GIS and Augmented Reality : State of the Art and Issues

Olivier Hugues, Jean-Marc Cieutat, Pascal Guitton

Chapter 1

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Abstract

In this chapter we propose a joint exploration of Geographic Information System (GIS) and Augmented Reality (AR). Thanks to some factors, we will detail hereafter, these two domains have greatly converged in recent years further to certain factors which we shall detail hereafter. We then outline applications combining GIS and a display technique using AR in order to identify the scientific issues, as well as the functional and technical issues. Starting from this extensive state of the art of existing work, we propose a new functional classification, before concluding with different perspectives.

1.1 Introduction

Until recently Augmented Reality (AR) was still seen as a technology used only by researchers in laboratories, but it is now becoming increasingly accessible to a public at large. This technology can be observed according to two different axes: a technological axis and a functional axis. On the one hand, the technological perspective leads us to observe that AR is based on three main pillars. The first pillar corresponds to hardware technologies. Miniaturisation, the multiplication of various different sensors and the increased performance of equipment have enabled this technology to be implemented using many different devices. The second pillar corresponds to software technologies. Progress in image analysis [1, 2], new ever higher performance algorithms [3, 4, 5, 6, 7] and new multi-sensor data merging methods [8, 9, 10, 11]

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enable this technology to better satisfy expectations. Finally, the third pillar, corresponds to data and access to these data. Data relocation, supported by cloud computing and ubiquitous computing [12], provides easier access to information from anywhere and at any time. On the other hand, by observing AR according to the functional axis, it is possible to consider it as an interface between the user and the machine [13, 14]. In this respect, as is commonly the case with user-machine interfaces, such a process cannot exclude seriously taking into account user-based parameters and those linked to the environment. According to [15], "using a new technical device modifies our sensory-motor coupling with the environment; and at the same time it modifies our perception". However, we cannot "only" apply ourselves to better perceiving since perception is not an aim in itself, but a way to achieve an action objective [16]. Indeed, the issues (which we shall examine later on) which a GIS is able to satisfy aim to be pragmatic. It is in this context that Information Systems (IS) and more particularly Geographic Information System (GIS) are used in this context. The architectures of these systems therefore now need to be reorganized based on these three elements: the user, the environment and the data. On the one hand, technological developments have enabled a new functionality in addition to those already present in IS: locating data in time and space. On the other hand, mobile computing has added an extra essential component: locating the user in time and space. This technological revolution requires the implementation of methods and architectures which are coherent with the entities at stake. We shall begin by showing how AR suffers from a major lack which GIS can fill. We then propose to define GIS and to show what they can contribute to AR. Finally, after a state of the art of different applications combining GIS and AR for which we propose a new classification, we shall present an analysis of the stakes of this type of applications.

1.2 Augmented Reality: a still emerging technology

We shall not discuss in this chapter the different definitions proposed for AR and we invite readers to refer to the first chapters of this manual on the Basis of Augmented Reality. We can however note a certain distinction between communities which deal with this technology. On the one hand, AR is seen as a non-immersive approach (in opposition to Virtual Reality). Instead of proposing a fully digital environment, AR modifies the world perceived by the individual by add some digital informations [17, 18]. On the other hand, AR is not seen as being opposed to Virtual Reality (VR), but rather as an extension which involves mixing real and virtual information in the same scene [19, 20]. By considering this second point, the authors of [21] have identified five barriers which must be overcome by those involved:

Techniques Need to improve technical developments. This corresponds for example to the reliability and interoperability of different technologies used in order to be able to easily integrate them in demonstrators and test new applications.

Methodology Lack of methods in order to analyse and to evaluate needs in terms of AR systems and available solutions.

Evaluation Poor quality of clearly functional applications and limited proof of their added value. Answering a question by an industrialist - "What are the advantages of a stereoscopic system?" - is not easy.

Safety Applications often call into play the safety and health of users.

Usability Potential difficulties due to the non-intuitive nature of certain interfaces.

