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Research paper

Smart maintenance of riverbanks using a standard data layer and Augmented Reality

Roberto Pierdicca [a,*], Emanuele Frontoni [a], Primo Zingaretti [a], Adriano Mancini [a], Eva Savina Malinverni [b], Anna Nora Tassetti [b], Ernesto Marcheggiani [c,d], Andrea Galli [c]

[a] *Università Politecnica delle Marche, Dipartimento di Ingegneria dell'Informazione, Italy*
[b] *Università Politecnica delle Marche, Dipartimento di Ingegneria Civile, Edile e Architettura, Italy*
[c] *Università Politecnica delle Marche, Dipartimento di Scienze Agrarie, Alimentari ed Ambientali, Italy*
[d] *Department of Earth and Environmental Research, KU Leuven, Belgium*

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ABSTRACT

Linear buffer strips (BS) along watercourses are commonly adopted to reduce run-off, accumulation of bank-top sediments and the leaking of pesticides into fresh-waters, which strongly increase water pollution. However, the monitoring of their conditions is a difficult task because they are scattered over wide rural areas. This work demonstrates the benefits of using a standard data layer and Augmented Reality (AR) in watershed control and outlines the guideline of a novel approach for the health-check of linear BS. We designed a mobile environmental monitoring system for smart maintenance of riverbanks by embedding the AR technology within a Geographical Information System (GIS). From the technological point of view, the system's architecture consists of a cloud-based service for data sharing, using a standard data layer, and of a mobile device provided with a GPS based AR engine for augmented data visualization. The proposed solution aims to ease the overall inspection process by reducing the time required to run a survey. Indeed, ordinary operational survey conditions are usually performed basing the fieldwork on just classical digitized maps. Our application proposes to enrich inspections by superimposing information on the device screen with the same point of view of the camera, providing an intuitive visualization of buffer strip location. This way, the inspection officer can quickly and dynamically access relevant information overlaying geographic features, comments and other contents in real time. The solution has been tested in fieldwork to prove at what extent this cutting-edge technology contributes to an effective monitoring over large territorial settings. The aim is to encourage officers, land managers and practitioners toward more effective monitoring and management practices.

1. Introduction

In the general context of nowadays-environmental crisis, the key challenge for modern agriculture is twofold: on one hand, there is the necessity to feed many billions of people. On the other hand, the preservation of good quality conditions is compulsory. Accordingly, the quality of fresh running and underground water is a key issue (Stoate et al., 2009). In the agricultural landscape and over wide rural territories, the modern approach of water protection is based, among others, on the use of linear buffer strips (BS) along watercourses. These conservation buffers are small bands of land in permanent vegetation, designed to reduce the run-off, the accumulation of bank-top sediments and the leaking of pesticides into fresh-waters. These vegetated strips benefit the overall quality of surface waters reducing the potential impacts due to agricultural activities and other sources of pollution (Roberts et al., 2012; Balestrini et al., 2011). As a matter of fact, buffer strips play a set of positive functions, such as pollutant adsorption, riverbank stabilization, micro-climate improvement etc. To achieve effective protection, it is well known that the network of vegetated strips must be designed with a carefully installed and well-maintained stringent scheme. The protective network needs to comply with two main conditions: the integrity of the spatial continuity of the protecting belt and constant man-hours of maintenance of riverbanks. The monitoring over a wide network of vegetated linear features, whose pattern stretches across thousands of miles, is a hard task. Despite the potentialities of GIS in managing geo-datasets and delivering relevant thematic maps are well known, the use of specific applications is still broadly missing; indeed, geographical visualization of wide datasets directly in the field requires costly and specialized equipment. A significant improvement of the environmental monitoring and

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* Corresponding author.
E-mail address: r.pierdicca@univpm.it (R. Pierdicca).

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control can be achieved by adopting effective management strategies to increase the awareness of risks (Armenakis and Nirupama, 2013; Hochrainer-Stigler et al., 2013; Hsu et al., 2013). The possibility of taking sound strategies depends on the amount and on the quality of the information available for all the people involved in the management and control-chain. The visualization of geographic data is a suitable approach to enhance communication during decision-making processes (Rhyne et al., 2004; Jiang and Li, 2005; Shahabi et al., 2010). In particular, viewing the physical real world "augmented" by computer-generated sensory inputs represents a powerful tool to deliver supplementary information about the surrounding environment and its objects, enriching the human perception. This kind of visualization is known as Augmented Reality (AR), a technology able to integrate multiple datasets with one view, enhancing the user cognition of the surroundings (Lee et al., 2015). AR could trigger smarter watershed control and riverbank maintenance with less time-consuming during on-site inspections; furthermore, it can be used to cope with the technological limitations that cannot be overcome by using GIS as a stand alone platform. By merging these technologies into a single platform, data become available in real time.

