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## Cost-effective and lightweight mobile units for MixAR: a comparative trial among different setups

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### Abstract

Cultural heritage has arousing the interest of the general public (e.g. tourists), resulting in the increasing number of visitations to archaeological sites. However, many buildings and monuments are severely damaged or completely destroyed, which doesn't allow to get a full experience of “travelling in time”. Over the years, several Augmented Reality (AR) approaches were proposed to overcome these issues by providing three-dimensional visualization of reconstructed ancient structures *in situ*. However, most of these systems were made available through heavy and expensive technological bundles. Alternatively, MixAR intends to be a lightweight and cost-effective Mixed Reality system which aims to provide the visualization of virtual ancient buildings reconstructions *in situ*, properly superimposed and aligned with real-world ruins.

This paper proposes and compares different AR mobile units setups to be used in the MixAR system, with low-cost and lightweight requirements in mind, providing different levels of immersion. It was propounded four different mobile units, based on: a laptop computer, a single-board computer (SBC), a tablet and a smartphone, which underwent a set of tests to evaluate their performances.

The results show that mobile units based on laptop computer and SBC reached a good overall performance while mobile units based on tablet and smartphone did not meet such a satisfactory result even though they are acceptable for the intended use.

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## 1. Introduction

Cultural heritage sites are rich in history and are visited by a large number of persons who intend to glimpse the cultural context of our ancestors. However, in many of these sites the architectonic structures are severely damaged or even completely destroyed preventing the best possible visual experience on the past appearance of those structures. One possible solution for this problem is the use of three-dimensional models that display detailed reconstructions of how these structures originally were. We believe that, allied with AR approaches, the resulting models provide its visualization in reliable mixed environments, as an on-site guide, making possible to provide appealing experiences to tourists on cultural heritage and archaeological sites. Such solutions may be transformed in a successful business model to museums and archaeological sites, aiming the promotion of cultural heritage, bringing new and returning visitors to this kind of places.

Following similar research lines several works have been proposed, aiming the development of portable augmented reality systems. Nevertheless, most of them are made available through overly heavy and expensive technological bundles compromising cost-effectiveness required to market product distribution. Currently, very-large-scale integration (VLSI) process enables the production of increasingly smaller sized integrated circuit boards capable of carrying built-in or attached electronic components such as sensors or processing units. The range of devices taking advantage from the compression capabilities of VLSI vary from mobile units such as smartphones and SBC to visualization components like head-mounted displays (HMD).

Taking into consideration the aforementioned issues and facts, MixAR was proposed [1]. This adaptive mixed reality system is composed by mobile units, a server and a network infrastructure and aims to provide the visualization *in situ* of three-dimensional building reconstructions superimposed to ruins.

Furthermore, MixAR also aims to provide two main innovative features: the realistic visualization of the mixed environment through the proper overriding of real light conditions with virtual illumination and the soft transition among the interior and the exterior of each virtual building during the visitation.

The main objective of this paper is to present and compare a set of AR mobile units proposed for the MixAR project, regarding of weight and low-price. Additionally, the mobile units were compared in terms of performance, by measuring the number of frames per second (FPS) depending on the number of vertices and objects loaded to the scene, at runtime. The corresponding results are presented and discussed.

In terms of organization, this paper is structured as following: the next section provides a brief overview of the related work in mobile augmented reality systems; in section 3, a system architecture for mobile augmented reality is presented; in the fourth section, some augmented reality mobile units setups are presented and described; performance results and discussion over the proposed AR mobile units are presented in section 5; finally, conclusions and future work are presented in section 6.

## 2. Related Work

Milgram and Kishino [2], defined a taxonomy for virtual and real environments, proposing the “Virtuality Continuum”: a continuum whose extremes spans from the completely virtual environment (VR) to the real environment. In between there is the mixed reality (MR), which represents every environment that results from a combination of the virtual and real world, with varying levels of mixture between the two worlds, where virtual and real objects/persons may interact. In this context AR can be characterized by the predominance of the real over the virtual content allowing the insertion of virtual objects on the real world, while the virtual reality it's the opposite, since there is a predominance of the virtual over the real as well as the possibility to bring real objects to the virtual environment.