Although these difficulties are encountered in Virtual Reality too, [22] considers "*that these limitations are also characteristic of AR technologies*". In this context, [23, 15] have identified the three main elements which occur when using a technical device. The first element, hierarchically the most important, is the **user**. Then, the **device** or platform, which is described in terms of resources and finally the **environment** which is defined by a series of objects, people, events and phenomena peripheral to the user's activity, but which have an impact on the system or user's behaviour. Considering all these elements, we can complete the diagram proposed by [24] which initially represents the building blocks of an AR system, by adding some functional building blocks (Figure 1.1). We add a "Data" block at the bottom of the diagram, a "Hardware" block as well as a "Software" block to clearly identify the importance of developing both hardware and software for this type of application. We thus add the "Platform" block, directly made up of two previously mentioned blocks, to clearly identify one of the three pillars described in Sect. 1.1. Less technical, but just as important are the user and the user's environment, which are to be taken into account for the design of an AR system. Although certain blocks are not specific to AR systems, associating all these blocks enables such a functionality to be created.

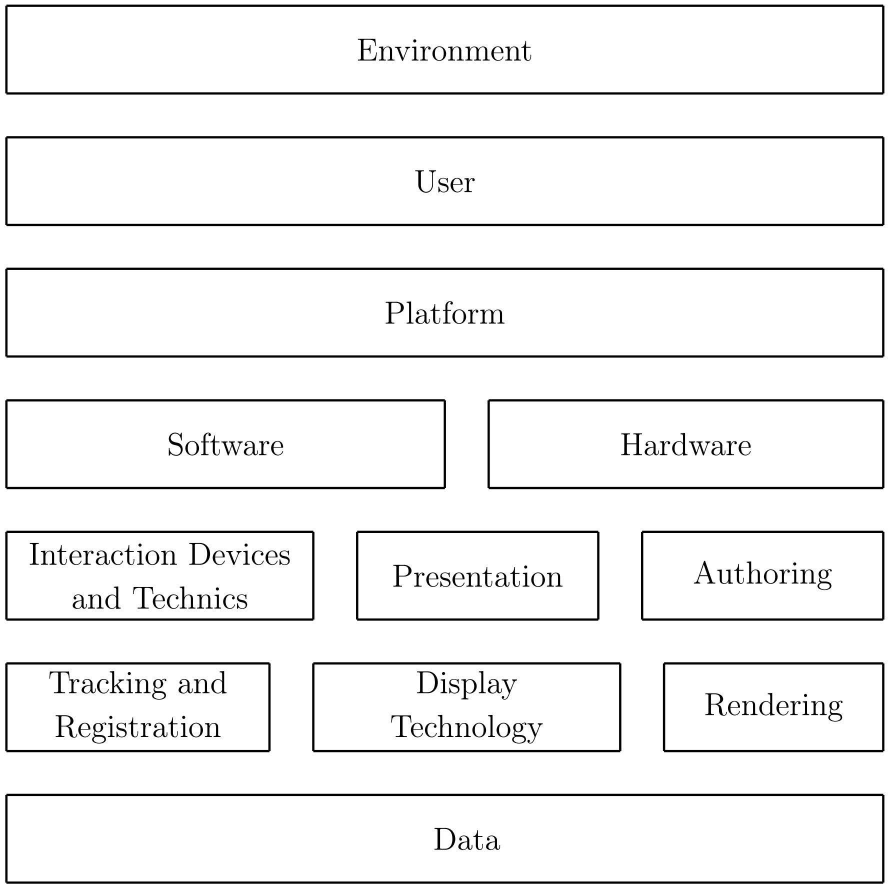


Fig. 1.1: Blocks of an Augmented Reality system. Based on the [24] diagram.

As stated in the introduction, AR requires the use of different hardware technologies[4] which are becoming less and less cumbersome, costly and energy-consumer. Indeed, the explosion of the number of various applications using AR is linked to the technological development of devices (mobile phones, webcams, OLED screens, CCD sensors, etc). Morover, certain forms of AR[5] also need access to data sources (digital 3D or 2D models, video, images, sounds, symbols or event text). The applications also need to access

[4] We invite readers to refer to this manual's "Technological" chapters.