In this light, our purpose is to provide management authorities, land managers and insiders with an intuitive and dynamic real-time visualization tool. The proposed solution combines an existing Geographical Information System (GIS) with the use of relevant Augmented Reality technology. We have designed an experimental data visualization test to encourage land managers and other potential users to perform more advanced monitoring and management practices. More in depth, we have outlined a novel approach to the way in which officers could perform the health-check of linear vegetated BS protecting riverbanks. The GIS coverage, which usually builds the base of reference for the auditing and for the on-site inspections, has been enriched by AR driven information on the position of targeted features, environmental state, degree of pollution, etc. within the reporting area, at river basin scale. From the technological point of view, the system architecture is made of a cloud-based service for data sharing and of a mobile application using a GPS-based AR engine for augmented data visualization using smart phones or glasses. On one hand, GIS allows for managing, modeling and maintaining relevant amount of geo-data, delivering suitable thematic layers. On the other hand, AR enriches the geo-layers with a real-time visualization on-site. In this way we increase and improve geographic information management, whose readability becomes more explicit thanks to the connection between the real world and its modeled representation displayed by thematic maps. Such new forms of enriched or, better, augmented geo-information reduce the efforts in operating a mental transformation from map to reality (Schall et al., 2009). In turn this enables users (i.e., managers and field-workers) to interact in a more intuitive way with risk maps and management plans. All that is of particular importance for field workers, because using GIS-based AR services would help risk control surveyors by reducing the operational time of surveying, as well as improving the access to relevant information not always available during field campaigns. The paper is partially following the schema of Lee et al. (2015) and main novelties and differences are: on the particular proposed application; on the use of a standard platform for AR, that is a popular framework for location based AR applications; on the proposal of a novel data layer as standard and common way of describing riverbank maintenance toward a consistence standard data layer; on the applicability of the proposed architecture to smart phones and glasses; on the automation of the whole pipeline, going from satellite images, to GIS-ready data, to cloud based services, until AR user interactions; on the experimental test bed, based on real user experiences and real data, that provides a powerful contamination experience between computer scientists and geo-scientists. The paper is organized in the following sections. Section 2 illustrates a survey about environmental monitoring by mobile devices and AR, Section 3 describes the case study adopted for the tests, Section 4 is dedicated to the explanation of the application workflow. Afterwards, in Section 5 we comment on experimental results illustrating the reliability and affordability of the proposed application. Concluding remarks and future developments are reported in Sections 6.

2. Environmental monitoring

The environmental management includes the monitoring of specific areas to understand the changes and the evolutionary dynamics. The mobile environmental monitoring has proved to represent a promising field of application for mobile devices (Kruijff et al., 2010). Such an advanced method of environmental monitoring could represent a key approach to re-interpreting the concepts of monitoring and maintenance. Certainly, on-site inspection is a base need for planners and managers. Information collected during field surveys allows a deep understanding of reporting areas. Environmental officers and other land management authorities usually perform on-site inspections, during their daily work, for monitoring changes, designing activities, searching for patterns or for better understanding the specific existing conditions. Nevertheless, the practice to manage the environmental processes by paper plans, which are plotted as needed and manually annotated on a construction or maintenance site, is still widespread (Schall et al., 2009). Therefore, the environmental data analysis process needs the introduction of technological tools to make more effective and reliable monitoring and maintenance phases (Hugues et al., 2013). These tools should considerably improve on-site inspections to assist authorities in the narrow implications with environmental changes; in this way, the process of context understanding should be improved and the solution easier to find. These considerations entail addressing the entire process of environmental management toward the mobile approach (Yoo and Cheon, 2006; Chittaro, 2006). On-site work remains the only efficient link with the office work, because it allows the gathering of self-impressions and an aware method of data processing. Nowadays, on-site work means mobile devices and activities always involve the use of different hardware devices, especially because they are increasingly portable and less expensive. On-site activities do not replace the office work but they have become mandatory for the entire workflow of an environmental analysis. Furthermore, mobile devices are equipped with sensors that help user in orientation and navigation and, above all, they network the devices, and hence the user, with the real world. The introduction of the user location, everywhere at every time, leads insiders and developers to rethink the mobile approaches in a new manner, meaning that applications would tend to always put in contact the user with the real world. The challenge is to find the best way to exploit the system potentiality since the most important thing for risk managers is the visualization of data. Considering the needs of a geoscientist (e.g., availability of data, intuitive tools, reducing inspection time), the challenge is to make GIS data suitable for mobile environment (e.g., visualization for monitoring), exploiting the metadata intrinsic with the GIS objects and necessary for their geo-localization and visualization. GIS and visualization systems are both approaches to discovering and understanding patterns and issues found in geospatial data (Hugues et al., 2013). Indeed, according to Deakin (2009), GIS is strictly related to the visualization for its effectiveness.

For this kind of application, AR could be considered the ultimate immersive system (Liarokapis et al., 2005); even if in large

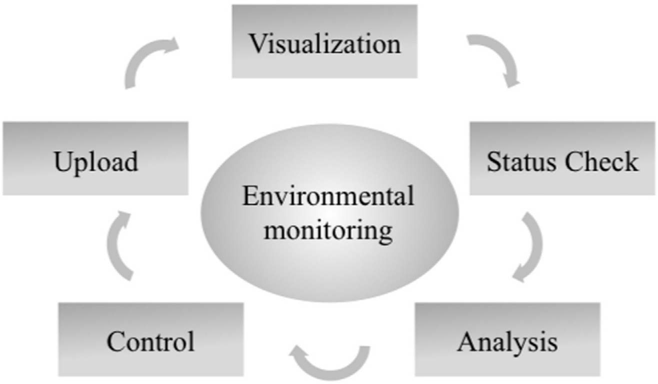


Fig. 1. The cycle of environmental monitoring: the process starts with the AR visualization of GIS data and can be endlessly repeated since the app is directly linked with the server.

urban areas the image recognition will become the norm by opening the way for sub-meter GIS functionality (Jang and Andrew, 2010), for landscape monitoring sensor based AR is the best solution (Schmid and Langerenken, 2014). Thus all the sensors embedded inside devices should cooperate simultaneously to visualize supplementary information as part of the real world. Furthermore, once data are displayed, the user is able to interact, to update, to upload, to share or to modify data during his or her investigation of a specific area. The cycle of work is explained in Fig. 1. To perform a monitoring task, in addition to object visualization, the system must be able to guide the user toward the real position and, when arrived, to recognize it in the real environment. Only under these conditions, an accurate analysis and correct control activities will be possible.

