DigitalQuest: A Mixed Reality Approach to Scavenger Hunts

Marco Cavallo* and Angus Graeme Forbes†
Electronic Visualization Laboratory
Deptartment of Computer Science
University Of Illinois At Chicago

Abstract

This paper presents a novel approach for the design of creative location-based mixed reality applications. We introduce a framework called *DigitalQuest* that simplifies adding geolocated virtual content on top of real-world camera input. Unlike previous work, which relies solely on markers or image pattern recognition, we define a "mirror world" that facilitates interactive mixed reality. *DigitalQuest* consists of an editor that allows users to easily add their own content as desired and a mobile application that loads content from a server based on the location of the device. Each piece of virtual content can be organized through the editor so that it appears only in certain circumstances, allowing a designer to determine when and where a virtual object is attached to a real-world location. We have used our editor to create a series of futuristic scavenger hunts in which participating teams must solve puzzles in order to access new virtual context appearing in a mixed reality environment via a mobile phone application. In this paper, we introduce our editor and present an example scavenger hunt game, *Morimondo*, that was built using it. Specifically, we describe our technique to utilize camera and motion sensors on the mobile phone to enable an appropriate level of user engagement within this game. We are able to obtain realistic augmentations with accurate positioning by leveraging sensor fusion and through the use of filters that compensate for sensor noise, using image processing only for error correction or in special situations. The initial success of this project leads us to believe that *DigitalQuest* could be used to design a wide range of creative multi-user mixed reality applications.

Index Terms: H.5.1 [Information interfaces and presentation (e.g., HCI)]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.3 [Group and Organization Interfaces]: Collaborative computing—Games.

1 Introduction

Despite much progress and increased interest, mixed reality applications are not yet in widespread use by the general public. Our framework, *DigitalQuest*, facilitates the creation of mixed reality applications, providing application designers with the ability to add custom virtual content to the real world. Specifically it supports the creation of futuristic "scavenger hunts", where multiple users search for virtual objects positioned in the real world, and where each object is related to a riddle or a challenge to be solved. Each player can compete with the other participants by finding virtual objects and solving puzzles, thereby unlocking additional challenges. Virtual objects are represented by animated 3D meshes locked to a determined position in the real world. The objects are activated when a player gets within a proximity threshold and then taps the object on the screen of his or her mobile phone. In our demonstration application, configurable virtual content appears, followed by a question that must be answered in order to be pass to the next challenge. The displayed content may consist of images, video and audio streams, graphical effects, or a text message that provides hints on how to advance in the game. The editor makes it easy to create puzzles that can be solved by exploring the surroundings of the virtual object in order to discover clues and making use of location-specific knowledge. When a participant figures out the correct solution, he or she scores points related to the complexity of the challenge and also unlocks remaining puzzles that cause new virtual object to appear in the world. At the end of the event, the player with more points wins. Fig. 1 shows an example of a virtual object attached to a real-world location; in this case, a public sculpture on the East Campus of University of Illinois at Chicago.

*e-mail: mcaval4@uic.edu
†e-mail: aforbes@uic.edu, web: http://creativecoding.evl.uic.edu/

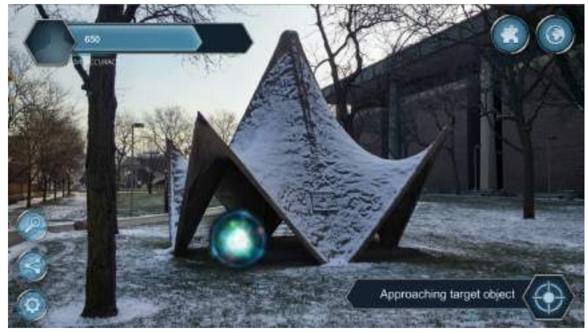

Figure 1: A sample camera view of the mobile application showing the user arriving in proximity of a virtual object. The buttons in the upright corner allow the user to change to map view and to see the current active challenge; the buttons on the bottom-left corner bring up a options. The upper-left bar indicates instead the score for the current *DigitalQuest* and the current GPS accuracy.

