the global one. Therefore, it cannot be used for representing geolocalised objects.

Existing location-based AR applications:

- *GeoBoids* The first location-based AR application was developed at the HIT Lab NZ, in a project from 2011/2012 called GeoBoids (Lindeman et al. 2012), where players could run around and catch geometric creatures from another dimension using their Android phones. It was conceived as an outdoor AR game, where users had to capture creatures using whistling to attract them (Fig. 1).
- *Ingress* It is a location-based, AR mobile game developed by Niantic, a company spun off from Google, in 2012. The game consists of capturing “portals” at places of cultural significance, such as public art, landmarks, monuments, etc., and linking them to create virtual triangular “control fields” over geographical areas. Within the game, the players are grouped in two opposing factions: the enlightened and the resistance. These two factions are the opposing “sides” or “teams” in the game. The resistance is represented in the game by a blue colour, and the enlightened by green. In terms of business model, Ingress is supported by advertising. The companies can pay for their locations to be used as portals in the game, thus making their stores a pilgrimage site for Ingress players, which may translate into real-world sales (Fig. 1).
- *Pokémon Go* Pokémon Go (Rauschnabel et al. 2017) is a free-to-play, location-based AR game developed by Niantic for iOS and Android devices. It has been launched in July 2016 and rapidly achieved a number of records since its debut. Specifically, it was the most downloaded app in its first week ever and the fastest to reach 50 million downloads on Google Play, as well as the fastest mobile game to reach \$500 millions in revenue (60 days). In that game, players use the GNSS capability of a mobile device to locate, capture, battle and train virtual creatures, called Pokémon that appear on the screen as if they were in the same real-world location as the player. The locations of the creatures (“PokeStops”) are gener-

ated by the game. The game supports in-app purchases for additional in-game items (Fig. 2). The unprecedented success of this location-based AR game is due to several specific factors, such as the following:

- The game is innovative and stands on geolocalisation and AR.
- The branding around the existing concept of Pokémon is unique and fitting.
- The application is extremely easy to use, intuitive and simple.
- The target audience is fitting.
- The game is free to play, but users can pay to get additional features.
- The social aspects are tangible: collaboration to obtain more rewards, competitions in teams, possibility to meet other gamers.

3 The LARA Project

The LARA project⁵ is a H2020⁶ project, co-funded by the EC for the period 2015–2017. Understanding the real market needs of the utilities and construction companies, a group of partners, from academia and research, SMEs and end users, successfully implemented this interdisciplinary project. Within the LARA project, the consortium partners introduce a mobile (tablet) device to support the utility management professionals and workers in the field and under real conditions. The LARA hand-held and mobile device is incorporating state-of-the-art technologies in the domain of AR, positioning and sensors and 3D GIS geodatabases (Stylianidis et al. 2016a, b).

LARA has some key innovations such as the following:

- The combination of GNSS technology—primarily targeting Galileo-, and AR technology to provide precise positioning of geolocalised assets.
- The use of GIS technology to transfer GIS information into the system.
- The use of rendering approaches to convert abstract GIS information into virtual 3D objects.
- Novel AR visualisation approaches to deal with hidden objects’ specificities.

3.1 Rationale and Aims

The LARA project developed a highly innovative and adaptive application that takes advantage of GNSS

⁵ <http://www.lara-project.eu>.

⁶ <http://ec.europa.eu/programmes/horizon2020/>.