2.1. Real time data visualization using AR

Augmented Reality is a cutting-edge technology which combines the reality with computer-generated data, enhancing the perception of the real world through layers of digital information. AR is the enrichment of the sensory understanding through a series of digital or computer-generated contents (Behzadan and Kamat, 2007; Carmigniani et al., 2011); it is able to enhance the knowledge of the real world with information overlaid in real time, merging real world views captured by video cameras with synthetic data. Even if virtual objects often help the user to simulate the reality (superimposing items that blend into a mixed reality), we consider the visualization of GIS data as particularly suitable not so much for enhancing the reality perception but for helping risk managers during on-site inspections. It allows the user to walk around and observe the environment, continuously getting a “correct view” on sensor data, since information overlapping gives the possibility to improve the knowledge of the real world. The AR technology strives to render computer-generated artifacts correctly blended with the real world in real time. These artifacts appear in the correct position relative to the point of view of the user. Furthermore, interactive visualization enables the communication and the exchange of data (e.g., images, data, graphs) between an on-site observer and decision makers. In fact, end users are expected to have a better view of the global situation before, during and after an event by adopting image overlay techniques depending on the user's location. In recent years many GIS-based approaches and AR services have been experienced for different usages and manifold applications (Pundt and Brinkkötter-Runde, 2000). Whereas AR is widely spreading its usefulness for a variety of outdoor applications such as Urban Excavation Operations (Talmaki et al., 2010), Urban environment exploration (Feiner et al., 1997; Liarokapis et al., 2007), GIS in architecture (Guo et al., 2008), Underground Infrastructure, Maintenance and Repair (Henderson and Feiner, 2009), the usage of AR in environmental monitoring is quite novel (Veas et al., 2013). The case study of this paper is particularly suitable for the visualization of information on mobile devices; vegetated buffer strips are constantly evolving because of the sudden growth of surrounding vegetation and because riverbanks are continuously changing. Besides, since buffer strips are disseminated among wide areas, on-site monitoring is a challenging activity. Given the above, the only way to ensure their correct maintenance by the owner is on-site inspection using tools that can identify the Point of Interest (POI) in the correct location in the real world. If the main purpose is the one described above, other important aspects are the availability of shared comments during the inspection and the internal data storage in case of the lack of an Internet connection, both of which are described in this paper.

3. Case study settings: GIS context for AR geo-layers' creation

The case study chosen for the experimental test is located in central Italy, into the Musone valley (Province of Ancona, Marche Region, Italy). The area surrounding the Musone River is a typical rural complex with hilly farmland setting, with some urban and small industrial settlements. The operational background for the case study is the new Common Agriculture Policy (CAP), with a focus on the standards named Good Agricultural and Environmental Condition (CE Reg 73/2009, annex III), revised according to Common Agriculture Policy in 2009, known as “Health Check” (CE Reg. 72/2009, CE Reg. 73/2009, CE Reg. 74/2009, Directive 2009/61/CE). Our attention is given to the GAEC standard number 5.2, which requires European member states to implement and protect vegetated Buffer Strips along watercourses. The 5.2 standard aims to hamper, or at least to reduce the run-off and the accumulation of sediments, organic matter and pesticides; in other words, water pollution. The GAEC 5.2 has been introduced in Italy in January 2011 and adopted by the Marche Region (Italy) in early 2012. Vegetated buffers along river streams have therefore become a requirement for farmers who want to step into the funding and payments of subsidies. Despite Common Agriculture Policies (CAP) never meant to be a planning tool, their impacts on the management of primary sector are widely known. Far beyond the mere delivering of goods, agriculture has the multi-functional role of driving worldwide changes. The monitoring of these changes and the analysis of policies compel for the implementation of suitable tools enabling sound planning systems and supporting the decision-making. This urge has become paramount in Europe. Within this frame, a previous research delivered a suitable geo-database and tested a multi-scale GIS approach to determine the optimal type and location of buffer strips, at both parcel and collection level, and to investigate their adaptability to the Marche Region. The work by the Division of Earth and Environmental Sciences at KU Leuven in Belgium (Tsakiris et al., 2013) delivered a GIS model to support land managers in deciding the best alternative Buffer Strip typology, starting from given spatial conditions. Floodplain maps, land use maps, erosion maps, DEMs, etc. were used to accommodate the best allocation of buffer strip typology. The model has a parametric iterative decisional tree structure, made of two sequential sub-models: the first one sets the pre-conditions that define and split the problems into different layers; the second sub-model classifies lands (usually parcels) assigning specific buffer strip categories according to outcomes of the above iterative sequence. The adaptation of the model to the Italian conditions was possible thanks to the contribution of an Italian team (Piselli et al., 2013). In particular, land use maps were updated thanks to a hybrid Land Cover Land Use (LCLU) classification by high spatial

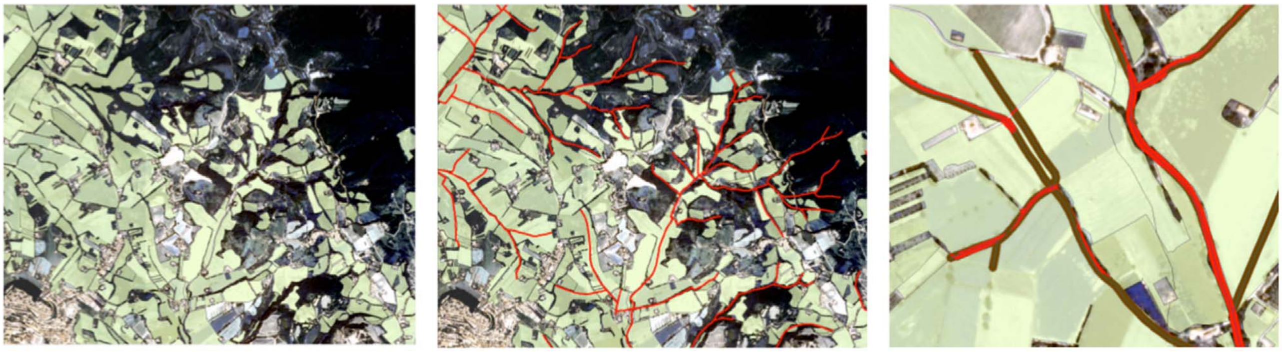


Fig. 2. Case study area viewed on WorldView 2. Left: assignment of each piece of land along the water courses to a specific buffer strip typology. Center: buffer strips built by buffering parcels according to a given distance from the river streams (red). Right: detailed view of intersections between classified parcels and buffer strips. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