DigitalQuest provides a general approach for adding user-defined virtual content to the real world, allowing the personalization of a "mirror world" that could be explored by anyone with a GPS-enabled mobile device simply by using our application. Though these *Quest*s were originally meant for creative exploration and mixed reality scavenger hunts, our framework also could potentially support a wide range of applications, for example: team building and team-work enhancement events, tourism, virtual galleries, and cultural heritage. As we demonstrate in our case study, *DigitalQuest* can also be used to create augmented narratives, engaging users by telling an interactive story that makes use of real-world architecture. We also believe that our framework could be used to provide context-aware opportunities for learning. *DigitalQuest* could additionally be used for marketing purposes, allowing companies to organize events with customized content in order to make customers more attached to the brand. Ultimately, the framework is meant to provide a way for designers to flexibly express creative approaches to generating virtual content within the real-world.

2 RELATED WORK

Scavenger hunts are an effective means to provide a continuous mixed reality engagement that mediates between a virtual environment and the real world [6]. Traditionally, virtual content is delivered through location-based applications, mostly used indoors, or via markers or image patterns, exploiting live input from a mobile phone camera. A recent example of a mixed reality scavenger hunts is *HUNT* [7], where users seek a set of objects and scan them with the built-in camera on a smartphone, enabling the display of associated multi-media AR content that includes images and videos overlaid on top of the real world view. Some scavenger hunts utilize game-based learning environments. For example, Loiseau et al. [6] propose an MMORPG videogame approach applied to the archaeological domain aimed at raising awareness of cultural heritage by providing relevant information in the virtual environment. They leverage Game-Based Learning (GBL) by immersing learners in digital environments and rely on collaboration order to enhance learning and motivation. Considering that digitalization, for better or worse, is natural for children, Doong et al. [2] explore how educational environments can enable individuals or groups of users to embark on a "quest for knowledge". *ARLearn* [12] similarly adopts a learning-oriented approach.

Scavenger hunts have also been used to orient people to new environments. Rogers et al. [10] exploit the use of pervasive augmented reality for the design of a serious game that teaches navigational skills in public environments. The University of Illinois at Urbana-Champaign proposed a similar idea for a team-based orientation activity that orients incoming freshmen in the Department of Computer Science, demonstrating how these types of game foster a sense of community and effectively acclimate new students to university life [11].

Some works broaden the concept of augmented reality based scavenger hunts by introducing new elements. Focusing on the growing trend of Internet of Things, *TagHunt* [4] allows smartphones to interact with ordinary objects using additional technologies such as NFC. This encourages the user to interact through "hyperlinking" with the surrounding environment, asking them to look for clues in the game. Gonzales et al. [5] analyze the creative collaboration environment in their *GISHWES* (The Greatest Scavenger Hunt the World Has Ever Seen), a scavenger hunt where each item consists of a request for an image or a video with a focus on making the players produce art and/or helping others while attempting complex, creative and time-limited collaborative tasks.

While most of the above works focus on enabling digital content through the use of classical augmented reality (e.g. marker detection or pattern-based recognition), our framework concentrates on outdoor location-based mixed reality, making use of GPS and mobile sensors and resolving issues related to accuracy. Similar projects include for instance *Tidy City* [13], where players physically explore their city by interpreting clues to find the correct target destination, or *LMAC* mobile application [9], where children are able to gather geo-referenced information to learn about the environment in a playful way. Zund et al. [14] similarly proposes a city-wide gaming framework that overlays interactive elements on top of the existing structure of buildings, parks, and roads.

A main issue regarding location-based mixed reality is that it is difficult to ensure the accuracy of the position of virtual objects. Accuracy is greatly affected by the measurement errors generated by the sensors of mobile devices. Our approach leverages the improved technology in current mobile phone sensors, mitigating poor accuracy by enabling a sensor fusion approach to minimize the positioning error. This allows us to conceive of scavenger hunts in a novel way and provides new creative opportunities. For instance, virtual objects can be represented as animated 3D meshes without using computer vision techniques. Instead, their position is computed through the filtered measurements obtained from mobile sensors, such as the accelerometer and gyroscope. A similar sensor-based approach is used in *MIPos* [3], which describes the detection of movement and orientation of a user's device by leveraging sensor fusion and filters to compensate sensor noise, thus avoiding excessive image processing. Using the sensors available on smartphones allows us to define a virtual scene where all objects can be located at the same time, mirroring their position in the real world. This simplifies both content management (from the designer's perspective) and introduces new interaction possibilities (from the player's point of view).

