# MOBILE PANORAMA-BASED VIRTUAL REALITY CAPABILITY FOR ON-SITE ARCHITECTURAL AND URBAN VISUALIZATION

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## 1. INTRODUCTION

### 1.1. Background

Virtual Reality (VR) is now commonly used for visualizing 3D models in architectural and urban design fields (Al-Kodmany 2002, Vince 2004). Numerous previous studies on VR use focused on some design presentations (Caneparo 2001, Heldal 2007, Shen and Kawakami 2010) or test tools (Bishop and Gimblett 2000, Sussmann and Vanhegan 2000, Westerdahl et al. 2006) in a conference room. In contrast, for outdoor use, several studies which include both virtual and augmented reality have been reported (Azuma et al. 1999, Bruce and Wayne 2003, Chung et al. 2009). However, outdoor VR capability for field studies and on-site landscape simulations, etc. have not been extensively investigated so far for end-users. Therefore, in terms of practical utility for 3D visualization, printed media such as freehand drawings and photomontages have usually been employed for on-site use up to now.

On the other hand, the development and spread of high performance mobile devices such as smartphones and tablets allow handling of rich media such as animations, real-time data, sounds and VR which cannot be expressed via printed media. These new digital media can be integrated and mutually linked via the Internet.

The biggest challenge in this research is to clarify the following hypothesis: Is it useful to see a virtual scene of the past or future from the same real-world viewpoint when simulating a landscape by using VR outdoors? When simulating from the same viewpoint, the virtual scene may be quite different from the current scene due to urban development and building demolition. At that time, if some characteristics to match the virtual scene with real-world landscape remain in a viewpoint, can users intuitively understand the past or future landscape from the same real-world viewpoint?

### 1.2. System Overview

In order to clarify the hypothesis described in Section 1.1, a VR system for outdoor field use in this research was required that had the following three characteristics: 1) enabling the reproduction of a virtual scene such as buildings, streets, cityscapes or landscapes (in the past or future); 2) using ordinary mobile devices such as smartphones or tablets; 3) allowing not only VR professionals, but layman users to easily operate the system and experience the virtual scene.

In order to achieve the best possible ease-of-use, we enhanced a panorama-based VR system for outdoor use (Stellingwerff and Breen 1995, Xiao 2000). Fig. 1 shows a conceptual diagram of the mobile panorama-based VR system. The system architecture contains four aspects: the VR interface, mobile positioning and posture technology, multiple cylindrical panorama CG images from various viewpoints, and hot spots which can be embedded into a panorama CG image, which when selected can invoke some action, for example moving to another panorama node. Cylindrical panorama CG images to represent virtual scene in 360° at pre-defined viewpoints are created. Moreover, the system can identify a user´s location and orientation by using information from a mobile-GPS device, an electronic compass, and an acceleration sensor installed in the mobile device. Additionally, an image corresponding to the user’s position and posture is automatically displayed on the mobile device in real time. The current position is also set manually by tapping an electronic map if location information cannot be acquired via GPS. A user can experience the immersive landscape of the current position in the past or future by means of a VR panorama. Furthermore, by creating a panorama-based VR linking to other viewpoints, a user can move to other panorama-based VRs through so-called hot spots which are predefined linked areas. Therefore, architectural and urban space can be virtually moved and a user can experience the feeling of “being physically there”. The hot spot can link to texts or images besides the panorama-based VR, and can provide detailed information to the user as well. The enhanced panorama-based VR application is operated using the standard interaction possibilities of a smartphone or tablet and thus it allows non-VR expert end-users to experience VR by using familiar smartphone or tablet features.