resolution multispectral imagery and LiDAR data (Malinverni et al., 2011). As shown in Fig. 2, a set of features buffered along watercourses are generated. In this context, our purpose is to take advantage of a new solution assigning buffer zone to specific areas, adjacent watercourses, and turning this information in an AR environment. This solution enables us to visualize buffer strips as geo-layers in the physical world thanks to AR.

4. Methodology

The visualization of buffer strips directly on-site is fundamental; as a matter of fact, farmers who want to step-up into the Common Agriculture Policy funding scheme and claim for the payments of subsidies, must compel with a set of conditions (Good Agricultural Environmental Conditions), among which the maintenance of vegetated strips (BS) along watercourses is compulsory. Local authority has to ensure that the network of BS is kept and maintained over the time by the farmer. The faster way to monitor the operational state of the network is to identify the linear pattern and verify its maintenance status. In the following section a mobile AR application for GIS data visualization is described. Our tool provides the necessary information to properly inspect the area of investigation and to visualize in real time the buffer strips. Buffer strips are contextualized within the real environment once the camera is on and placed in the correct location where they are located in the GIS cartography. The purpose is to provide a geo-visualization method for real time and on-site data visualization, particularly suitable for this case study, but that could be used for many other GIS datasets. Details of the development phases, libraries and functionality of the application are presented in the following section.

4.1. From GIS to AR environment

To move from GIS model to AR geo-layer we designed a workflow based sequential several items. Starting from the decisional model described in Section 3, we need:

1. availability of geo-referenced data from the GIS;
2. contents to be overlaid once the user is on-site;
3. a tracking system;
4. link to sending data to the cloud;
5. interaction with the superimposed contents.

The first part of the workflow consists in translating the polyline shape file ("shp") of the BS and all related files ("sbn", "sbx", "shx", "dbf") to "kmz" or "dxf" exchange CAD formats. For the AR experience in situ, the visualization of a 3D model is preferable, so we extruded the "shp" polygon importing it into a three-dimensional modeling program (e.g., Sketch-up); once the model is imported, the user can apply every required changes (e.g., material, color, extrusion, and so on). The next step is to edit this model by a Layar3D model converter, a powerful tool which enable this transformation (Layar, 2009); the most suitable format for this kind of operation is the ".obj", because of its capability to maintain the original file object and the possibility of being edited. In this phase, it is also possible to geo-reference the model on a common Open-Street Map environment. The final output is an "l3d" file, which can be defined as a geo-layer ready for being uploaded to a web-server. For a web based implementation, a Relational Database Management System (RDBMS) is necessary, as well as a classical web-server which hosts php pages. For this test we adopted the open source MySQL server. In the database we built a table that contains data regarding the Points of Interest (POIs), geometrical transformation, description and link to external resources. A web service is needed to fetch the POI information (in JSON format) and get it back to the AR platform. In greater depth, the POIs are stored within the database by assigning to them a table with specific parameters like latitude and longitude (to correctly register geo-location), title, description and other information of interest for the user. These parameters are computed by the application, permitting us to overlay the virtual model of the buffer strips into the real scene. To retrieve these points at user's request it is also necessary that the application generates a php script that returns the POIs. In order to visualize only a subset of buffer strips, we set a radius of influence limited to 1 km from the user location. Within this radius, the application looks for relevant POIs. At this stage, the last step to complete the workflow is to perform a series of asynchronous calls to activate the php script, which is possible from any operative system, passing the user's location coordinates as parameters. Fig. 3 is an explanatory scheme of how the architecture works. From this point the mobile app can interact with the contents captured from the RDBMS.

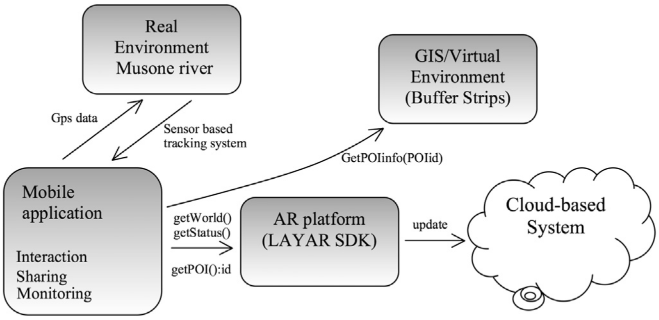


Fig. 3. System architecture diagram and test-bed.