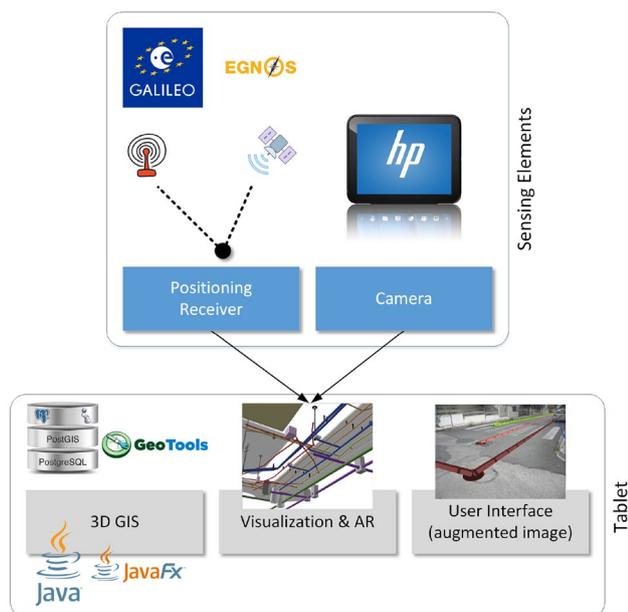


Fig. 3 The LARA system architecture

infrastructures, such as Galileo and EGNOS. In particular, LARA project designed and developed an entirely practical mobile device for the utility field workers, based on the real needs of the end users. The developed system uses different technologies like AR, positioning and sensors, GIS, geodatabases, etc. In practise, it is a S/H solution for visualizing registered 3D underground (infrastructure) models in real time. The models are retrieved from a geodatabase. The registration and augmentation of the 3D geospatial information in the mobile device assumes the accurate positioning and orientation tracking in real time. This is feasible through the fusion of navigation and inertial sensors. Registered visualisation requires the rendering of complex 3D models of the underground utilities, in a sense that is easily understandable and practically useful to the field workers in their daily business. This requires novel visualisation techniques for geometric and non-geometric information acquired from the geodatabase, especially for the hidden objects, something the project assumes as an “X-ray image” of the underground utilities. The visualization techniques are adaptive to both scene complexity and spatial conditions. The 3D geometry is not available per default, but is extracted from a geodatabase and interpreted on-the-fly as a 3D visualization and augmentation parameter. The overlays show 3D visualizations of the underground infrastructure in a way that is comprehensive and meaningful to the field worker, in order to perform any work efficiently. Interaction with mobile AR devices in outdoor environments is a special mode of 3D interaction, which works differently from VR systems, since

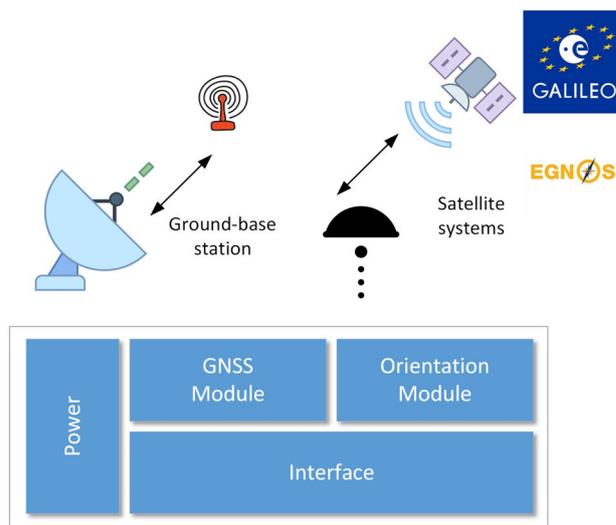


Fig. 4 Positioning receiver block diagram

it incorporates real-world objects and unavoidably incomplete (spatial) information.

4 Augmented Reality in LARA System

4.1 The Architecture of the LARA System

The LARA system architecture is depicted in Fig. 3. The system consists of the two sensing elements (positioning receiver, camera) and the tablet with the 3D GIS, visualisation and AR modules. The image is taken using the tablet’s camera and the utilities are superimposed on the image using the AR module. The system has the following modules: user interface (UI), positioning receiver (PR), sensor fusion (SF), 3D GIS-Geodatabase (3DG) and visualisation and AR (AR).

More specifically, the LARA system first accesses the GIS information with a data importer that is able to read typical GIS information from the utilities network operators. Typically, this information is abstract and tailored to a use in a classical 2D map view. For example, the start and end positions of the pipes, as well as the depth of the start and end points under ground level, as stored as GNSS coordinates. The diameter of the pipe is commonly defined by the pipe type. It might contain information about the purpose of the pipe, as well as colour information that is useful for a 2D representation. In the LARA system, this information has first to be converted into a graph of connected 3D objects. These 3D objects are cylinders for pipes, flat circles for manholes and planes for buildings. The construction of the object graph is made by a GIS file parser that generates basic parameterized objects and replaces the parameters by the

actual values. The output of this process is a full 3D model of the network, with correct sizes. Once this 3D model is generated, the scene can be rendered from any observation point. The key issue is to compute the observation point that corresponds to the position of the real camera of the tablet. When this is correct, the 3D model can be rendered in the perspective, corresponding exactly to the camera viewpoint. Special care should be given to the use of the same intrinsic values (focal length, principal point) of the real camera. For this reason, the camera is calibrated in an off-line process to estimate the values of these parameters. Once the 3D model is rendered from the correct perspective, the AR scene can be composed by taking the real image as background and representing the 3D model in front of the background. At the end of the process, the 3D model appears as seamlessly integrated into the real image.

The UI was implemented using JavaFX (in Windows environment), a library that is included in Java 8. It implements the model-view-controller (MVC) pattern, creating a central controller that captures user interaction and establishes the starting point of the orchestration process. The 3DG module was also implemented in Java and is based on Geotools open source library. PostgreSQL is used as a database management system (DBMS) in combination with the PostGIS plugin in order to support the spatial character of LARA's data. The main function which is supported in this service is the editing; the users of the LARA system can use this service to update these geospatial objects. Geotools implements its views as Swing components, which can be natively integrated with JavaFX.

The PR subsystem consists of an external hardware module composed of a microcontroller and position and orientation sensors as shown in Fig. 4. In order to communicate with the PR, a background service running on the tablet obtains the position and orientation and publishes it to a local message queue telemetry transport (MQTT) broker. The UI is subscribed to the position and orientation topics to receive all the updates asynchronously.