[5] We invite readers to refer to the first two chapters of this manual to find out about all forms of AR.

space and time location metadata, both local and online. AR, as a man-machine interaction paradigm [13, 14], enables information to be offered to users with associations of different types[6] between digital entities (generated by computers) and physical entities (our natural environment). The rate of evolution of technological devices was therefore necessary, but insufficient. Apart from hardware, AR requires sources of information content to be relevant. Although the evolution of hardware has already begun, the explosion of localised information platforms accessible to the public at large [25, 26, 27, 28] and even [29][7] enables the necessary lacks in the development of AR technologies to be compensated. Although from a technological point of view AR aims to "link" digital entities to the physical world, it is obviously necessary to have these digital entities. And despite the fact that generating digital models is quite long, costly and tedious, GIS offer an abundant source of digital information which AR can use. Obviously, the processing of different sources of information affects the evolution of AR. Issues arising from information sources can create difficulties on these systems like data updating times for example [31][8].

1.3 "IS" is included in "GIS"

A lot of different definitions have been proposed during technological evolutions to define IS and this multitude of definitions stems from the difficulty in defining objects and subjects involved in this type of application [32]. Due to the diversity of layers (hardware, software, dataware and humanware), we can for example find in the literature both functional [33] and technological [34] approaches. Generally, we consider Information Systems (IS) from a functional point of view as an organised series of elements which provide information [35] to be grouped, classified, processed and disseminated. These systems have been developped until they achieve a level of complexity as it requires many adaptations with regard to interfaces (abstraction, symbolisation, etc).

[6] These associations can be in space, in time, semantic or a combination of these types of associations.

[7] Company which in 2010 opened an Android based AR application development platform [30].

[8] This application is based on website date. Data may sometimes only be updated every two hours.

1.4 From IS to GIS

GIS are information systems (IS) which can organise and present spatially referenced alphanumerical data. GIS encompass four components named "**Personal**", "**Software**", "**Data**" and "**Hardware**" in [36]. Based on different databases, these systems provide digital geographical information to be **acquired** digitally. They enable the **analysis** of geographical data by handling and interrogation. They **display** this information using visualisation techniques which make it easily understandable. Finally, they sometimes enable future phenomena to be anticipated. GIS face to several technical issues:

Acquisition Import of digital data captured on site.

Archiving Management of the database (integrity, coherence...).

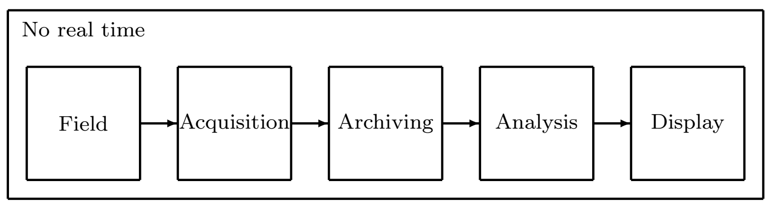
Analysis Handling and interrogation of data. Data may target objects of all types, phenomena, events, etc. GIS globally enable five questions to be answered.

Where:	the geographical location of a set of elements or a specific element.
What:	the type of set of elements or element in the region of interest.
How:	a set of elements or an element concerning the distribution of entities and their links in the region of interest to be spatially analyzed.
When:	Enables a temporal analysis to be carried out on a series of elements or a specific element.
And if:	Enables a uchronic analysis to be carried out.

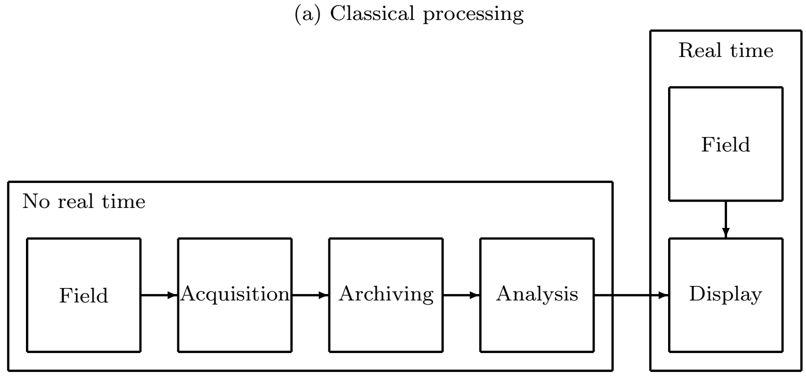
Display Visualization of information contained in the database in order to make it understandable by the user. Different abstractions are created to make the system lighter (vector, raster, resolutions multi-scale, symbolization, etc). This component can thus be considered as a virtual environment, close to a form of Virtual Reality since it is a digitally created environment.