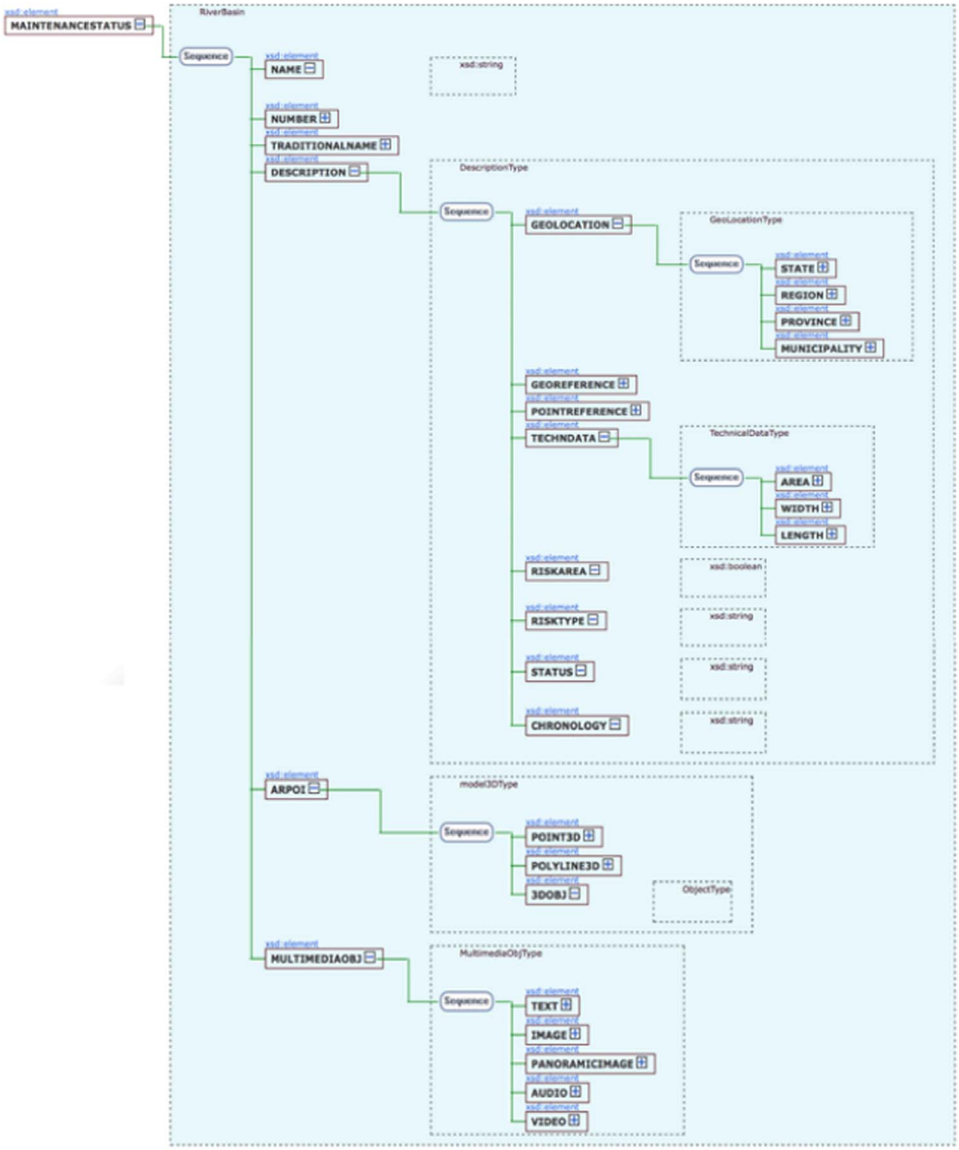


Fig. 4. Standard data layer architecture of the main system, with the data structure of every components.

4.2. *Standard data layer and mobile application*

The developed application has been designed to allow the user to complete the following tasks: to interact with the buffer strips, to update comments, to send reports and to give users the possibility of localizing POIs. The data structure of the whole architecture is summarized in Fig. 4.

The data layer describes the following components of the XSD element named MAINTENANCESTATUS:

- *Identification data*: are used for textual and id identification of the maintenance POIs, use a short name (NAME), an id number and a long name (TRADITIONALNAME).
- *Description data* (DESCRIPTION): are used to describe the maintenance POIs and use geolocation, identified by an international standard address, the maintenance area (TECHDATA), the identification of this area as a risky one and every details about the risk type, the status of the risk, etc.
- *AR data* (ARPOI): are used to show in AR all the spatial information superimposed to the real scene, using the LayAR standard description for points, polylines and shapes.
- *Multimedia data*: are used to add multimedia information to the POIs. Every virtual layer can be enriched by the user, who can link to the POI his own content related to it (e.g. tag, text, images, panoramic images, audio and video contents). All this data is a part of the proposed standard and detailed description can be found on the project web page.