Azuma [3], in his survey, says that in order to be considered suitable for AR a system must combine real and virtual content in the real world, operate interactively and in real time, and align objects with each other. Azuma's definition does not limit AR systems to some kind of hardware, making it suitable for several types of devices such as mobile devices like tablets and smartphones, laptops or wearable computers. So, mobile augmented reality systems allow users to combine virtual and real objects in a real environment, in real-time and in a motion context, providing these systems a high potential of applicability in some fields, especially in cultural heritage.

Following this definition, many AR applications have been developed over the years covering several areas such as entertainment, tourism and navigation, training and education, assembly and maintenance.

The rest of this section will present a brief overview of the related work concerning mobile augmented reality.

The Touring Machine [4][5] was the first AR mobile unit. The users carrying the AR mobile unit while they navigated freely in the Columbia University were presented with information about the campus. This mobile prototype, along with its numerous cables and hardware had a total weight of 18 kg.

Pierkaski and Thomas [6] developed the ARQuake system, which allowed users to play an outdoors version of Quake, in an AR context. Users played against virtual enemies which were generated by the system taking into account a real world based map. The mobile set carried by users had 16 kg of weight.

Also, the classical problem of navigating inside the buildings was addressed by, Kalkusch et al. [7] who proposed SIGNPOST: an AR indoor navigation system. It used a mobile unit endowed with the capability of tracking fiducial markers exposed on corridors' walls to determine users' location.

Reitmayr and Schmalstieg [8] brought to the streets of Vienna a collaborative augmented reality system that gave information about the user surroundings, helping in navigation tasks and enabling collaboration among the users.

ARCHEOGUIDE (Augmented Reality based Cultural Heritage On-site GUIDE) provided archaeological information to cultural heritage sites visitors, in an innovative and compelling way [9][10]. The AR-based system showed three-dimensional reconstructed virtual models upon missing parts or damaged artefacts and buildings in an archaeological site. Using an AR backpack mobile unit, outweighing 6 kg, users were capable of visualizing virtual reconstructions *in loco*, seamlessly integrated into the natural field of view. Besides two more mobile units were adopted: one was based on a tablet PC and the other based on a Personal Data Agenda (PDA) device [9].

Cheok et al. [11] proposed the Human Pacman which used the key concepts of the original pac-man game in an AR environment. Carrying a mobile augmented reality unit, users were able to play as one of the available characters and interact with each other while a helper player provides orientations based on a VR game. The AR mobile unit is equipped with a mobile keyboard enabling the communication between the helper and user and also a touch sensor designed to make possible the interaction between all users.

Each previously described prototype was mainly composed by a HMD, a laptop, a WLAN interface, a GPS receiver, an inertial sensor, several cables and a backpack for equipment transportation purposes. Most of them used optical sensors, as cameras, to give visual feedback to the users, considering vision-based tracking techniques. Devices that provided greater mobility emerged, like Ultra Mobile PC (UMPC), PDAs and mobile phones. Such devices were used to build AR mobile systems, including museum's AR applications, as it is shown in [12] and [13]. Later, PDAs and mobile phones concepts merged into a single segment giving place to the smartphones [14], which are compact handheld devices that include most of the addressed AR solutions hardware. Currently, the use of these devices, a segment that also includes tablets, are widely used in everyday life. Furthermore, they are commonly supported by online stores, allowing the dissemination of applications. Both of these facts contribute for a sustainable and easy distribution of AR applications for enterprises or customers.

Regarding the AR development for smartphones, Tokusho and Feiner [15] created "AR street view", an application for android smartphones that enabled users to visualize geolocation content based on the current user location and orientation (eg: street names, addresses, building facades, and so forth). Besides the Smartphone, the system also integrates an external inertial sensor, used instead of the smartphone inertial sensor to increase the accuracy, and an UMPC which communicates with the smartphone via Bluetooth.