Quality Whether internal (adequation between a card/BDD and what it should have been) or external (adequation between the card/BDD and the needs of its user). Quality has been subject to many discussions for almost 30 years [37].

It is possible to consider the "Field" (the environment which is concerned) as being the natural environment or a sub-element of this, and the display of data by the GIS as a virtual environment made up of digital entities semantically linked with the real environment. The symbolisation of data leads to a difference of representation between the natural environment and the artificial environment which does not facilitate the matching of information for users. It should however be noted that, as defined by [19], technologies are available to limit this gap between reality and a digital world. It is partially, for this reason that AR takes on its full meaning as a technology which reduces the gap between the physical world and the digital world since, by definition, AR brings together digital entities and physical entities in both time and space [20, 38]. The final aim of using this technology combined with a GIS is therefore to act on the “Display” phase of GIS. With the combined use of AR and GIS, we try to reduce the semantic gap between real data and digital data (Figure 1.2).



(a) Classical processing



(b) Processing with AR.

Fig. 1.2: GIS data processing chain.

More than a link between GIS data and the environment, adding an AR display system completely modifies the way GIS are used. In classical cases, the display system requires two input vectors:

1. User request
2. Display parameters (factors of scale, abstractions, symbolisations, etc.)

For the display system using AR, adding a new component must be taken into account:

1. User's position and orientation

To obtain information from GIS, the user should not only launch the right request, but also choose the right position and orientation. Geographic Information System therefore offer a vast field of action for AR. We can now find a wide range of applications combining AR and GIS. In the next section we take a look at the different applications combining GIS and AR according to a taxonomy directly taken from the literature.

1.5 Joint use of GIS and AR

Developing a GIS using AR for its display induce some technological, methodological, industrial and commercial challenges. Indeed, associating these two types of technologies requires both the common and specific stakes of these applications to be taken into account. From a technological point of view, it is necessary to perfect new adapted hardware and software architectures. It is also necessary to develop new interactions and visualizations of geographical digital data. It is also useful to study the implications of the use of AR techniques on a GIS (and vice versa). Exploring the synergy between digital geographical data and AR becomes inevitable and the development of new GIS methods specific to this type of application should be created. Many different fields such as tourism, environment, civil engineering, road and sea navigation are interested by this type of application.

1.5.1 Towards a functional classification

If we consider AR, seen as a set of technologies enabling different associations of digital entities and physical entities to be implemented, we can consider AR using two approaches. Furthermore, we know that developing an AR functionality indoor or outdoor do not involve the same stakes [39]. In our application context, combining GIS and AR, we can initially extract two categories from the literature.

1. Indoor exploration of geographical data.
2. Outdoor exploration of geographical data.

However, we propose a different classification, which is much more specific to the joint use of GIS and a display system using AR. We hope that this classification, whose initial aim is to describe and compare, will be considered to be generative [40]. In this context of geographical information, we need to distinguish between the source of this information and its representation. Indeed, the map is not the territory. We therefore propose separating applications into two major groups. The first includes applications which aim at handling geographical data. Digital augmentations target GIS data. In this case we are referring to an *Augmented Map* (AM) functionality. These applications translate the modification of the display system's sub-component intended to take into account user requests to then update the display of data. The second characterizes applications which aim at enabling users to work more efficiently in their environment. The target of digital augmentations is not representing the environment as in the first case, but the environment itself. We therefore refer to an *Augmented Territory* (AT) functionality. These applications translate the modification of the sub-component of the display system enabling the application's data with location in time and space to be updated.

1.5.2 Augmented Map

We called the first functionality of our classification *Augmented Map*. The aim of an application of this type is to enable one or several people to explore geographical data coming indifferently from the physical world or the digital world. For example, the prototype proposed by [41] is a system for presenting geographical information. Data are described by 3D digital models. Presented as a specific GIS framework for presenting geographical data inside or outside, the experiments proposed only show the indoor application by proposing handling data via markers (Figure 1.3). This approach enables these data to be explored according to different points of view by handling markers.

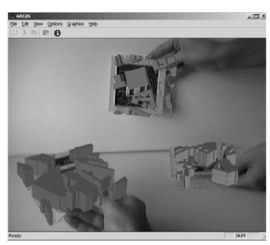


Fig. 1.3: Exploring Geographical data by modifying the point of view [41].