Our framework provides an editor for creating *Quest*s, advancing previous work proposed by Wetzel [13] and Pirker [9]. In particular, our version enables more sophisticated logic to control when and where virtual objects appear. It also provides additional types of triggers, enables the use of a 3D window for positioning objects in space, and provides a preview mode for viewing the final appearance of virtual objects in the mobile application.

3 METHOD

The *DigitalQuest* framework is composed of two main applications: 1) an editor for allowing users to add their own virtual content (text, multimedia, 3D objects) in specific locations; and 2) a mobile application that runs natively on both Android and iOS devices. *DigitalQuest* currently relies on a client-server model. Once a *Quest* is created or updated from the editor, its information is encoded and stored on a server whose application logic responds to queries sent by the mobile clients.

3.1 The *QuestEditor* Application

The editor itself consists of a user interface for defining and editing a *Quest* as well as a specific module for positioning virtual objects in the real world. The editor can also be simply used for adding virtual content outside the context of a *Quest*, thus making it publicly accessible by anyone at anytime.

3.1.1 *Quest* Creation and Editing

The *QuestEditor* facilitates the definition of all the locations and events in a *Quest*. Using this editor, a designer defines and positions virtual objects within the *Quest*. Each object is represented by a 3D mesh that will appear on screen when the player approaches the specified position. The designer defines the logic with which these object appear and what type of content is related to them. For example, we can define a trigger so that when a participant reaches a first object a textual indication of the position of a second object will pop up, that is, that causes the first object to disappear and "unlocks" the second one. The second object may instead ask the user to solve a riddle after having shown an image or having played an audio, then unlocking the third and forth objects. Currently, text messages, questions, images, audio streams, and video streams can be combined and bound to objects. If not available by default, the editor uploads the content to the server which takes care of streaming them to the mobile application when required. Objects may be set to be "visible" or "not visible" on the map view when unlocked. In other words, the accessibility of particular objects can be programmatically defined to be dependent on how much of the *Quest* has been completed. The designer can explicitly control these dependencies in order to fully customize the experience.

A *Quest* can be imagined as a directed graph structure where each node corresponds to a virtual object and further is characterized by a set of properties, such as: 3D mesh, map pointer, latitude, longitude, altitude, and scale. Based on object type, additional parameters indicating specific behaviors or multimedia content (e.g. the link from which a video file needs to be streamed) are available. The main idea is to allow objects to be flexibly extended with new behaviors, for instance to programmatically start a specific animation or play an audio file whose volume is linearly related to the distance of the player. By default, each object has three parameters: the message to be displayed when the object is reached (that often corresponds to a riddle), a set of possible correct answers, and a message to be displayed after the challenge is solved (usually a hint to the next object). Those three attributes can also remain empty, thus enabling configurations where objects are used simply to represent clues, without any puzzle that be solved. Again, regarding the dependencies between objects, each node of the graph becomes unlocked when a configurable logical expression involving its ancestors is satisfied For example, a fourth challenge could become available only if the player has completed puzzles one and two or puzzle three, but has not yet solved challenge number five.

3.1.2 Positioning Objects in 3D Space

Each virtual object consists of a 3D mesh that can be chosen from a set of predefined meshes or that is manually uploaded through the editor. The main properties of the object are related to its position in the real world (using GPS coordinates), its scale, and its altitude. A dedicated module provides a precise and realistic positioning of the virtual object in the real world. The designer is prompted to input an address or to select a location from Google Maps, and then the editor loads the closest Google Street View panoramic image, if available. By leveraging WebGL and Google APIs, the imagery is projected onto a sphere in order to obtain a spherical panorama viewer. The user can then drag and drop the virtual object into the scene in order to preview how the augmentation will look like when running on the mobile application. In order to place objects inside the spherical projection, we need to retrieve the depth map corresponding to the current panorama in order to determine distances and permitted positions. The Google Maps REST API provides functionality to download a compressed JSON representation of the depth image, which contains the distance from the camera to the nearest surface at each pixel of the panorama. We obtain a grid of pixels after decoding the image from Base64 and converting it to a more suitable data structure. Each of the pixels in this grid corresponds to one of several planes, defined by its normal vector and its distance to the camera. Therefore, in order to calculate the depth at each pixel we have to determine the intersection point of a ray starting at the center of the camera and the plane corresponding to the pixel. Iterating for all the planes, we can then populate our depth map which will have a representation similar to the one in Fig. 2.