Also, Mohammed-Amin et al. [16] developed an AR application for smartphones, named as Arbela Layers Uncovered. This application was used to guide tourists in the ancient place of Arbela, Iraq, to help them to discover the history of their 7000 years of existence, through geo-tagged information.

There is also a substantial number of AR browsers available for smartphones and tablets, such as Layar [17], Junaio [18], Wikitude [19], which enable developers to produce and disclose their own AR applications.

A final remark goes to the use of mobile devices (smartphones/tablets) versus backpacks/mobile units in AR solutions: the choice should consider the inherent advantages/disadvantages of each one. On the other hand, AR backpacks/mobile units along with HMD devices ensure a greater level of immersion, providing compelling experiences, despite their weight and cost. On the other hand, smartphones are lighter and usually less expensive. In addition, the existence of application distribution channels for the general public makes them a viable commercial option for development.

### 3. MixAR mobile units general architecture

MixAR system was proposed regarding a client-server architecture constituted by three main components: a high-performance server to store, manage and deliver relevant data to the MR experience; mobile units carried by the users, responsible for managing and providing the MR experience to them; a network infrastructure to allow the communication between the mobile units and the server [1].

The server main role is to store and grant access to all information about the archaeological site and experience. Besides, it can be used as a high-performance remote processing unit. It will also contain a MR experience authoring tool which will provide functionalities to manage the contents to be shown as well as to configure the MR experience. The network infrastructure enables communication between access points and mobile units, ensuring an effective cover of the archaeological site. As the main focus of this paper is the mobile unit, both server and network infrastructure will not be detailed.

The AR mobile units, accordingly to [1], are composed by three main components: visualization, context and processing component. To keep the unit working autonomously, a power supply is also integrated. The connectivity is ensured through the network interfaces. Fig. 1 describes the proposed general architecture for the AR mobile units.

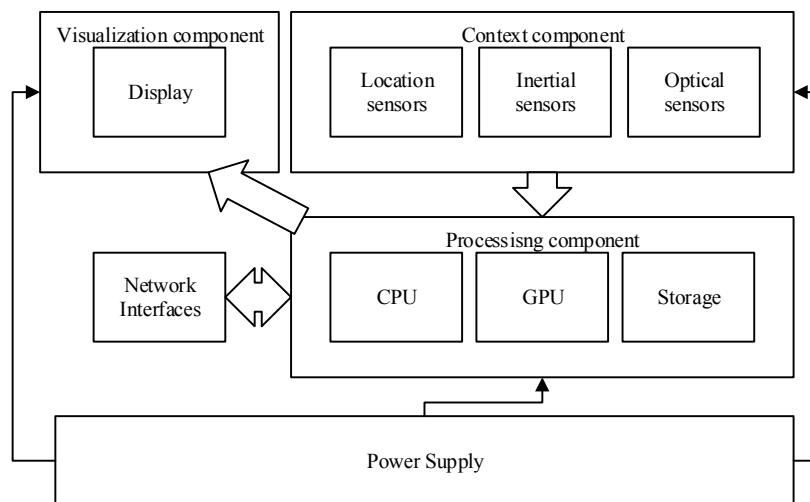


Fig. 1. MixAR mobile unit architecture, composed by three main components: context, processing and visualization. Power source and network interfaces also integrate the proposed architecture.

The visualization component aims the real-time presentation of the virtual contents embedded in real world. The context component is responsible for capturing contextual information from the real world such as orientation and positioning. Thereby, it is composed by three different devices: location sensors, to provide user's current position; inertial sensors, to determine user's orientation; optical sensors for image-based acquisition of real world. Finally, the processing component is responsible for gathering the information collected from the other components and perform operations over it, specifically regarding tracking purposes. The processed information is then forwarded to the visualization component for proper exhibition. Moreover, the processing component also communicates with the network interfaces to make requests to the MixAR server and to obtain data from it.