In [42], the authors propose two possibilities to collaboratively explore geographical data. The first one is an interface which combines AR and the user's hand tracking through image analysis. Users can thus look at a real geographical map (paper) and see a 3D model adjusted on this map (Figure 1.4a). The second one offers different interaction techniques (zoom, move, notes, etc.) by using for example the zoom tool metaphor so users can explore data (Figure 1.4b).

(a) Visualisation of data (b) Interaction ("Paddle Interaction")

Fig. 1.4: Visualisation and interaction with geographical data [42]

In [43], the authors use the vision-based AR technique[9] popularized by [44]. They also propose several techniques to explore the geographical data of a NASA mission to the moon using "telescopic" (baguette) interactors. Markers are used as metaphors (Figure 1.5) from real life (zoom tool) or from computing interfaces like sliders to vary the linear value of certain parameters.

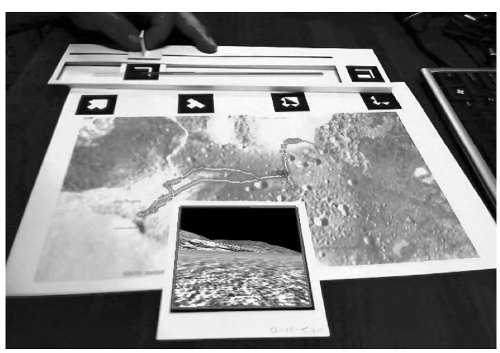


Fig. 1.5: Interaction metaphors (slider example)[43]

[9] Single camera position/orientation tracking with tracking code that uses simple black squares.

Another example (based on detecting points of interest [45, 46] proposes using AR combined with a PDA to facilitate the use of a paper map. Video content or images are thus offered to users in context with the paper map. In addition to these augmentations, they offer interactions like exploring images according to a selected point on the map (Figure 1.6).

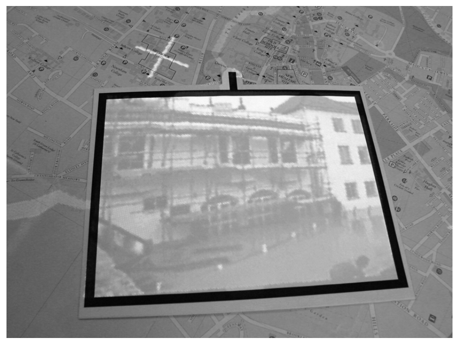


Fig. 1.6: Exploring an image from the map [47]

In [48], the authors propose comparing paper maps and electronic maps. They propose to compare these two means of consulting geographical information by distinguishing four main categories: **functionalities** and **content** as well as **use** and **interaction**. This analysis enables the authors to conclude that both approaches (paper and digital) are complementary in many cases. This conclusion leads the authors to develop a prototype using a PDA and marker-based positioning to consult the geographical data on a mobile's electronic map.

1.5.3 Augmented Territory

We call the second functionality of our classification Augmented Territory. The aim of an application of this type is to provide one or several people additional information to explore our natural environment. For example, in [49], the authors propose two indoor AR applications. The first helps explore a building (Figure 1.7b) and the second is an application to help browse through a library (Figure 1.7a). These applications are based on a marker system.

(a) Help finding your way inside a building.

(b) Help finding a book in a library.

Fig. 1.7: Two marker-based AR applications.

In [50], we can see an AR system whose camera is fitted on a helicopter. The helicopter flies over buildings and sends the video back to the ground as well as its position and orientation wirelessly. Once the data (video, position, orientation) have been collected, they are added to a database enabling, for example, the names of buildings to be displayed on the video. The demonstrator suffers from a huge lack of precision when adding the virtual information in the video. The authors of [51] propose an AR demonstrator with indirect vision enabling this geographical information to be incrusted (street names and numbers, names of monuments, etc.) as illustrated in Figure 1.8 in a video flow available to the user through a screen (indirect vision AR). Geographical data is extracted from the English database maintained by [52]. Retiming is carried out by combining a GPS for the position and an internal navigator for orientation. Access to data is by Wifi. Work has been done on placing the labels and synchronising the orientation.

Fig. 1.8: View of monuments from Westminster Bridge (London) [51].