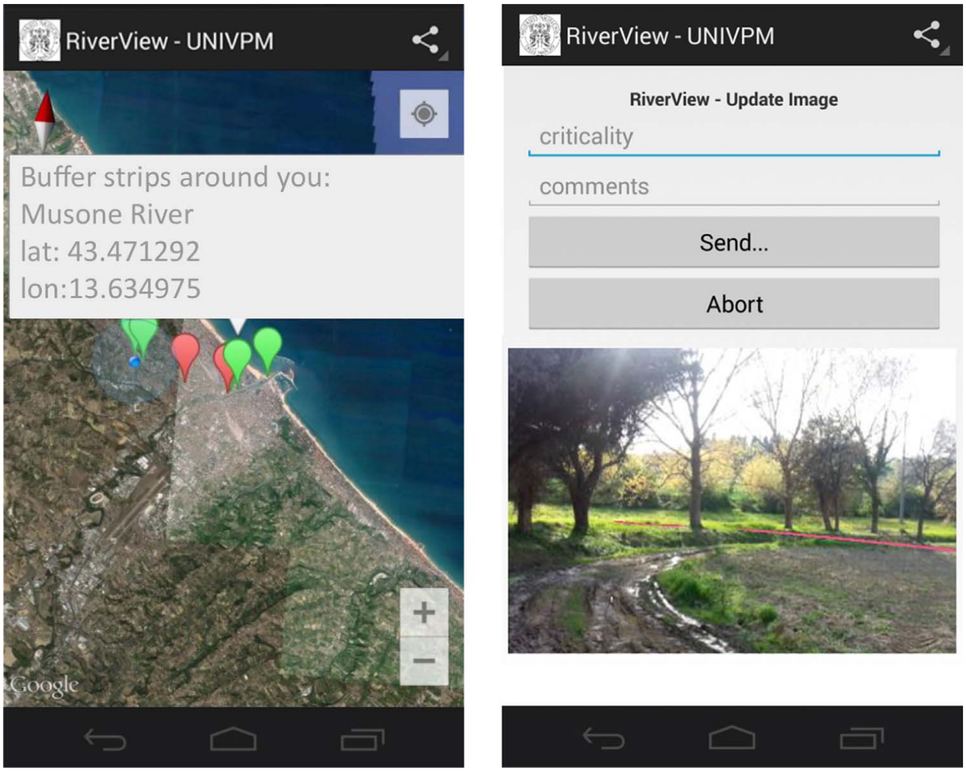
The application has been developed also considering the usability user test described in Section 5, which permitted the development of a user friendly interface. Besides, as per users' suggestions, we also implemented a caching service giving the possibility to operate without network connection. The main functionality of the application is listed below.

- *Augmented Reality tool*: This functionality allows the user to exploit the Augmented Reality browser to search for the buffer strips closer to him/her. The compass, displayed on the screen, visualizes the nearest one; in this way the user can easily reach the area where the strip is located. To implement this feature we took advantage from the set of embedded sensors of mobile devices e.g. compass, gyroscope, accelerometer and GPS receiver. A good examination about AR tracking systems can be found in Zhou et al. (2008). For adjusting the search area, the

Fig. 5. Screenshot in landscape mode, taken during on-site inspection. On the upper side, the radar guides the user among the countryside towards the POIs. The red line is the buffer strip that appears automatically when the user gets into the radius of influence. The lower side shows the strip typology, the metadata arising from the GIS database. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

user can set a search radius from the device. This is particularly helpful during the campaign to retrieve information of a limited set of POI nearby the user. As default, the radius value is 500 m. Moreover, the application allows obtaining more information by displaying in a popup window the title, description, footnote and the image associated with the POI selected, as well as the BS typology. All these features have been implemented by using libraries provided by API LayarSDK: a static library that implements Augmented Reality and geo-localization functions. Fig. 5 shows an example of AR applied to river basin on the study area.

- *The use of the map*: The map function is a key tool to have a quick overview of all the relevant POIs of a specific area, keeping trace about previous comments associated to it. The map module was designed to expedite the inspection; in fact, it helps to immediately identify the BS distribution and assists in understanding the nearby environment. Thanks to the map visualization, the user can quickly reach the complete set of information such as typology, length, coordinates and all data stored into the database regarding BS (see Fig. 6). These functions were implemented using the Google Maps V3 API.
- *Management of Points of Interest*: Each time a specific buffer strip


RiverView - UNIVPM

Buffer strips around you:
Musone River
lat: 43.471292
lon:13.634975

RiverView - UNIVPM

RiverView - Update Image
criticality
comments

Fig. 6. Left: POI visualization on the map. Center: real time visualization of buffer strip (in red) with the possibility to share information or comments. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

is selected by clicking on it, users can choose between two alternative actions: to "add a comment" or to "enrich" the scene with AR contents. The first one allows us to report relevant information about the specific POI by simply posting a comment, or to mark any potential issue affecting a specific strip feature. Being stored into the remote server, these comments are suddenly available in GIS-ready mode. The second option allows users to enrich the scene by enhancing information with all comments regarding a specific POI. This function helps surveyor in making critical choice during the trip and also to easily retrieve all the information once he is back at office (see Fig. 6).

- *Data management*: This functionality copes with the need of updating POI comments also in case of lack of network connection; data are locally stored into a mobile device (i.e., tablet or smartphone). A structure containing the local database and a POI table was created in order to add, to read and to update POI locally. A suitable class is created to manage the POI data structure within the local database. The Database class is used each time a user needs to store a comment or a related file (i.e. a picture) in offline mode. To upload local data into the remote database a specific class is instantiated every time an item of the application's main menu is selected: it checks if the local database is empty, checks the network connection and, in case of affirmative result, uploads the local data to the remote database.

5. Results and validation

We have designed different test cases under different conditions. The tests were made in real scenarios, at a latitude of 43°33′36″N and longitude of 13°30′05″E with different daytime, mainly focusing on the usability and positioning accuracy. During the testing phase we observed that the application retrieved and displayed the buffer strips in less than a second. The system proved to be responsive to user commands, having a quick access the database. Furthermore, all the 3D models linked with the GIS system were displayed correctly in the landscape. For evaluation the usability we have tested the system with subjects involved in the environmental management such as planners, land-managers, officers and practitioners of different age. To make up the panel of expert involved with the planning and management of the environment for the tests, we also gathered information about their habits and technological skills. Even if the sample of practitioner were not skilled in the use of technology they appreciated the system. Almost all users did not know AR but appreciated this technology. The majority of the sample (70%) retains that similar applications are necessary resources to improve monitoring activities. They have generally found that the application is simple to use, although with respect to the general idea, they suggest the improvement of the relationship between the GIS platform and the mobile application. For testing the accuracy of the tracking system, we tried different 3D models of the buffer strips, in different locations and times. The devices used in our test were an iPad 2 and a Samsung S3. The system is also compatible with LayAR for Google Glasses. With the overlapping of several screen shots, we checked that the positioning of the virtual contents was stable and visualized in the same position for both devices. With the GNSS service available, accuracy was between 5 m and 10 m, depending on vegetation canopy coverage. By the way, the accuracy of the superimposing of digital contents is strictly dependent on the current accuracy of consumer grade GPS receiver. The current state of sensor-based and marker-less AR technology is mainly limited by positioning accuracy; moreover, the spreading of geospatial applications will depend on the growth of the customer market for more accurate positioning systems. Despite the system architecture is complex, we have designed a simple user interface (UI) to ease user's approach. In this way it is possible to cope with all potential difficulties that users could face during the work on field, such as bad weather conditions or impervious accessible areas. The more intuitive is the UI the faster the inspection will be. It is important to highlight that the developed tool can serve monitoring and maintenance tasks at the same time. In fact, the proposed solution, besides allowing monitor and supervise reporting area (in our specific case, the buffer strips at collection basin scale), also allows us to share observations and surveyed data in real time, by uploading and linking this information in a GIS environment. In particular, the cycle shown in Section 3 can be re-iterated endlessly: the health-check status of buffer strips can be monitored and verified at any time and the environment constantly maintained.