#### 4. Proposed Augmented Reality Mobile Units

Regarding the aforementioned architecture, four AR mobile units based on a laptop, an SBC, a tablet and a smartphone, with distinct costs, weights and performances are proposed. Moreover, they were selected considering affordable prices and designed to be lightweight and easy to carry in order to tackle with the issues revealed by most of the existing AR solutions, the Fig. 2 shows the different proposals in use. This kind of devices, specially the tablet and smartphone, were selected due to is large number of users and their exponential worldwide growth. Cisco in its Visual Network Index for 2014 to 2019 [20], shows that the estimated number of mobile users, in 2014, were around 4.3 billion with an estimated growth to 5.2 billion in 2019 and more than 11 billion mobile devices in 2019 will be connected to internet, corresponding to 1.5 per capita, Cisco also considers that the internet data traffic from smartphones and tablets will overcome the laptops traffic.

The laptop based mobile unit is composed in the processing component by a Toshiba P750-103 which integrates an Intel Core i7 CPU, a dedicated NVidia GPU, 8 GB of RAM, a solid state drive with 250GB of storage capacity, a built-in WLAN and Bluetooth adapters. The selected visualization component was a Vuzix STAR 1200XLD optical see through HMD which integrates a full HD 1080p camera with 30Hz of frame rate and a head tracker, both constituting the context component. The used location sensor is a Navicom NAV-GP01S GPS receiver. A six cell lithium battery, built-in the laptop, supplies the power to the whole hardware.

Another AR mobile unit proposal relies on the Eurotech Antares SBC processing component, which is distributed with an Intel Core i7 CPU at 2.53GHz, an integrated Intel HD Graphics GPU, 4GB of RAM, and a 250GB HDD storage. Besides, this device has several USB and HDMI interfaces available to connect other peripheral devices. These interfaces were used to attach the following devices: an external USB WLAN card for networking purposes; a 1200DXAR video see through HMD, used as visualization component, containing a built-in head tracker and two VGA cameras; and a Navicom NAV-GP01S GPS device to track user's location. The power supply is a lightweight external battery, with a power capacity of 9000mAh.

The tablet solution consists in a Samsung Galaxy Tab Pro 8.4. It has an ARM-based quad-core CPU with 2.4 GHz, 2GB of RAM and 16GB of internal storage capacity. Its display component is a built-in 8.4" display with a resolution of 2560x1600. This tablet also comes equipped with an 8MP rear camera, and other relevant built-in components which fulfil architecture requirements: inertial and location sensors, and WLAN adapter. An integrated battery of 4800mAh provides sufficient power to keep the device in use for a considerable amount of time.

Finally, a Samsung Galaxy Note 4 with an ARM based quad-core CPU running at 2.7 GHz, 3 GB of RAM, 32 GB of storage and a built-in battery of 3320mAh constitutes the lightest mobile unit device. The visualization component is a 5.7" display with a resolution of 2560x1440 and the context unit is constituted by the following built-in components: a 16MP rear camera, an integrated GPS receiver and a set of inertial sensors.

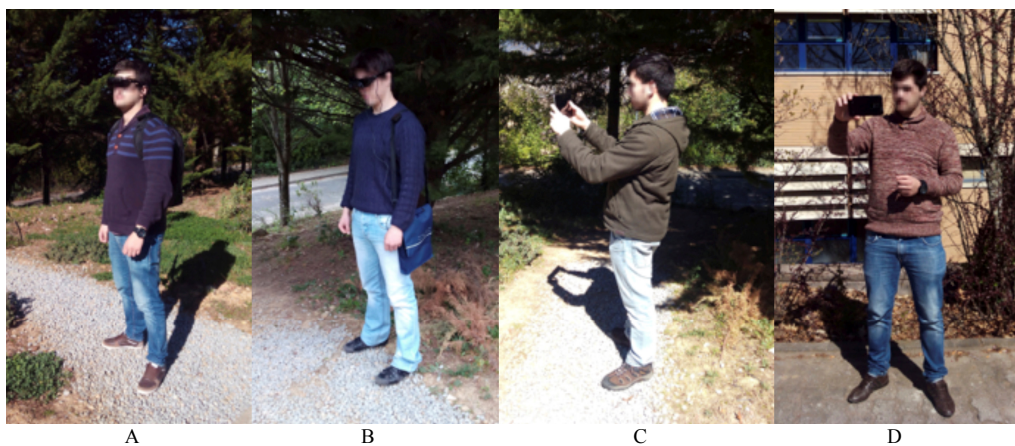


Fig. 2. Users wearing the proposed AR mobile units. (A) Backpack laptop. (B) SBC carried on a side bag (C) Tablet mobile unit (D) Smartphone mobile unit.