[53] describes an application where users are informed about their position, the name and altitude of surrounding summits. Users look at the summits of mountains through the screen of their mobile phone and the Peak.AR application provides useful information by incrusting text labels (Figure 1.9).

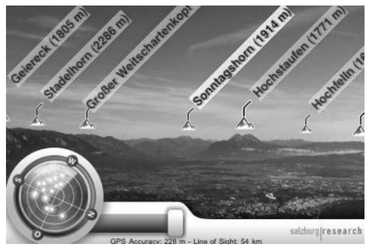


Fig. 1.9: Peak.AR: an application combining AR and GIS on mobiles.

ARVino is a demonstrator resulting from the Tinmith project [54] for the augmented visualisation of geolocated wine-growing data. Presented at ISMAR05, [55] propose solutions to avoid colour overloads in virtual information as well as managing the transparency of these objects with the aim of not concealing data from the physical world (Figure 1.10).

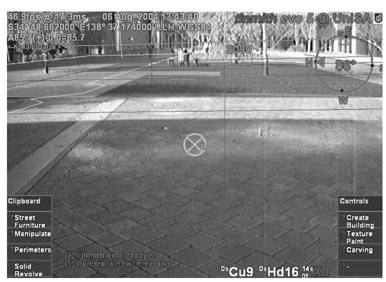


Fig. 1.10: Example of ARVino demonstrator augmentation [55]

In [8], a Real-Time Kinematic GPS, more precise than a classic GPS, enables the team to propose a demonstrator christened "Geo-Media", allowing the physical world to be mixed with artistic virtual objects. Augurscope is an interface also using a GPS and inertial sensors so as to propose a virtual environment whose point of view (in the virtual environment) depends on the point of view in the physical environment (Figure). It is used in [56] for an application enabling the public to explore a medieval castle.

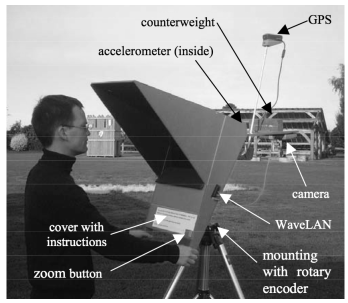


Fig. 1.11: Augurscope details [56]

ARGIS is a project for visualising information during a project for building an aerodrome [57]. Besides the classic retiming mechanism for virtual geographic information on the video flow by detecting points of interest, they propose an “X-ray” augmented visualisation enabling users to see what the naked eye is unable to see (Figure 1.12).

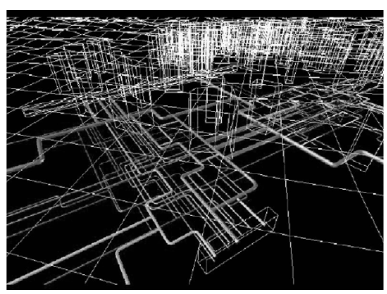
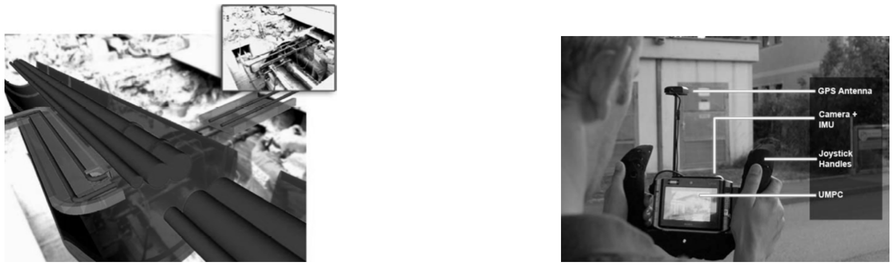


Fig. 1.12: "X-ray" visualisation mode for information on a building site [57]

With regard to visualising buried geographical data, [58] proposed in 2008 an indirect vision Augmented reality application resulting from the Vidente project and enabling underground pipes to be visualised (Figure 1.13a) via an UMPC (Figure 1.13b).



(a) View of a model georeferenced on site.

(b) UMPC (Ultra Mobile Personal Computer) enabling underground information to be visualised.

Fig. 1.13: Visualisation of underground infrastructures.