The PR leverages the state-of-the-art technology advances from GNSS which aims at estimating the geographic location and velocity of an object in 3D. In order to estimate the location, the GNSS uses a group of satellites orbiting around the Earth combined with ground-based stations. Two main systems are fully operational, the GPS by USA and the GLONASS by Russia. Two other GNSS systems are under development to be fully functional; the Galileo by Europe and the BeiDou by China (Madry 2015). The LARA system is compatible and takes advantage of all the merits that the aforementioned GNSS systems offer. The estimated geographic location accuracy is affected by a number of errors including ionosphere, multipath, etc. (such errors can go up to 10 m), see Petovello (2014); therefore, the technology has been developed so as to eliminate those

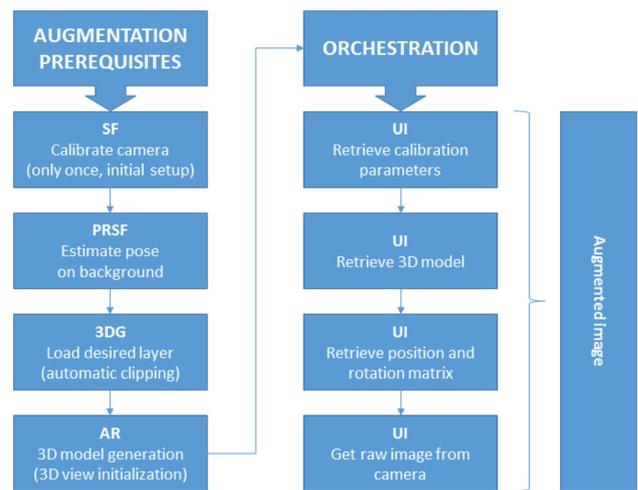


Fig. 5 LARA workflow towards image augmentation

errors. The accuracy can be reduced at the level of 1 m using satellite-based augmentation system (SBAS), down to few centimetres (cm) using differential positioning systems (Gerhard et al. 1996). High precision receivers are able to achieve accuracies at a centimetre level, using state-of-the-art RTK (Petovello 2011) or precise point positioning (PPP) (Chassagne 2012; Lachapelle et al. 2006) precision. Low power with long autonomy GNSS receiver modules are able to achieve accuracies of a centimetre using the RTK technology.

The orientation of the LARA receiver is also essential. Therefore, it is also equipped with a state-of-the-art high-precision orientation sensor for the 3D orientation estimation (pitch, yaw, roll angles).

The European state-of-the-art Galileo is designed to offer improved accuracy and to increase satellite availability and integrity. The satellite availability and integrity is enhanced as a result of the large number of satellites, but further improvement of the accuracy is required. Therefore, differential corrections technology (EGNOS, DGNSS and RTK) is leveraged in order to reduce the geolocation error to around 1 cm.

Flexibility and long autonomy of the LARA system, as well as suitable high-level UI compatible with commercial tablet, are required in order to promote the system in the market.

In case the position and orientation are not available—or not accurate enough—the pose estimation algorithms can still be used to provide the user with a photogrammetry-based estimation. This is done by matching elements in the GIS data to its respective location on a photograph through a user-friendly interface. As expected, the accuracy of this method is highly related to the accuracy of the GIS data and



Fig. 6 LARA system as a prototype

the number and geometrical configuration of the selected points (Patias et al. 2016).

The AR component is compiled as a console application, which analyses the available GIS layers in order to render a 3D model of the underground infrastructure, based on the pose provided by either the hardware or the pose estimation algorithms.

In order to achieve the goal for an integrated system, all the modules composing the LARA system must keep a constant stream of data between them, e.g., images, position and orientation, GIS data. This mutual dependency between the modules along with different programming languages and the input data format, makes it necessary to implement an orchestration layer on top (Fig. 5). Since the UI module must establish contact with every module in order to display their data, the orchestration engine is implemented within the UI module.

Several information flows need to be orchestrated by the UI layer in order to make the different modules that compose the LARA system work properly as a whole. The best example is the AR engine. In order to depict the underground utilities via AR, the renderer module needs the following information as input:

- The camera parameters (extracted from the calibration during the initial system setup).
- The pose estimation (extracted from the MQTT bus as inserted by the PR-SF background service).
- Load desired layer of the GIS information as a clipped XML file (a reduced area around the user's position).
- Compute the 3D model from the GIS information.

The orchestration layer gathers all these pieces of information and generates the input files in the proper format for the AR module, as it is a prerequisite to produce an augmented image. This process is depicted in the workflow in Fig. 5.

The prototype of the receiver developed in LARA project is shown in Fig. 6. It is a fully autonomous device able to operate for about 8 hours continuously. The enclosure is printed using a polylactic acid (PLA) material with a fused deposition modeling (FDM), the MakerBot in our case.

4.2 The AR Component of the LARA System

The AR component of the LARA system deals with the visualization of the underground utilities in a mixed reality mode, i.e., merging real image information with virtual objects in a seamless way.