The proposed AR mobile units have different characteristics aiming different purposes. Although, laptop and SBC solutions can be used for immersive experiences; but, they require the use of a wider range of external devices to accomplish the requirements of the established architecture. On the other hand, mobile units based on mobile devices tablet and smartphone are less immersive. Nevertheless, they are lighter in terms of weight, and less expensive. Moreover, the suggested mobile devices assemble the proposed architecture with built-in components. Table 1 summarizes the used mobile units, regarding the following specifications: visualization, processing and context units and also network interfaces, power supply, weight and prices. Of the four proposals AR mobile units, the mobile unit based on a laptop is the heaviest (almost 4 kg) and, at the same time, the most expensive (€5560). On the other extreme, the unit based on a smartphone is the lightest and the tablet one is the cheapest. Although smartphones and tablets' prices may be similar depending on the adopted version.

Table 1. AR mobile units hardware composition, weight and price.

Mobile Unit		Laptop	SBC	Tablet	Smartphone
Features					
Processing component	CPU	Intel Core i7 2630QM at 2.0GHz	Intel Core i7 610E at 2.53GHz	ARM based quad-core CPU at 2.4GHz	ARM based quad-core CPU at 2.7GHz
	GPU	Nvidia GeForce GT 540M with 1GB	Intel HD Graphics	Adreno 330	Adreno 420
	Storage and RAM	250 GB and 8 GB of RAM	200GB and 4GB of RAM	16GB and 2GB of RAM	32GB and 3GB of RAM
Visualization component	Display	Vuzix STAR 1200XLD	Vuzix 1200DXAR	8.4” display	5.7” display
Context component	Location Sensors	Navicom NAV-GP01S	Navicom NAV-GP01S	Buil-in GPS receiver	Buil-in GPS receiver
	Inertial Sensors	Vuzix Wrap Tracker	Vuzix Wrap Tracker	Built-in Inertial sensors	Built-in Inertial sensors
	Optical Sensors	Full HD 1080p	Two VGA cameras	8MP built-in rear camera	16MP built-in rear camera
Network Interfaces		Built-in WLAN and Bluetooth	WLAN usb micro adapter	Built-in WLAN Adapter	Built-in WLAN Adapter
Power Supply		Built-in battery	Powertraveller’s Minigorilla	Built-in battery of 4800mAh	Built-in battery of 3320mAh
Weight (g)		3850	1335	331	176
Price (€)		5560	3740	310	620

Choosing lighter and less expensive AR mobile units may have a significant impact on the performance diminishing the overall user's satisfaction. Next section is reserved to the presentation and discussion of the performance tests conducted to compare the proposed mobile units.

## 5. Tests and results

To measure the performance of the different proposed mobile units a set of load tests was made using a small AR application, developed specifically for testing purposes. The application was built using Unity3D, to streamline multi-platform deployment, specifically for Microsoft Windows and Google Android, and Metaio Software Development Kit (SDK) for Unity3D, to take advantage of pre-implemented computer-vision algorithms. It must be referred that the light conditions were maintained along the tests: the most relevant source light was a fluorescent lamp positioned on the ceiling with direct incidence on the test area. Also, camera resolution was down sampled to the same resolution in every device in order to ensure the same image resolution.

The AR application consists in tracking a real-world coloured cube, Fig. 3 (A), placed upon a table and using one of the available tracking techniques provided by Metaio SDK: edge-based tracking. This option was taken considering the previous work [1] in which was established the use of a markerless approach in order to avoid the intrusiveness caused by the use of fiducial markers.