By considering the following correspondence between the points in the 2D texture and the points projected on the sphere we can calculate the 3D position of the objects (e.g. the walls of the buildings) that are present in the panoramic image. We can then restrict the positions that are available for the virtual object to placed at. By mapping the 3D scene distances with the real world ones, we can obtain the absolute coordinates, orientation, and dimensions of the object *as if it were a real object*. This information is stored on the server and loaded by the mobile application.

3.2 The *DigitalQuest* Mobile Application

Users can access the virtual content configured in the editor from a mobile application, currently working on Android and iOS devices. The application first geolocalizes the user and then loads a map of the surroundings, allowing two possible views: the camera view, which shows the live camera input of the device along with the augmented content; and the map view, which shows the position of the user with respect to available *Quest*s or nearby virtual objects. When the user gets within a specified proximity of an object, he or she can interact with it by tapping its mesh on the display. This is generally followed by audiovisual feedback (i.e. an predefined animation), after which the intended virtual content is shown and the behavioral logic previously defined in the editor is applied.

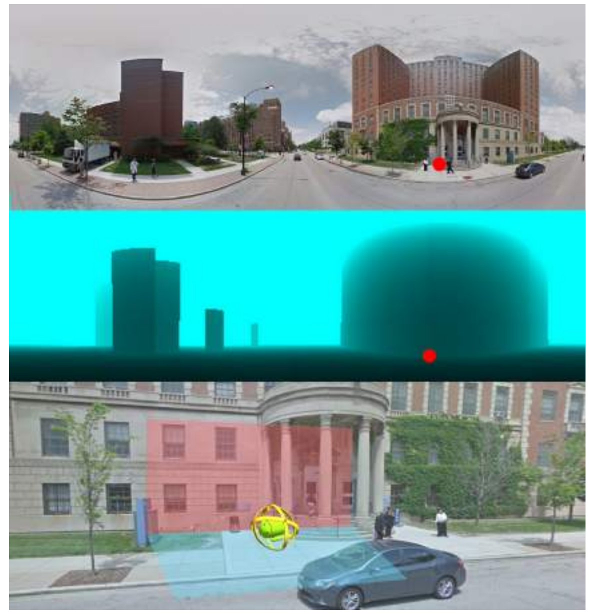

Figure 2: An example panoramic image (top) and its relative computed depth map (middle). The depth information is available in the *Quest* editor to allow a more precise positioning of the virtual objects in the real world (bottom), which can simply be dragged into the scene and then moved, scaled or rotated.

3.2.1 Mapping Virtual Objects to the Real World

DigitalQuest enables the creation of a parallel virtual world that coexists with and overlaps the real world. A virtual camera moves consistently with the device, rendering the augmentations on top of the normal camera input. In order to make this possible, some basic projections are used to convert real world GPS coordinates to virtual 3D positions. The origin of the virtual world is first located where the user is initially situated and successive locations are then calculated in relation to that original position. In this way, each object in the real world has its corresponding position in the virtual world (and vice versa), allowing more flexibility and an easier management of 3D content with respect to classical AR, which instead relies on activating and moving multiple cameras around objects located at the origin of a coordinate system.

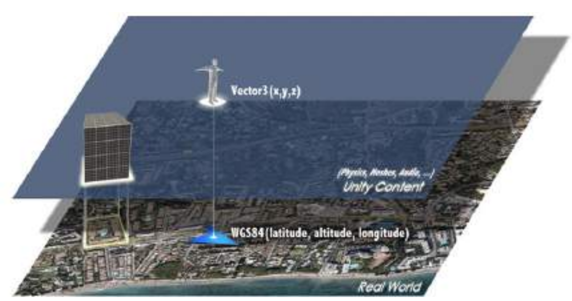

Figure 3: The virtual character navigates the scene as the user walks in the real world by leveraging a one-to-one mapping from real to virtual coordinates.