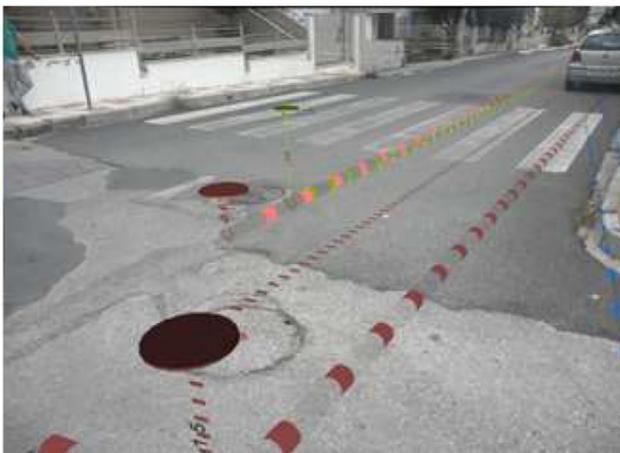
In order to achieve seamless integration, the AR component needs a precise camera pose estimate, as well as the information about the optical system (e.g., focal length, distortion parameters, central point). This information can be computed and stored once for all in a calibration phase, which is usually implemented by capturing images of known patterns, allowing the determination of the internal parameters (also called intrinsic calibration). The pose estimate is the 3D position of the camera projection centre, the camera and the inclination of the camera (pitch, yaw, roll). It is, therefore, often called as the 6 degrees-of-freedom (DoF) camera pose. In the LARA system, this pose is computed from the available sensors: GNSS and IMU information. A proper hand-eye calibration transfers the retrieved pose to the camera's coordinate system. All in all, the LARA AR component receives the pose of the camera and its calibration parameters as input.

The visualisation part of the AR component is responsible for generating a scene, composed of a background (real image), and virtual objects such as pipes, manholes and building footprints. In fact, the AR module receive as an input an XML (extensible markup language) file from the GIS module that contains the list of existing geospatial infrastructure in the area of interest. The AR module reads this XML file and generates object primitives according to the object type (e.g., colour cylinder for the pipes, disks for manholes). The scene is created by placing these primitives in a virtual world, following their positions as provided in the XML file. The colours of the different elements can also be specified in the XML file, and usually follow a typical rules (e.g., blue for water pipes, green for rainwater pipes).

From the rendering perspective, the AR component integrates an off-screen rendering engine that generates the augmented view and stores the result in an image file. This engine is based on the Unity rendering platform, which has been used in off-screen mode. For the final scene composition, the virtual camera is placed at the position of the real camera as provided by the external modules, and the intrinsic parameters of the virtual camera are adapted so as to correspond to the intrinsic parameters of the real camera. The real picture taken by the tablet's camera is placed as



(a)



(b)

Fig. 7 StreetLevel mode (a) and XRay mode (b): images created by LARA system

background in the virtual scene to produce the mixed-reality image.

The use of unity rendering engine allows to address specific requests such as alpha-channel to handle the transparency of the rendered objects (e.g., pipes), easier rendering of additional objects such as dashed lines, handling of depth-based fading of the 3D objects and enhanced flexibility when changing the design of the 3D objects.

In terms of look-and-feel, the module implements two visualisation modes (Fig. 7):

- The “StreetLevel” visualization mode, where the pipes are rendered as if they were lying directly on the street. This mode is the default one and is useful for the users to know the position on the street that is vertically above the pipe.
- The “XRay” visualisation mode, where the pipes are rendered as if the user could see “through” the street

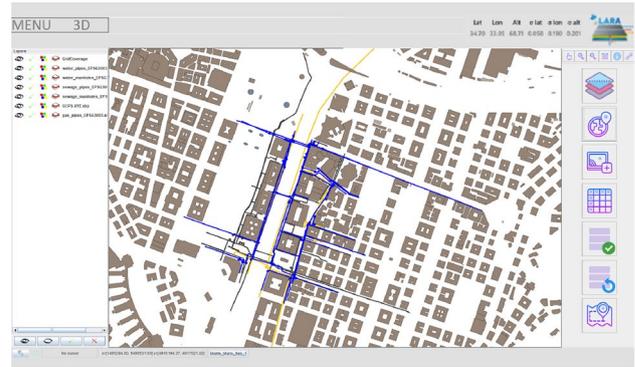


Fig. 8 The GIS GUI of LARA system

level (as if the user is using an X-ray device). In this mode, the trace of the pipe on the street is represented as a dashed line.