## 2. RELATED WORKS

The features of the enhanced panorama-based VR system that

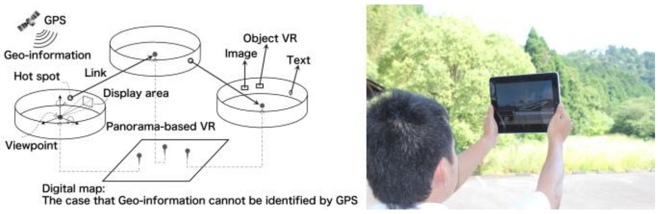


**Fig. 1** Enhanced panorama-based VR: Concept (left), Usage (right).

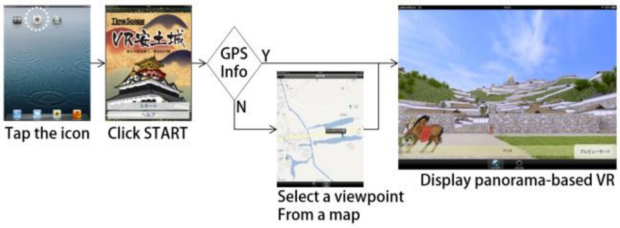


**Fig. 2** How to use the prototype system

was described in Section 1.2 will be illustrated by comparing it to a related VR system. In order to display a predefined 360° panorama-based view, the panorama-based VR system is not able to freely move to any points in 3D virtual space. In contrast, there are some VR systems which define 3D models directly in 3D virtual space, and allow a user to move around in a 3D virtual space by real-time rendering (Yeo 2005, Danilo 2010). However, the graphic processing capacity of smartphones or tablets strictly limit their ability in real time rendering. Additionally, a user has to be holding the mobile device while standing in an outdoor field. As it is necessary to operate and simultaneously move in a physical space to change a viewpoint in a 3D virtual space, it is cognitively challenging. Additionally, VR and AR (Augmented Reality) use much the similar technology to provide enriched experiences for users. AR adds some information to the existing environment to enhance the real world, while VR actually creates an entirely new virtual world. In the case of VR, a 3D virtual space is created by all the 3DCG models. In contrast, AR is defined as a superimposed method that uses 3DCG models only to express scenes which do not exist in the real world, and employs video streaming or the optical see-through technique to display other scenes which really exist (Milgram 1994, Chung et al. 2009). AR for architecture and urban studies is thriving at present, and there are also many reports about performance on mobile devices (Kuo et al. 2004, Anders and Lonsing 2005, Lertlakkhanakul et al. 2005, Fukuda 2012). However, technical issues are still faced when using these devices to simulate landscapes by using AR systems for practice. These issues concern the geometric and optical integrity of 3DCG and video streaming, and the limit of graphic processing capacity targeting large-scale data from architecture and urban design. To overcome these shortcomings for end-user operation, we enhanced the mobile panorama-based VR system in this research.

## 3. PROTOTYPE DEVELOPMENT: THE AZUCHI CASTLE VR PROJECT

The Azuchi Castle ruin and the old castle town were selected to develop a prototype to clarify the research hypothesis. Historically speaking, Azuchi Castle and its castle town were built in Omihachiman city, Shiga prefecture, Japan in the early 1580s. Throughout the last decades, restoring the castle's original structure that was built by Nobunaga Oda at the top of Azuchi Mountain, has been going on. However, a full reconstruction of the castle would require many documents about the historical site, such as drawings, photos, etc. Yet, the available data and structures are barely sufficient to reconstruct the real castle. Additionally, even if all the materials could be prepared, the overly large construction costs remain a major challenge to the restoration. Therefore, by using VR techniques, a digital reproduction project of the Azuchi Castle and its old castle town is being promoted by Omihachiman city government.

For the prototypical implementation, we first selected two viewpoints and created a panorama-based VR representation for each one. From the front of the Bungei Seminariyo as a viewpoint, Azuchi Mountain which looks exactly as it did in the early 1580s can be viewed. In contrast, from the front of the Azuchi Castle museum as another viewpoint, Azuchi Mountain cannot be seen because man-made structures block the line of sight, and no other things which remain as they were in the early 1580s can be viewed. In the 3D modeling stage of the Tenshu which is the central tower of Azuchi Castle, the restoration drawing by Prof. Akira Naito was selected. A 3D digital Tenshu was modelled by using Trimble SketchUP, in a process that took 10 months. Based on a special excavation investigation report on historic relics from the ruins of Azuchi Castle, the Kuruwa which is the Azuchi Castle walls, and Azuchi castle town which was built at the foot of Azuchi Mountain were modelled by using Autodesk 3ds Max in a process that took six months.

Fig. 2 illustrates the use of the developed prototype application. Fig. 3 shows each cylindrical panorama CG from two viewpoints and the experiment viewpoint respectively. The panorama-based VRs display the Azuchi castle Tenshu, Kuruwa, Azuchi Mountain and its castle town. Through a hot spot, it can link viewpoints of VR panoramas and the object VR of the Azuchi Castle Tenshu. A total of 48 still images at 75° and 90° vertical angles, and a 15° horizontal angle are used to create an object VR of 3D Tenshu.