It is partly to satisfy the stakes previously described in Sect 1.5 that [59] propose a flexible client-server solution where geographical data and 3D models are located on the server and the data display and presentation components are located with the client. We also find in [60] a geographical information management strategy whose three tier architecture enable these data to be used for a collaborative Augmented Reality application (two users) and reusing data for other applications. The demonstrator is an application to assist in exploring a town or city.

Fig. 1.14: Example of augmentation during whilst following a route in a town or city [60].

An environmental change visualisation application using AR and geographical data is proposed by [61]. They propose augmenting geographical data via an erosion model enabling users to understand damage on the environment over time. In [61], the authors propose a method allowing a physically realistic yield of GIS data using AR. Sea navigation is one of the most attractive fields concerning the use of GIS. Although still subject to debate with regard to traditional paper maps, the adoption in 2009 by the IMO maritime safety committee [62] of amendments introducing a rule forcing all vessels making international voyages to carry on board an electronic mapping system confirms this interest. However, few applications in the field of shipping use AR in their information display components. The "Ship Ahoy!" application by [31] is a mobile application which recovers AIS[10] targets from a specialised website and displays these data by basing retiming on the GPS position and the terminal's magnetometer. Since data is only updated approximately every hour, the application is difficult to use and is only available with an internet connection.

(a) Scene augmented with AIS information. (b) A vessel augmented with AIS information

Fig. 1.15: Example of AIS augmentation.

We can mention work by "Technologie Systems Inc." which proposes an application using AR to help plan missions [63] of which an example of augmentation can be seen in Figure 1.16. Another approach, which we have developed in [64, 65], enables visual data using the same definition set to be merged in certain conditions. We use mapping and a georeferenced video flow to merge these two sources so that users can simultaneously have whichever of the two sources of information they need (real or digital).

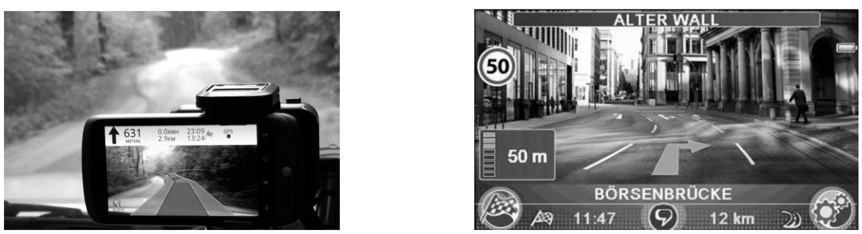
[10] Automated message exchange system between vessels.

(a) Augmented maritime scene [63]

(b) Augmented maritime scene [64]

Fig. 1.16: AR in assisting sailing.

In the field of cars, we can mention Wikitude Drive [27] which is an application which uses the Android operating system [30] and which must be installed on a mobile platform mobile with a video sensor and GPS. Blaupunkt [66] has been selling an assisted driving device whose display uses an embedded video sensor since 2009.



(a) Wikitude Drive

(b) Blaupunkt assisted driving

Fig. 1.17: Assisted car driving application combining GIS and AR.

1.5.3.1 Building one's own *augmented territory*

All the applications presented above are determinist. Augmentations are planned by the designer. Users are only able to carry out very limited modifications on the symbolism or types of augmentations. However, there are also applications enabling users to define their own *Augmented Territory*. Through web interfaces or creation modules directly integrated in applications, certain solutions enable users to build their own augmentations, eg.

Layar [25], Wikitude [27], Tonchidot [26], Qualcomm [29] and Junaio [28] are applications sold as AR "search engines". These applications offer users the ability to define layers of information or points of interest (POI) defined by users themselves. When these layers are activated in the interface of different respective applications, the latter use hardware resources for the platform on which they are installed (GPS, gyroscope, accelerometer, video sensor, etc.) to position POI on the mobile's video flow. Using the latest surrounding tweets for the position of restaurants, hairdressers or cultural venues, these platforms provide a framework for development allowing each individual user to create his or her own *Augmented Territory*.

1.6 Conclusion

In this chapter we have proposed to explore two domains which have converged due to certain factors which we have detailed. We have proposed a functional classification of these new applications enabling them to be described and compared. Combining GIS and display techniques using AR presents many challenges both with regard to technologies (hardware, software), methods (visualising geographical data, interaction with major data sources, etc.) and industry. There are still a number of issues remaining to be solved in order for both of these technologies to be able to take full advantage of their respective progress.

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