3.2.2 Location and Camera Pose Correction

The accuracy of mobile sensors has greatly improved over the last years; a fundamental idea behind the *Digital Quest* mobile application is that the position and pose of the virtual camera can be calculated directly from the A-GPS sensor and the IMU. Through a combination of accelerometer, gyroscope, and compass—nowadays supported by almost all new devices—it is possible to obtain a rotation vector that identifies the orientation of the camera in the 3D space. The camera can be moved in space by leveraging the location information gathered via GPS, WiFi, and cellular network triangulation. The main drawback of this sensor-based approach is the drift of the camera. Under certain circumstances, due to GPS instability, the camera may move even if the device is stationary. Considering that GPS has a horizontal accuracy of approximately 14 feet, in a worst case scenario a virtual object in front of a user could suddenly be abruptly shifted. Thus we decided to apply the sensor fusion algorithms provided by the ROAMFREE framework in order to combine sensor data and remove outlier measurements. Originally meant to be used by robots, ROAMFREE provides a robust odometry based on multisensor fusion and delivers out-of-the-box online 6DOF pose tracking and sensor parameters self calibration. In particular, it represents measurements with graph-based time frames that take into account the different sample rates. For example, if the GPS position is not updating even though the user is moving, ROAMFREE allows us to statistically compute the meantime position with the remaining available sensors [1].

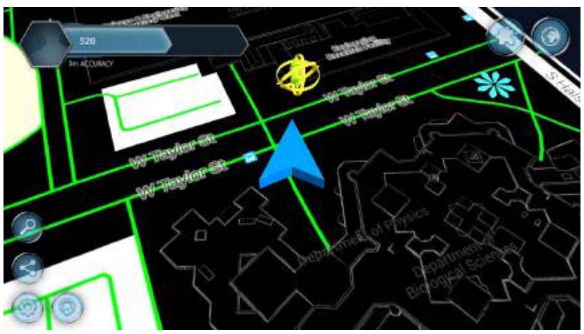

Figure 4: Sample map view showing the user approaching his next challenge, represented by an animation on the map (which differs from the virtual object that will be shown in the camera view). The light blue element on the upper-right corner is instead a virtual sound zone— a particular type of virtual object that emits a sound whose intensity is proportional to the its distance from the player.

4 CASE STUDY: THE *Morimondo* SCAVENGER HUNT

Digital Quest was used to design a public mixed reality event in Morimondo, a small town in Italy that is admired for its Abbey and beautiful landscapes. The aim of the event was to increase the awareness of people about the history of Morimondo and its cultural and artistic heritage. On August 9th, 2015, 32 participants gathered at the entrance of the town and formed 10 teams with varying number of players; each team logged into the *DigitalQuest* mobile application sharing a single device, which was used to view the virtual content, to solve puzzles, and to see their progress in comparison to the competition (the other teams). At exactly 12 noon the *Quest* began, and an indication was sent to all devices that the first puzzle was available. The *Morimondo Quest* was composed of 19 virtual objects, each one consisting of a puzzle that needed to be solved in order to unlock one or more of the remaining objects. The puzzle was organized around a simple narrative plot about the history of Morimondo. For instance, the first object appeared in front of the players as a floating orb: when they touched the object on the screen a popup window appeared (on their mobile device) that described a legend about the town and its foundation and that then provided new instructions so that the players could continue the game. In order to unlock the next object, a player on the team needed to type the answer to a simple question regarding the meaning of the name Morimondo. After the correct solution was entered, the current object disappeared, points were added to the team's scoreboard, and a message was sent to the other teams in order to foster a greater sense of competition.

For this specific *Quest*, players had to move by foot throughout the town. Each of the riddles involved real world items that could be found in proximity of the virtual object. For example, objects included a gem hidden in an old mosaic and a Latin phrase that was located close to the Abbey, and the questions involved information about those items. Other puzzles involved exploring specific environments, like an ancient ice house or a votive chapel hidden in the woods, forcing the players to search for particular hints. Alternatively, some challenges required teamwork, reasoning, or special actions, such as asking a question directly to the owner of a shop (e.g., for the name of the saint represented in a sculpture) or querying online websites for specific information (e.g., the year in which the apsis of the Abbey was rebuilt). After the first few puzzles, solving the remaining puzzles unlocked multiple puzzles at once, allowing teams to go to different places and to choose a specific strategy for solving them. After the time limit passed, the application stopped and all the teams were directed to gather at a certain location where the final ranking was announced and prizes were awarded.