6. Conclusions and future works

In this paper we presented an approach to prove the potentials offered by Augmented Reality (AR). By combining GIS-based environmental modeling with the use of relevant AR technologies we outlined a novel approach to the health-check of linear vegetated strips protecting river banks, overcoming several limitations of a classical approach to mobile environmental monitoring. Thanks to this application, the operational tasks during on-site inspections over large territories can be carried out in easily and with less time-consuming procedures. The methodology offers a set of improvements. Above all, it gives users a quick access to relevant information, thanks to the dynamic superimposing of geographic features, comments and other contents. Furthermore, the user-friendly interface makes the system suitable for different users. The system allows for real-time interactions of GIS data and AR contents; in particular, thanks to the cloud based DB for GIS data, modification of data is possible in the real-time.

In a further development of our research we aim to integrate the technology of Augmented Reality in a video/image stream from a remote manned/unmanned robotic platform equipped with a wide range of sensors. The idea will be experienced within the "River View" project granted by the Ministry for Economic Development to support research programs; the project deals with the study, design and prototyping of a system for mapping and classification of risk cases at river and lake basins by using autonomous robotic systems and sensory advanced platforms. We are building unmanned robotic vehicles, both aerial (UAV) and surface (USV), to perform fast environmental surveys on targeted regions of interest with particular focus on small river basins and lakes (Fig. 7). These platforms are particularly suitable to all that sites where human access is unease or forbidden due to specific restrictions for natural protection. We are currently working to make the overlaying of GIS data and AR contents fully operative in real time. This will make the video stream enriched with additional information related to the survey (e.g. weak lake bank, dangerous area and so on). It does not represent a simple overlay of telemetry data, rather an actual interaction of the reality, as perceived by the user, with a set of complex contents, such as 2D/3D objects, linked with the user's point of view. The whole system can be performed in a constant stream of information about the area under investigation, in GIS and geo-DB environment. Users could benefit of the Augmented Reality for a more reliable control on the survey. Although in many countries the world-as-a-user interface paradigm, introduced by Schmalstieg et al. (2007), is spreading widely for commercial use, no monitoring applications for Head Mounted Devices (HMD) have been realized yet. Therefore we also expect, for the near future, to test this kind of application for wearable devices. Finally, potential scenario to further explore the potential of an AR solution, in combination with geographic representations,

Fig. 7. Use case for AR applications. Left: USV survey platform. Right. USV during the river basin survey.

is the quality control of automatic land use classification. A previous research (Malinverni et al., 2014) has delivered an interesting tool for automatic Land Cover/Land Use classification; the idea is to use AR as a tool to validate the performance of classification.

We expect that in the next few years AR will become a widespread technology and a best practice application for environmental protection, monitoring and land management, using smart phones and glasses. Faster and smarter operations would lead towards an improved and more effective decision-making chain, lowering the operational costs and making more effective the containment of risks.

References

Armenakis, C., Nirupama, N., 2013. Prioritization of disaster risk in a community using gis. Nat. Hazards 66 (1), 15–29.

Balestrini, R., Arese, C., Delconte, C., Lotti, A., Salerno, F., 2011. Nitrogen removal in subsurface water by narrow buffer strips in the intensive farming landscape of the po river watershed, Italy. Ecol. Eng. 37 (2), 148–157.

Behzadan, A.H., Kamat, V.R., 2007. Georeferenced registration of construction graphics in mobile outdoor augmented reality. J. Comput. Civil. Eng. 21 (4), 247–258.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., Ivkovic, M., 2011. Augmented reality technologies, systems and applications. Multimed. Tools Appl. 51 (1), 341–377.

Chittaro, L., 2006. Visualizing information on mobile devices. Computer 39 (3), 40–45.

Deakin, A., 2009. Evolution of Geographic Information Systems and Visualization Systems. Environmental Monitoring. EOLSS.

Feiner, S., MacIntyre, B., Hllerer, T., Webster, A., 1997. A touring machine: prototyping 3d mobile augmented reality systems for exploring the urban environment. Pers. Ubiquitous Comput. 1 (4), 208–217.

Guo, Y., Du, Q., Luo, Y., Zhang, W., Xu, L., 2008. Application of Augmented Reality gis in Architecture. In: ISPRS VIII.

Henderson, S. J., Feiner, S., 2009. Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In Mixed and Augmented Reality, ISMAR 2009. 8th IEEE International Symposium on, IEEE, pp. 135–144.

Hochrainer-Stigler, S., Pflug, G., Lugeri, N., 2013. Flood risk in a changing climate: a multilevel approach for risk management. Integr. Catastr. Risk Model., 263–279.