## 4. VALIDATION EXPERIMENT


**Fig. 3** VR display cut and experimental viewpoints

Our validation experiment method is an empirical study described as follows: randomly-selected general end-users experienced the panorama-based VR of Azuchi Castle at one viewpoint, and then completed a questionnaire. Finally, 57 subjects participated in the experiment, which was conducted between 2 p.m. and 5 p.m., on 30 October 2012 (see also Table 1, individual attributes). The experiment involved two viewpoints, one in front of Bungei Seminariyo and the other one in front of the Azuchi Castle museum. From the front of the Bungei Seminariyo, Azuchi Mountain, which has been in the same state since the early 1580s, can be viewed. However, from the front of the Azuchi Castle museum, Azuchi Mountain cannot be viewed.

First, the subjects were informed about the aim of the experiment. Next, they held mobile devices (Apple iPad2) in a standing posture for 5–10 minutes while they viewed the landscape such as Azuchi Castle and its castle town as it existed in old times. Then, they reviewed detailed images of other linked panorama VR and the object VR of Tenshu. During the observations of this experiment, all the study participants were able to use the system without problems. Moreover, because the day of the experiment was cloudy there was little difficulty caused by the sun, which can occur when the sun shines directly into the system's display from behind the user so that the user cannot see the display clearly. After experiencing the system, 50 subjects filled out a questionnaire.

The evaluation items included six aspects: a) general use of the VR system, b) simulating the past landscape from the same viewpoint as the present, c) operation of the VR system, d) reaction speed of the VR system, e) reproducibility of the past landscape, and f) the visibility of the VR system display in the outdoor field. As an analytical method, 5-point scores for each survey item were computed by weighted averages. Table 1 shows a general overview of the experiment's properties, survey items, scoring method, and the basic results.

**Table 1** Experimental overview

| | |
|---|---|
| **Date** | 2 p.m. to 5 p.m., 30th October, 2012 |
| **Duration** | 5〜10 min/person |
| **Subject** | 57 people (Bungei Seminariyo 39, Azuchi Castle museum 18) |
| **Content** | Experience Azuchi Castle VR from the same view as the present |
| **Method** | After the panorama-based VR experience running on iPad2 (iOS5), each subject answers questionnaire. |
| **Survey items and score** | a) General use: Very good: 5, Good: 4, Normal: 3, Bad: 2, Very bad: 1<br>b) Simulation at the same position: Very interesting: 5, Interesting: 4, Normal: 3, Not interesting: 2, Not at all interesting: 1<br>c) Operation: Operate immediately: 5, Operate during use: 4, Either: 3, Cannot use without learning: 2, Cannot use: 1<br>d) Reaction speed: Very good: 5, Good: 4, Normal: 3, Bad: 2, Very bad: 1<br>e) Reproducibility: Well reproduced: 5, Reproduced: 4, Either: 3, Not well reproduced: 2, Not reproduced: 1<br>f) Visibility: Clearly visible: 5, Visible: 4, Either: 3, Not clearly visible: 2, Not visible: 1<br>g) Free comments: VR simulation at the same position, points of attention, potential additional functions. |
| **Collection** | 50 ans. (Bungei Seminariyo 32, Azuchi Castle museum 18) |
| **Individual attributes** | 1) Gender: Male: 26 (52.0%), Female: 24 (48.0%)<br>2) Age: within 20s: 6 (12.0%), 30s: 4 (8.0%), 40s: 8 (16.0%), 50s: 3 (6.0%), 60s: 23 (46.0%), over 70s: 6 (12.0%), No answer: 1 (2.0%)<br>3) Address: in Omihachiman City: 28 (56.0%), not in Omihachiman City but in Shiga Prefecture: 13 (26.0%), not in Shiga Prefecture: 9 (18.0%)<br>4) Smartphone or tablet use: Use: 15 (30.0%); including everyday: 12 (24.0%), 2–3 times/week: 2 (4.0%), 1 time/month: 1 (2.0%), Do not use: 34 (68.0%); including do not use: 1 (2.0%), Do not have: 33 (66.0%); No answer: 1 (2.0%)<br>5) VR Experience: used: 16 (32.0%), designed: 0 (0%), first time: 34 (68.0%) |

## 5. RESULTS AND DISCUSSION

### 5.1. Results

Figure 4 summarize the scores for each item in the experiment. The total average and difference between each viewpoint's average and total average and t-test result are shown in Table 2. The results from the quantitative results can be summed up as follows.

・The total average scores for each item were higher than 3.7 out of 5 points.

・The viewpoint of the Bungei Seminariyo scored better than the Azuchi Castle museum for all the items. The former overlooks Azuchi Mountain but the latter does not.