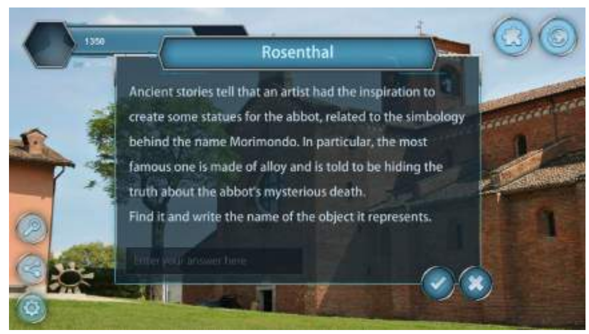

Figure 5: An example of a simple puzzle appearing on screen after a team reaches a virtual object during the *Morimondo* scavenger hunt.

4.1 User Evaluation

As an initial step to gauging the interest of users and its effectiveness as a means to promote tourism, we provided a questionnaire to the 32 players who took part in the *Morimondo Quest* event. All of them indicated that they enjoyed this experience, and 30 players stated that they discovered new information about the town of Morimondo, while 23 indicated that they would gladly revisit the town in the near future.

As for the performance of the application (which was tested primarily on Android devices without implementing the ROAMFREE error correction), we registered an average GPS positioning accuracy of 4 meters at the moment of reaching a virtual object, with a minimum of 2 and a worst case of 8 meters accuracy. However, considering that the *Morimondo Quest* made use of mainly open, outdoor spaces, the majority of players (28 out of the 32) stated that the poor resolution did not negatively affect their experience while playing.

All of the players agreed that it was important to have access to a map view and a menu for checking information related to both the current and past *Quest*s. Nearly half of the players took advantage of a feature that allowed them to highlight the position of a current challenge on a map, and all participants noted it that it would be a necessary feature in cases where a user strays far from the initial position or wants to pause the game and pick up from the same location at a later time. 30 players considered it very useful to have both audio and visual feedback provided by the application when approaching a virtual object (e.g. the notifications involving the distance from the target), stating that it mitigated some difficulties that arose in perceiving the depth of the virtual content. However, 5 players also stated that they would have preferred additional more visual hints for finding particular objects. Since this aspect is intrinsically tied to the type of experience that we want to create, we plan to improve the editor so that it is possible to enable these kinds of customizable visual clues for specific objects. Finally, an interesting consideration that was identified by answers to the questionnaire involved the use of audio playback. Currently, audio is solely related to the distance the player is from an object and does not take into account the direction of the audio source. A possible improvement could be to filter audio according to the direction that the player is facing, allowing him or her to understand where a sound comes from, even with a single mobile speaker. We plan to more rigorously evaluate *DigitalQuest* and the quality of players' experience in the *Morimondo* scavenger hunt in a future study.

5 Future Work

Future work will improve the mobile application with state-of-the-art computer vision techniques in order to obtain a better accuracy when positioning virtual objects and to improve interaction with the objects in 3D space. Sensor fusion techniques have proved to be effective for enabling users to reach a target object, but can still be problematic when requiring players to perform more nuanced movements within the proximity of a virtual object. A possible solution could be to implement a SLAM (Simultaneous Localization And Mapping) algorithm that would be used once a user comes close to an object in order to better track its surroundings and make it align perfectly to the desired position. Since SLAM methods allow a partial reconstruction of the 3D scene, many other types of interaction may also be explored by leveraging the real-time generated map of the environment. For example, by detecting the floor, the walls, and the objects near the virtual object, it could be possible to apply animations to the object in a much more realistic way. This would also allow the insertion of more complex animated objects— including humanoid avatars— that could live in the virtual world and interact with the users.