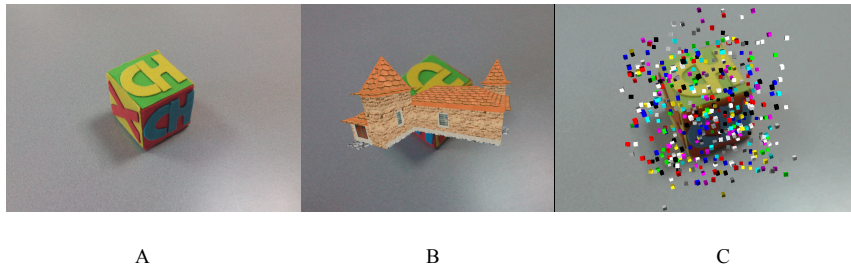


Fig. 3 Object to tack (A); Augmented model (B); Augmented objects after tracking (C);

The developed application aims the extraction of performance data from three tests. For each test and during successful tracking, a virtual model with a certain number of vertices is loaded to a confined visible scene area, Fig. 3 (B). From test to test, the loaded virtual model are different and with an increasing number of vertices. A church, formed by 10 different objects, with approximately 6500 vertices and 3500 polygons was used for the first test of this experiment. In the second test, a roman domus, formed by different 17 objects, with nearly 9000 polygons and 16000 vertices was used. The last test of this experiment considered another domus, the most complex model of this set, having about 16000 polygons and 31000 vertices and formed by 19 objects. Frames per second (FPS) and the current tracking state were determined and registered into a file.

Offline data analysis, depicted on Fig. 4, revealed that the best overall performance was achieved by laptop, in each building load. Nevertheless a noticeable decrease of FPS along the experiment, SBC came second on this ranking. Unsurprisingly, both non-immersive devices presented the lowest number of FPS. With the increasing of the complexity the performance decreases, although is still acceptable in all the mobile units.

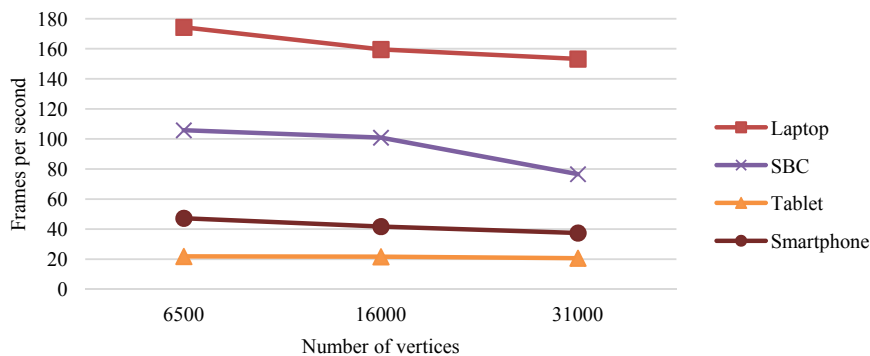


Fig. 4. Results of the performance tests made with a basic AR application

A second set of tests was made to analyze the performance of the proposed mobile units as the number of objects loaded into the augmented scene increases. The application used for these tests is similar to the first one but, instead of loading only a virtual model with a large number of vertices and a small number of objects, an increasing number of cubes, with a small number of vertices, is loaded to the visible scene area, as seen on Fig. 3 (C), where each cube represents one object.

The Fig. 5 shows the results of the second set of tests. It's noticeable that even with a large number of objects the performance of the mobile units based on the laptop and SBC maintains a good frame rate. As expected, with an increasing number of objects present in the scene, the number of FPS decreases. For the mobile units based on a smartphone and a tablet the performance is much lower but it remains above or close to 20 fps. With 400 objects the tablet achieved the worst results of this tests, with just 13 FPS.