The LARA system development followed a user-centred principles, and the users’ feedback was of high priority and importance for the development team. In AR systems, the visualisation of the virtual objects—in this case, manholes, pipes, etc.—and supplementary pointers (e.g., lines, text), is very important for the users and should be adapted to the users’ needs. In this particular use case, the objects of interest are normally not visible, as they are buried under the ground level. When using AR to make them appear, care has to be taken by means that the target user group understands the augmentations. In standard AR, the virtual 3D objects are presented at their location in the environment, with the real image as background. However, in the case of LARA the background image contains objects that would normally occlude the virtual elements, such as the street surface, sidewalks and buildings. Therefore, we opted for a non-conventional visualization metaphor and created two dedicated visualization modes. In the “XRay” visualization mode, the pipes are rendered as if the user could see “through” the street level (as if the user was using an “X-ray device”). Since the pipes are rendered at their real depth, they might appear as shifted in the user’s eyes. We therefore projected horizontal dashed lines for each pipe that represents the trace of the pipe on the street level. At manholes’ positions, the vertical dashed lines show the depth of the pipe, which is added as a textual information (depth in meters). Figure 7, right, shows an example of this visualization. After our preliminary tests with a user group, a general feedback was that the workers actually do not only need the position of the real pipe, but are also more interested in the trace of the pipe on the street level (the dashed line of the “X-ray” mode). We, therefore, developed a second visualisation mode, called “Street Level” (Fig. 7, left), where the pipes

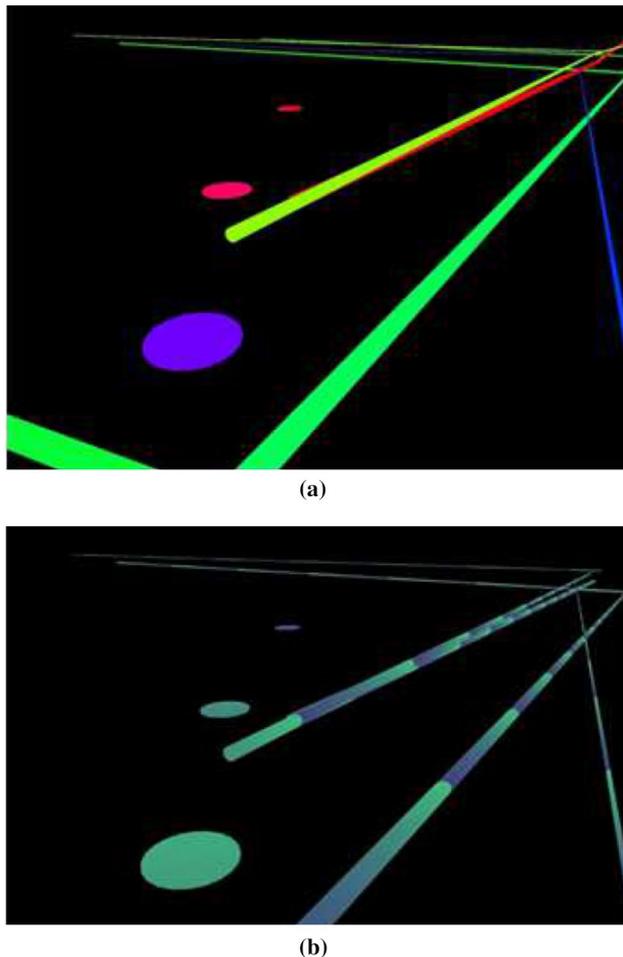


Fig. 9 ID-image for depth computation (a) and Z-buffer image for depth computation (b)

are represented as half-cylinders lying on the surface of the street. Although this representation is geometrically wrong, it is generally better accepted and normally is a better hint for the user group. The GIS UI of LARA system is given in Fig. 8.

The offset between the manholes and their AR that correspondents in Fig. 7 is due to two main factors: (1) positioning inaccuracies and (2) insufficiency between the real position of the manhole and the stored value in the geodatabase. The positioning error has been measured in the LARA system and is not more than 10 cm, which is perfectly acceptable for the considered user group. The second problem might generate much bigger errors (up to several meters). This is due to wrong information being stored and maintained by the utility network operators. This cannot be corrected by LARA technology, unless it is discovered during the fieldwork. However, these errors are quite likely to happen in a real setup. This is the reason why the LARA system has foreseen the possibility

to make a note when a discrepancy is observed, so as to provide feedback to the operator who is responsible to update the information.

In addition to the rendering of the mixed reality scene, the AR component also includes a selection submodule. The selection submodule allows to retrieve the depth of the pipes on a given position (when clicking on the pipe). In order to allow this depth computation, the renderer submodule generates helper images that encode the ID of the virtual object and the horizontal depth (z -buffer) of the virtual objects (Fig. 9). These two helper images allow to retrieve information on the clicked object and for finding the vertical depth under the street surface of the selected pipe end points. Using this information, the local depth is computed by linear interpolation. As a result, the user can click on the mixed reality image on a pipe and instantaneously receives an information on the local depth below the street level of that explicit pipe on that specific position. Undoubtedly, this information is extremely useful for the field workers before starting excavating the area of interest.

4.3 Visualisation in the LARA System

Visualisation is extremely important for the end-users of the LARA system. The visualisation covers different aspects in the system such as: (a) the GUI, (b) the 2D views of the surroundings and (c) the augmented reality view where virtual reality is mixed with the real environment.