・The scores of c) Operation, d) Speed, f) Visibility were higher than 3.8 out of 5 points (score average: higher than 75%). These are survey items on use of panorama-based VR. From this result, it is confirmed that end-users can use the enhanced panorama-based VR with little trouble.

### 5.2. Discussion

Discussion about research hypothesis based on the results described in section 5.1 and free-text comments collected in the questionnaire survey was described below.

・Is it useful to see a virtual scene from the same real-world viewpoint when simulating the landscape by using VR outdoors? Total average scores for each item received higher than 3.7 out of 5 points. Several comments were also collected such as "The panoramic view at the time that Azuchi Castle existed has been reproduced in an easy-to-use operation. (N=9)"; "A user can actually see how views changed in an expected direction to get a sense of being there. (N=6)". Further comments were collected to increase people's understanding of the history by using the panorama-based VR system such as "It is easy to understand, even by those who are not familiar with history. (N=2)". Therefore, it can be said that it is useful to see the image of the past (or future) from the same real-world viewpoint when simulating a landscape by using VR outdoors.

・If some characteristics to match the virtual scene with real-world landscape remain in a viewpoint, can users intuitively understand the past or future landscape from the same real-world viewpoint? In this experiment, Azuchi Mountain which has been in the same state since the early 1580s, becomes the remaining characteristic to match the past landscape with real-world landscape. From the viewpoint in front of the Bungei Seminariyo, Azuchi Mountain can be seen. However, from the viewpoint in front of the Azuchi Castle museum, Azuchi Mountain cannot be seen because man-made structures block the line of sight. When the score of b) Simulation at the same position, is considered, the score of Bungei Seminariyo is slightly higher than that of Azuchi Castle museum while no significant difference got between two scores of each survey item of Bungei Seminariyo and Azuchi Castle museum. In contrast, a further comment such as "A user could experience the past Azuchi Castle intuitively by

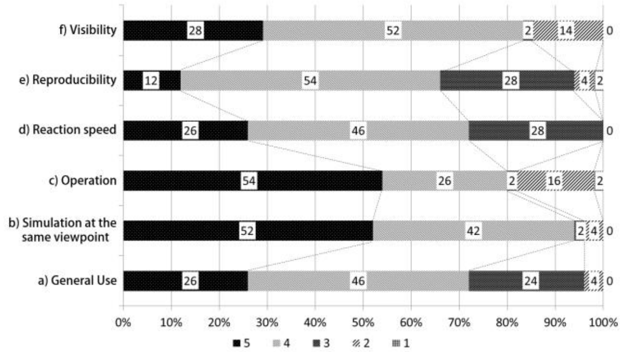


**Fig. 4** Scores of each item in the experiment (N=50)

**Table 2** Difference between each viewpoint average and the total, and t-test

| Survey items | | General Use | Simulation at the same position | Operation | Speed | Reproducibility | Visibility |
|---|---|---|---|---|---|---|---|
| View point | Bungei Seminariyo (N=32) | 0.091 | 0.018 | 0.173 | 0.020 | 0.081 | 0.118 |
| | Azuchi Castle museum (N=18) | -0.162 | -0.031 | -0.307 | -0.036 | -0.144 | -0.209 |
| Total average (N=50) | | 3.94 | 4.42 | 4.14 | 3.98 | 3.7 | 3.82 |

Non *: no significant difference

overlapping the Azuchi Mountain in the real-world with the Azuchi Mountain in the panorama-based VR from the viewpoint." was also given by the seven subjects whose viewpoint was the Bungei Seminariyo. A possible reason for this feedback is that people can see Azuchi Mountain from the Bungei Seminariyo, the same mountain on which Azuchi Castle existed. In other words, when simulating a virtual scene that does not exist, it is intuitively effective to find and overlap the remaining characteristic to match the past landscape with real-world landscape from the same real-world viewpoint.

・In addition to the discussion of the research hypothesis, the problems found with the system through the experiment are described. Concerning the weight of the used mobile device (iPad2), we received feedback that it was too heavy. The iPad used was 610g and was held vertically when carrying out the outdoor VR experiment. Although there are individual differences in terms of weight, it is necessary to reduce the burden of an iPad2 held upright. Furthermore, it was pointed out that "the image quality should be improved". The size at which the image is displayed on the screen was 400×320 pixels instead of the maximum resolution of the iPad2 (2048×1536 pixels). The reason for using a smaller size is implementation limit in setting up the maximum 2048×2048 pixels, when defining a 360° panorama CG as one image. In consequence, it is necessary to divide the defined panorama CG into multiple images to improve the screen display.