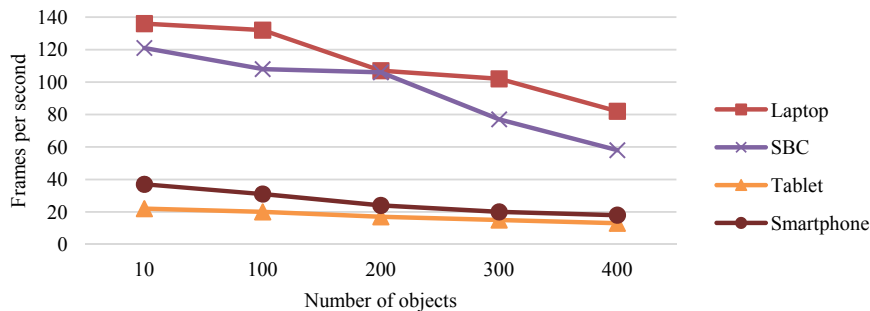


Fig. 5. Results of the performance tests made to each proposed MixAR mobile unit

Comparing the results from the first and the second sets of tests it is possible to infer that the best performance in each test was achieved by the laptop based mobile unit, followed by the SBC, then the smartphone and finally the tablet, which means that the performance decreases along with the descendent order of the prices. The number of objects has a higher influence on the performance, since when 400 different objects are loaded in the scene, corresponding to a total of 9600 vertices, the results are much worse than with 16000 vertices and only 17 loaded objects, obtained in the first set of tests. Comparing the results from this two situations there is an average drop of approximately 39 FPS.

Despite the best performance, the mobile unit based on a laptop computer is the heaviest proposed mobile unit with a weight of approximately 4 kg which may become uncomfortable to use for a long period of time. Both AR mobile units based on the laptop and SBC have an HMD as the visualization component, also bringing discomfort in form of headaches or dizziness if used for a while. Besides, the use of HMD have a substantial impact on the total cost of the AR mobile unit. Therefore, despite not having the best performance the AR mobile units based on the tablet and smartphone should be taken into consideration, since they are lighter and cheaper, but they offer a narrow field of view and require the extension of the user's arms to placing the devices in front of its vision to experience the AR content with success, which may become uncomfortable after a while.

## 6. Conclusion and Future Work

In this paper, a set of different AR mobile units' hardware setups was proposed and compared in terms of price and weight of the available AR solutions. They were selected considering the defined MixAR mobile unit architecture, which is composed by three main components: the visualization component, processing component and context component. Network interfaces and power supply are also integrated in the proposed architecture providing, respectively, network communication capabilities and electrical power. The referred set includes four different configurations based on different devices: a laptop, a SBC, a tablet and a smartphone.

Performance tests made to each device under the same light and image capturing conditions led us to conclude, as expected, that both SBC and laptop overcome the units based on mobile devices, obtaining higher frame rates. However, smartphone and tablet based mobile units obtained a reasonable performance, with a frame rate above or close to 20fps, and since they own a wide variety of sensors and reasonable processing power in a small hand-held bundle, shouldn't be neglected. Moreover, such kind of devices are daily used by thousands of persons representing an interesting target for the market for AR applications, by developing AR solutions for it.



During this study we came across with the possibility to assess another aspect beyond the weight, price and performance of the AR mobile unit's usability. Thus, in future, we intend to evaluate user satisfaction and comfort, in order to seek new ways of improving MixAR users' experience.