The GUI has been designed to be extremely simple in order to ease the use of the entire application. The user can navigate between different specific views by pressing buttons on the tablet. A parameter menu allows for setting various parameters such as type of coordinate system, calibration of the camera or date and time.

The 2D views of the surroundings show a 2D map centred on the user's location as received by the GNSS receiver. This map can be zoomed in and out, and shows the streets, the footprints of the buildings and the underground utilities as seen from above. This is the view that the end-users are the most acquainted with, as it looks like a standard paper map of the environment. The information shown can be directly extracted from a GIS system.

The augmented reality component is a view generated in 3D from the user perspective. It consists of two parts: first, the real image that is acquired by a camera located at the back side of the tablet. Thus, the tablet itself can be used as a "window" on reality. The second part consists of the virtual elements positioned at their exact location as seen by the same camera. Thus, by fusing the real image and the virtual elements, an augmented image is created.

In the current version of the LARA system, only a static image can be augmented. In order to generate a static augmented view, the user just presses a button, and the AR

visualisation is generated and then displayed on the tablet. This operation can be repeated regularly so that it is possible to generate an augmented view every second. For future work, we will develop a real-time augmentation module, which will allow to augment a live video of the scene at 25 frames per second. With this live augmentation, the end-users will be able to walk around the scene and explore the different utilities in a dynamic manner.

In terms of 3D graphics, the utilities are not rendered with a high level of realism, but rather as colour-coded pipes, made of cylinders that can be straight or curved. We opted for a non-realistic representation to better answer the users' needs, who need to recognise easily the type of utilities they encounter.

4.4 Dynamic Aspects in the LARA System

In the current version of the system, the visualisation is quite static. First, the AR views can be generated only at a frame rate of frame per second, which does not allow for an active exploration of the area. Second, the information shown to the user is the information coming from a static database, generally provided by the utilities operator.

For our future work, we see two ways of improving the dynamic aspects of the existing system: (1) we will implement a faster AR module by first generating a robust camera pose at video frame rate (25 Hz), and second creating a corresponding mixed visualisation without delay. This improvement mainly depends on the capacity of the GNSS receiver and the possibility to fuse IMU information with GNSS signal—the rendering of a augmented scene is not the bottleneck as modern graphic cards can easily generate the virtual images and the augmented reality view. (2) We will work on new modules that will allow to deal with dynamic data. Dynamic data can arise, for example, when the utilities' database is wrong, inaccurate or was changed. In that case, the new module will give the possibility to the user to modify the 3D position of a pipe or any other asset, and store this information in a documented note. This note will be sent back to the owner of the database who will have the possibility to change the information after the validation of the error. Another aspect of dynamic data is the case of the utilities' positions that change after events such as earthquakes or accidents. In that case, the system could be used to measure the amount of difference between the expected position and the actual position of the assets. To this aim, an interactive tool will be developed, with which the user will be able to take measurements directly in the system on the tablet. We believe that taking in consideration the dynamic aspects of the data will make the tool more convenient to use and will allow to report observed differences that would be otherwise perceived as disturbances in the system.

5 Testing the LARA System: Results

The LARA system was evaluated using the following two main methodologies: questionnaires and particular key performance indicators (KPIs). The evaluation procedure is simple and is performed through questionnaires, filled by the target user groups (e.g., computer experts, engineers, field workers, etc). The questions covered issues related to human computer interaction (HCI), user interface (UI), system's functionalities, hardware and software setup, etc. Simple but efficient indicators are used such as standard deviations, average scores, to illustrate the evaluation of the system by a team of potential users.

Features like efficiency, effectiveness, satisfaction were collected using questionnaires (Davis 2012). The questionnaires' results helped us to analyse the quality of the system as well as to collect the affective impressions of potential end users and the perceived benefits (Nielsen 1993). The questionnaires were designed in order to gather quantitative results and they are based on the key goals of the LARA project which are defined extensively in the description of work (DoW) document. This technical document is part of the contract with the European Commission.

The questionnaire is divided into two main parts: The first part includes general questions concerning user experience—training, device—hardware, etc.; in total 41 questions covering all the possible inquiries with respect to the user experience on LARA device. The second part of the questionnaire is dedicated to technical issues and includes 33 questions related to the steps to be followed by a typical user, while working in the field. A typical scenario was structured covering issues like system calibration, preparation, surveying precise localisation, etc. Regarding the score, a scale of six different classes was introduced, 1–5, where 0 is the not applicable choice for the users:

1. 1: Strongly agree/very important
2. 2: Agree/important
3. 3: Neutral
4. 4: Disagree/not important
5. 5: Strongly disagree/irrelevant
6. 0: Not applicable

The KPIs followed in this case are based on the ISO 9241-11 usability dimensions⁷. The main three indicators are:

1. *Effectiveness* the accuracy and completeness with which users achieve goals.
2. *Efficiency* the resources expended in relation to the accuracy and completeness.

⁷ <https://goo.gl/PKXr5k>.