Hsu, W.-K., Chiang, W.-L., Chen, C.-W., 2013. Earthquake risk assessment and optimal risk management strategies for hi-tech fabs in Taiwan. Nat. Hazards 65 (3), 2063–2076, cited By 5.

Hugues, O., Cieutat, J.-M., Guitton, P., 2011. Gis and augmented reality: state of the art and issues. In: Handbook of Augmented reality. Springer, New York, pp. 721–740.

Jang, S., Andrew, H., 2010. Gis and augmented reality in 2015. In: Association of Geographic Information (AGI) Foresight Study.

Jiang, B., Li, Z., 2005. Geovisualization: design, enhanced visual tools and applications. Cartogr. J. 42 (1), 3–4.

Kruijff, E., Mendez, E., Veas, E., Gruenewald, T., Simoni, S., Luyet, V., Salminen, O., Nurminen, A., Lehtinen, V., 2010. Hydrosys: onsite monitoring and management of environmental processes using handheld devices. Geohydroinf. : Integr. GIS Water Eng., 37–51.

Layar, 2009. Layar augmented reality, ⟨https://www.layar.com⟩.

Lee, S., Suh, J., Park, H.-D., 2015. Boreholear: a mobile tablet application for effective borehole database visualization using an augmented reality technology. Comput. Geosci. 76, 41–49.

Liarokapis, F., Brujic-Okretic, V., Papakonstantinou, S.,2007. Exploring urban environments using virtual and augmented reality. In: GRAPP 2006, vol. 3, pp. 1–13.

Liarokapis, F., Greatbatch, I., Mountain, D., Gunesh, A., Brujic-Okretic, V., Raper, J., 2005. Mobile Augmented Reality Techniques for Geovisualisation, vol. 2005, pp. 745–751.

Malinverni, E., Frontoni, E., Mancini, A., Tassetti, A., Pierdicca, R., Zingaretti., P., 2014. Integrating elevation data and multispectral high-resolution images for an improved hybrid land use/land cover mapping. SouthEastern Eur. J. Earth Obs. Geomat.

Malinverni, E., Tassetti, A., Mancini, A., Zingaretti, P., Frontoni, E., Bernardini, A., 2011. Hybrid object-based approach for land use/land cover mapping using high spatial resolution imagery. Int. J. Geogr. Inf. Sci. 25 (6), 1025–1043.

Piselli, V., Marcheggiani, E., Gulinck, H., Galli, A., 2013. Buffer strips in the Marche region. In: Rural Landscapes: Towards a Better Integration of Rural Development Policies, Urban and Landscape Planning.

Pundt, H., Brinkkötter-Runde, K., 2000. Visualization of spatial data for field based gis. Comput. Geosci. 26 (1), 51–56.

Rhyne, T., MacEachren, A., Gahegan, M., Pike, W., Brewer, I., Cai, G., Lengerich, E., Hardisty, F., 2004. Geovisualization for knowledge construction and decision support. IEEE Comput. Graph. Appl. 24 (1), 13–17.

Roberts, W.M., Stutter, M.I., Haygarth, P.M., 2012. Phosphorus retention and remobilisation in riparian vegetated buffer strips. In: EGU General Assembly Conference Abstracts, vol. 14, p. 11348.

Schall, G., Mendez, E., Kruijff, E., Veas, E., Junghanns, S., Reitinger, B., Schmalstieg, D., 2009. Handheld augmented reality for underground infrastructure visualization. Pers. Ubiquitous Comput. 13 (4), 281–291.

Schmalstieg, D., Reitmayr, G., 2007. The world as a user interface: augmented reality for ubiquitous computing. In: Location Based Services and Telecartography. Springer, Berlin Heidelberg, pp. 369–391.

Schmid, F., Langerenken, D., 2014. Augmented reality and gis: on the possibilities and limits of markerless ar, 2014, Connecting a Digital Europe through Location and Place. Proceedings of the AGILE'2014 International Conference on Geographic Information Science, Castellón, June, 3-6, 2014. ISBN: 978-90-816960-4-3, http://hdl.handle.net/10234/98738.

Shahabi, C., Banaei-Kashani, F., Khoshgozaran, A., Nocera, L., Xing, S., 2010. Geodec: a framework to visualize and query geospatial data for decision-making. Multimedia 17 (3), 14–23.

Stoate, C., Bldi, A., Beja, P., Boatman, N., Herzon, I., van Doorn, A., de Snoo, G., Rakosy, L., Ramwell, C., 2009. Ecological impacts of early 21st century agricultural change in europe - a review. J. Environ. Manag. 91 (1), 22–46.

Talmaki, S.A., Dong, S., Kamat, V.R., 2010. Geospatial databases and augmented reality visualization for improving safety in urban excavation operations. In Construction Research Congress, 2010, pp. 91-101.

Tsakiris, G., Nalbantis, I., Vangelis, H., Verbeiren, B., Huysmans, M., Tychon, B., Jacquemin, I., Canters, F., Vanderhaegen, S., Engelen, G., Poelmans, L., De Becker, P., Batelaan, O.g., 2013. A system-based paradigm of drought analysis for operational management. Water Resour. Manag. 27 (15), 5281–5297.

Veas, E., Grasset, R., Ferencik, I., Grnewald, T., Schmalstieg, D., 2013. Mobile augmented reality for environmental monitoring. Pers. Ubiquitous Comput. 17 (7), 1515–1531.

Yoo, H., Cheon, S., 2006. Visualization by Information Type on Mobile Device. 60; , pp. 143–146.

Zhou, F., Duh, H. B. L., Billinghurst, M., 2008. Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. In Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality, IEEE Computer Society, pp. 193–202.