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## References

- [1] L. G. Magalhaes, J. J. Sousa, R. Bento, T. Adao, F. Pereira, V. Filipe, and E. Peres, "Proposal of an Information System for an Adaptive Mixed Reality System for Archaeological Sites," *Procedia Technol.*, vol. 16, pp. 499–507, 2014.
- [2] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino, "Augmented Reality: A class of displays on the reality-virtuality continuum," *Telem manipulator Telepresence Technol.*, vol. 2351, pp. 282–292, 1994.
- [3] R. T. Azuma, "A survey of augmented reality," *Presence Teleoperators Virtual Environ.*, vol. 6, no. 4, p. 355, 1997.
- [4] S. Feiner, B. MacIntyre, T. Höllerer, and A. Webster, "A touring machine: prototyping 3D mobile augmented reality systems for exploring the urban environment," in *First International Symposium on Wearable Computers, 1997. Digest of Papers, 1997*, pp. 74–81.
- [5] S. Feiner, B. MacIntyre, and T. Höllerer, "Wearing It Out: First Steps Toward Mobile Augmented Reality Systems," in *In First International Symposium on Mixed Reality (ISMIR'99)*, 1999, pp. 363–377.
- [6] W. Piekarski and B. H. Thomas, "ARQuake-Modifications and hardware for outdoor augmented reality gaming," presented at the 4th Australian Linux Conference, Perth, Australia, 2003.
- [7] M. Kalkusch, T. Lidy, M. Knapp, G. Reitmayr, H. Kaufmann, and D. Schmalstieg, "Structured visual markers for indoor pathfinding," in *Augmented Reality Toolkit, The First IEEE International Workshop*, 2002.
- [8] G. Reitmayr and D. Schmalstieg, "Collaborative Augmented Reality for Outdoor Navigation and Information Browsing," *Proceedings of the Second Symposium on Location Based Services and TeleCartography*, TU, Wien, pp. 53 – 62, 2004.
- [9] V. Vlahakis, N. Ioannidis, J. Karigiannis, M. Tsotros, M. Gounaris, D. Stricker, T. Gleue, P. Daehne, and L. Almeida, "Archeoguide: an augmented reality guide for archaeological sites," *IEEE Comput. Graph. Appl.*, vol. 22, no. 5, pp. 52–60, 2002.
- [10] T. Gleue and P. Dähne, "Design and Implementation of a Mobile Device for Outdoor Augmented Reality in the Archeoguide Project," in *Proceedings of the 2001 Conference on Virtual Reality, Archeology, and Cultural Heritage*, New York, NY, USA, 2001, pp. 161–168.
- [11] A. D. Cheok, K. H. Goh, W. Liu, F. Farbiz, S. W. Fong, S. L. Teo, Y. Li, and X. Yang, "Human Pacman: a mobile, wide-area entertainment system based on physical, social, and ubiquitous computing," *Pers. Ubiquitous Comput.*, vol. 8, no. 2, pp. 71–81, 2004.
- [12] M. Zollner, J. Keil, H. Wust, and D. Pletinckx, "An augmented reality presentation system for remote cultural heritage sites," in *Proceedings of the 10th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST*, 2009, pp. 112–116.
- [13] T. Miyashita, P. Meier, T. Tachikawa, S. Orlic, T. Eble, V. Scholz, A. Gapel, O. Gerl, S. Arnaudov, and S. Lieberknecht, "An Augmented Reality museum guide," in *7th IEEE/ACM International Symposium on Mixed and Augmented Reality, 2008. ISMAR 2008*, 2008, pp. 103–106.
- [14] D. Wagner and D. Schmalstieg, "History and Future of Tracking for Mobile Phone Augmented Reality," in *International Symposium on Ubiquitous Virtual Reality, 2009. ISUVR '09*, 2009, pp. 7–10.
- [15] Y. Tokusho and S. Feiner, "Prototyping an outdoor mobile augmented reality street view application," in *Proceedings of ISMAR Workshop on Outdoor Mixed and Augmented Reality*, 2009, vol. 2.
- [16] R. K. Mohammed-Amin, R. M. Levy, and J. E. Boyd, "Mobile Augmented Reality for Interpretation of Archaeological Sites," in *Proceedings of the Second International ACM Workshop on Personalized Access to Cultural Heritage*, New York, NY, USA, 2012, pp. 11–14.
- [17] "Augmented Reality | Interactive Print," *Layar*. [Online]. Available: <https://www.layar.com/>. [Accessed: 12-Mar-2015].
- [18] "Junaio – Augmented Reality Browser," *Junaio – Augmented Reality Browser*. [Online]. Available: <http://www.junaio.com/>. [Accessed: 12-Mar-2015].
- [19] "Wikitude - The World's leading Augmented Reality SDK," *Wikitude*. [Online]. Available: <http://www.wikitude.com/>. [Accessed: 12-Mar-2015].
- [20] "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2014–2019 White Paper," *Cisco*. [Online]. Available: [http://cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white\\_paper\\_c11-520862.html](http://cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html). [Accessed: 25-May-2015].