(a)



(b)



(c)

Fig. 10 Birmingham—3D view, AR module

3. Satisfaction the comfort and acceptability of use.

The LARA system was finally tested in a pilot application in the city of Birmingham, UK. Prior to that, an interim evaluation took place in Kozani, Greece, at the early stage of development. Potential users and stakeholders had the opportunity to use the device and provide the consortium with valuable feedback. The final prototype allowed the consortium to get satisfactory results, as shown in the augmented images below (Fig. 10).

During the pilot application in Birmingham, UK, six different companies and seven participants in total were

invited to test the device and provide feedback through the questionnaire. All participants had the skills to use LARA technology, in terms of using the tablet device. The following companies participated in the Birmingham pilot:

- Transport for West Midlands—Strategic Modelling and Joint Data Team
- National Grid, Network Innovation—Network Strategy—
- Forkers Civil Engineering, Ground Engineering, Renewable Energy
- Webster and Horsfall, Tyseley Energy Park low/zero emission re-fuelling hub
- Western Power Distribution—Distribution Network Operator
- Birmingham City Council—Digital Connectivity and transport data

The gathered questionnaires were analysed based on the structure of the questionnaire as already explained. As a result, regarding the first and general part of the questionnaire, the following extracts came out:

1. Almost all participants have experience in using computers and navigation devices.
2. The vast majority of the participants agreed that, overall, the system is very well designed. In fact, 14% highly agrees, another 43% agrees and another 43% shows average agreement.
3. The vast majority of the participants agreed that the system is very useful. Specifically, 29% highly agrees, another 57% agrees and another 14% shows average agreement.
4. The vast majority of the participants agreed that the system covers the user needs—71% agrees, and another 29% shows average agreement.
5. The vast majority of the participants agreed that the system is useful and trustful.

Regarding the second part of the questionnaire, i.e., the technical orientation part, the participants responded in the following way:

1. The vast majority of the participants agreed that the accuracy of the Birmingham GIS infrastructure data is adequate; only 14% of the participants felt that is below average.
2. The vast majority of the participants agrees that the GNSS signal is satisfactory; only 14% of the participants felt that is below average.
3. Regarding the quality of the general 2D localization map and the on-the-right-spot functionality, the confirmation

is high; 42% of the participants indicated that the quality of the point's localization on the ground is high. Another 29% simply agrees too.

The conclusions were drawn based on the analysis of the KPIs. Combining the different questions of the questionnaire in three groups reflecting the effectiveness, efficiency and satisfaction, we concluded to the following results:

- *Effectiveness* the average median = 3.4 is above the set threshold, resulting that the participants judged that the system is adequately effective, useful and trustful.
- *Efficiency* the average median = 3.5 is above the set threshold, resulting that the participants judged that the system is adequately efficient and easy to use and learn.
- *Satisfaction* the average median = 3.1 is above the set threshold, resulting that the participants judged that the system is adequately satisfactory and comfortable in use.

6 Discussion and Future Work

Developments in AR and VR technologies are dramatically changing the way we execute many of our daily activities. The developments in the LARA project strongly support this notion. One of the sectors that is anticipated to be more profoundly influenced by this technological revolution is engineering and related field work activities. With AR and VR technology, the users will be completely immersed in computer-generated environments and become part of them. Mixed reality interfaces and HCI will provide the tools to not only enter the real world, but also to interact with it in a lively and productive way.

The big challenge for the mobile AR systems is and will be the processing power. Especially, when working in an outdoor and demanding environment, like engineering services in the case. For the LARA system, the team used an HP ElitePad 1000 G2 Intel Atom Z3795 (1.6 GHz, up to 2.39 GHz using Intel Burst Technology), 4 cores, 4 GB memory and Intel HD Graphics. This equipment functioned satisfactorily during the test and validation phases.

Needless to underline, the utilities sector is nowadays considered as one of the most important and strategic infrastructures in an urban environment. It is estimated that in the United Kingdom (UK) up to 4 million holes are cut into the road network each year in order to install or repair buried service (underground) pipes and cables⁸.

One flaw of the system is the dependence on the precision of the stored GIS data in the network operators' databases. For various reasons, it is not seldom that a pipe's position is

erroneously stored and does not correspond to the real position of the pipe. In that case, the virtual pipes will appear at the stored position, but will not correspond to the real one. These cases cannot be solved by the LARA technology alone. However, the team integrated the possibility to send a feedback to the operator about this discrepancy, so as to correct the databases.

Several companies, Small-Medium Enterprises (SMEs) but also giants of the utilities market, showed an incredible interest for in product. Now, considering the constructive criticism from the potential end users during the pilot applications, we are entering the next phase; to deliver a marketable product (Jimenez et al. 2016). The main criticism from the users that tested the system is directed to the housing of the LARA device (Fig. 6). This is somehow explicable as the outcome from a research project is a working prototype and not a real commercial product. Our efforts will be directed in delivering an ergonomic device which will facilitate the job of the users and make their life easier during the field activities with the underground network utilities.