## 6. CONCLUSION AND FUTURE WORK

This research presents mobile VR capability for on-site architectural and urban visualization. The enhanced panorama-based VR application described here is operated using standard interaction possibilities of a smartphone or tablet for non-VR expert end-users. The VR reproduction project of Azuchi Castle and its old castle town project was selected to develop a prototype, and to clarify the research hypothesis by empirical study from two contrasting viewpoints. The results of this study can be summarized as follows:

- It is useful to see a virtual scene from the same real-world viewpoint when simulating the landscape by using VR outdoors. By using the enhanced panorama-based VR, a panoramic view in the past or future was reproduced easily. End-users could actually see how views changed in an expected direction, to get a sense of being there.
- When simulating from the same viewpoint, the virtual scene may be quite different from the current scene due to urban development and building demolition. At such times, if some characteristics to match the virtual scene with real-world landscape remain in a viewpoint, users can intuitively understand to look at landscape of the past or future from the same real-world viewpoint.

As a significant part of future work, improvement of the image quality is urgently needed for the panorama-based VR system. In addition, the development of simpler VR or AR operating systems for outdoor use is a further step which could allow users to move to any point in a 3D virtual space. A separate future experiment needs to investigate the potential influence of a walking VR experience, including the future development of a wearable computer.

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# 建築・都市分野における現場利用のためのモバイル型パノラマ VR の可能性

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キーワード：バーチャル・リアリティ，視覚化，現場利用，携帯端末，アンケート

建築・都市分野の設計やプレゼンテーションの場面では、VR がよく用いられるようになった。VR を用いた検討会議は会議室等の室内で行われることが多いが、まち歩き、現地調査、実地試験など屋外の現場においても実在しない過去や未来の像を共有、検討する場面が存在する。このような屋外の現場では VR ではなくパースやフォトモンタージュなどの紙媒体が用いられることが多い。一方、情報通信分野では、スマートフォンやタブレットなど高性能携帯端末の開発、普及、応用が進む。このような背景の下、本研究では、建築・都市分野の現場利用のためのモバイル型 VR の可能性に着目した。設定した仮説は以下の通りである。屋外で VR を用いて景観シミュレーションを行う際に、現在と同じ地点で、未来や過去の像を眺めることは有用であろうか？未来や過去の像は、開発等により現在の像とは全く異なる可能性もある。その際、何か手がかりがあれば、現在と同じ地点で未来や過去の像を眺めていると認識しやすいのであろうか？

研究の方法として、まず、屋外の現場利用のための VR システムを構築する。システム要件として、過去や未来の景観の再現が可能、高性能携帯端末での利用が可能、一般ユーザが簡易な操作で景観の体験が可能であること、とした。結果、高性能携帯端末に搭載される GPS、電子コンパス、加速度センサにより得られるユーザの位置、方角、端末の傾きに一致した VR 画像をリアルタイムに表示可能な、パノラマ VR システムを構築した。次に、VR 安土城プロジェクト（近江八幡市安土城デジタル復元事業）を対象として、安土城天主、郭、城下町から成るプロトタイプシステムを構築した。仮説の検証実験に用いる視点場として、築城当時も存在していた安土山が現在も臨める文芸セミナリヨ前、現在は人工物に遮られて安土山を臨めない安土町城郭資料館前の 2 つとした。そして、2 つの視点場で計 57 名の一般ユーザにプロトタイプシステムを体験してもらい、アンケート評価を実施した。

本研究で得られた成果を示す。

1） 過去や未来の景観を視覚化でき、スマートフォンなどの高性能携帯端末上で一般ユーザが簡易な操作により、屋外の現地で景観シミュレーションが体験可能なパノラマ VR システムを開発した。
2） VR 安土城プロジェクトを対象とした検証の結果、現在と同じ地点で未来や過去の像を眺めることは有用であることが確認された。
3） VR 安土城プロジェクトを対象とした検証の結果、築城当時も存在していた安土山が現在も臨める視点場の方が高い評価が得られた。すなわち、未来や過去の像は、開発等により現在の像とは全く異なる可能性があるが、安土山のような手がかりがあれば、現在と同じ地点で未来や過去の像を眺めていると認識しやすいことが示唆された。

以上より、建築・都市分野の現場利用のためにモバイル型 VR を適応することは一定の評価を得られたといえる。一方で、パノラマ VR の画質向上は喫緊に対応が必要であること、今後普及が予想されるウェラブル・コンピュータへの検証も必要であることが明らかになった。今後の課題としたい。

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