By leveraging the above considerations, our aim was to enter the market with a product, namely the LARA system. This mobile AR location-based solution has successfully undergone the research and validation testing and now is entering the commercialisation phase. Transforming the (underground) real-world settings in even more amazing and powerful environments is the ultimate goal.

References

- Brovelli MA, Minghini M, Zamboni G (2016) Public participation in GIS via mobile applications. *ISPRS J Photogramm Remote Sens* 114:306–315
- Chassagne O (2012) One-centimeter accuracy with PPP. *InsideGNSS*, Red Bank, pp 49–54
- Davis FD (2012) Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q* 13:319–340
- Debevec P, Graham P, Busch J A, Bolas M (2012) A single-shot light probe. *ACM SIGGRAPH 2012 Talks, SIGGRAPH '12*, pp 10:1–10:1
- Gerhard W, Andreas B, Gimter S, Volker B, Hankemeier P (1996) Reducing distance dependent errors for real-time precise DGPS applications by establishing reference station network. In: *Conference proceedings of ion GPS*, Institute of Navigation, pp 845–852
- Huang W, Sun M, Li S (2016) A 3D GIS-based interactive registration mechanism for outdoor augmented reality system. *Expert Syst Appl* 55:48–58
- Imbert N, Vignat F, Kaewrat C, Boonbrahm P (2012) Adding physical properties to 3D models in augmented reality for realistic interactions experiments. *Proc Comput Sci* 25:364–369
- Jimenez R, Delgado E, Mohd Nor R, Smagas K, Valari E, Stylianidis E (2016) Market potential for a location based and augmented reality system for utilities management. In: *22nd international conference on virtual systems and multimedia (VSMM)*, pp 1–4
- Petovello M (2011) What is a virtual reference station and how does it work?. *InsideGNSS*, Red Bank

⁸ <http://www.mappingtheunderworld.ac.uk>.

- Van Krevelen DWF, Poelman R (2010) A survey of augmented reality technologies, applications and limitations. *Int J Virtual Real* 9(2):1–20
- Kwik F, Bahama R (2016) Using augmented reality to enhance aetherpet, a prototype of a social game. *Proc Comput Sci* 59:282–290
- Lachapelle G, Petovello M, Gao Y, Garin LJ (2006) Precise point positioning and its challenges, aided-GNSS and signal tracking. *InsideGNSS*, Red Bank, pp 12–16
- Lindeman R W., Lee G, Beattie L, Gamper H, Pathinarupothi R, Akhilesh A (2012) GeoBoids: A mobile AR application for exergaming. In: *IEEE international symposium on mixed and augmented reality—arts, media, and humanities (ISMAR-AMH)*, pp 93–94
- Scott Madry A (2015) *Global navigation satellite systems and their applications*. Springer, Berlin, pp 1–8
- Nielsen J (1993) *Usability engineering*. Academic Press, Cambridge
- Pagani A (2014) Modeling reality for camera registration in augmented reality applications. *Knstliche Intelligenz* 9(2):1–20
- Patias P, Tsioukas V, Pikridas C, Patonis F, Georgiadis Ch (2016) Robust pose estimation through visual/GNSS mixing. In: *22nd international conference on virtual systems and multimedia (VSMM)*, pp 1–8
- Petovello M (2014) How do measurement errors propagate into GNSS position estimates?. *InsideGNSS*, Red Bank, pp 30–34
- Rauschnabel PA, Rossmann A, Dieck MC (2017) An adoption framework for mobile augmented reality games: the case of Pokmon Go. *Comput Hum Behav* 26:276–286
- Schall G, Zollman S, Reitmayr G (2013) Smart Vidente: advances in mobile augmented reality for interactive visualization of underground infrastructure. *J Pers Ubiquitous Comput Issue* 7(17):1533–1549
- Schall G, Junghanns S, Schmalstieg D (2010) VIDENTE—3D visualization of underground infrastructure using handheld augmented reality. In: Anand S, Ware M, Jackson M, Vairava Moorthy K, Abrahart R (eds) *GeoHydroinformatics: integrating GIS and water engineering*. CRC Press, Boca Raton, pp 207–219
- Shin DH, Dunston PS (2008) Identification of application areas for augmented reality in industrial construction based on technology suitability. *Autom Constr* 17(7):882–894
- Stylianidis E, Valari E, Smagas K, Pagani A, Henriques J, Garca G, Jimeno E, Carrillo I, Patias P, Georgiadis Ch, Kounoudes A, Michail K (2016) LBS augmented reality assistive system for utilities infrastructure management through Galileo and EGNOS. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS)*, Heipke, pp 1179–1185
- Stylianidis E, Valari E, Smagas K, Pagani A, Henriques J, Garca G, Jimeno E, Carrillo I, Patias P, Georgiadis Ch, Kounoudes A, Michail K (2016) LARA: a location-based and augmented reality assistive system for underground utilities' networks through GNSS. In: *22nd international conference on virtual systems and multimedia (VSMM)*, pp 1–9