Allow players to interact with each other could enhance the gameplay of the *Quest*s. For instance, including items that provide an advantage to a user or that affect how the other players can navigate the world could provide a richer set of creative possibilities for designers. Items could be found in specific places in the world as virtual objects, collected, and eventually traded by the players, who could then use them during *Quest*s. Many other topics involving collaborative virtual environments could also be explored, such as allowing the participation of remote users or splitting puzzles into a separate subtasks for each player so that participants would have to cooperate and solve their part of the problem in order to complete a challenge [8].

6 Conclusion

This paper presents a novel approach to mixed reality that allows designers to add their own virtual content to the real world and create futuristic scavenger hunts. The proposed framework is based on two applications: an editor aimed at positioning the virtual content in space and defining the circumstances under which it should be shown; and a sensor-based mobile application that renders the scene by loading the created content from a server. *DigitalQuest* is a first step toward facilitating global-scale location-based mixed reality experiences via configuring virtual content and events within a "mirror world". We believe that this approach could be an exciting and effective approach to designing a wide range of creative applications, including games, educational applications, and artistic works.

References

[1] D. A. Cucci and M. Matteucci. A flexible framework for mobile robot pose estimation and multi-sensor self-calibration. In *ICINCO (2)*, pages 361–368, 2013.

[2] J.-L. Doong, C.-H. Lai, K.-H. Chuang, and C.-C. Hsu. Learning effects of location based mixed reality game: A pilot study. *Procedia Manufacturing*, 3:1603 – 1607, 2015. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, {AHFE} 2015.

[3] J. Etzold, M. Englert, P. Grimm, Y. Jung, and M. Klomann. Mipos: Towards mobile image positioning in mixed reality web applications based on mobile sensors. In *Proceedings of the 19th International ACM Conference on 3D Web Technologies*, Web3D '14, pages 17–25, New York, NY, USA, 2014. ACM.

[4] K. Gama, R. Wanderley, D. Maranhao, and V. Cardoso Garcia. A web-based platform for scavenger hunt games using the internet of things. In *Consumer Communications and Networking Conference (CCNC), 2015 12th Annual IEEE*, pages 835–840. IEEE, 2015.

[5] J. A. Gonzales, C. Fiesler, and A. Bruckman. Towards an appropriable cscw tool ecology: Lessons from the greatest international scavenger hunt the world has ever seen. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, CSCW '15, pages 946–957, New York, NY, USA, 2015. ACM.

[6] M. Loiseau, É. Lavoué, J.-C. Marty, and S. George. A multiplayer learning game based on mixed reality to enhance awareness on archaeology. *EAI Endorsed Transactions on Serious Games*, 1(3):e3, 2014.

[7] Y. Lu, J. T. Chao, and K. R. Parker. Hunt: Scavenger hunt with augmented reality. *IJIKM*, 10, 2015.

[8] O. Oyekoya, R. Stone, W. Steptoe, L. Alkurdi, S. Klare, A. Peer, T. Weyrich, B. Cohen, F. Tecchia, and A. Steed. Supporting interoperability and presence awareness in collaborative mixed reality environments. In *Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology*, VRST '13, pages 165–174, New York, NY, USA, 2013. ACM.

[9] J. Pirker, C. Gutl, P. Weiner, V. M. Garcia-Barrios, and M. Tomintz. Location-based mobile application creator creating educational mobile scavenger hunts. In *Interactive Mobile Communication Technologies and Learning (IMCL), 2014 International Conference on*, pages 160–164. IEEE, 2014.

[10] K. Rogers, J. Frommel, L. Breier, S. Celik, H. Kramer, S. Kreidel, J. Brich, V. Riemer, and C. Schrader. Mobile augmented reality as an orientation aid: A scavenger hunt prototype. In *Intelligent Environments (IE), 2015 International Conference on*, pages 172–175. IEEE, 2015.

[11] J. O. Talton, D. L. Peterson, S. Kamin, D. Israel, and J. Al-Muhtadi. Scavenger hunt: Computer science retention through orientation. In *Proceedings of the 37th SIGCSE Technical Symposium on Computer Science Education*, SIGCSE '06, pages 443–447, New York, NY, USA, 2006. ACM.

[12] S. Ternier, R. Klemke, M. Kalz, P. van Ulzen, and M. Specht. Arlearn: Augmented reality meets augmented virtuality. 18(15):2143–2164, aug 2012. `http://www.jucs.org/jucs_18_15/ARLearn_augmented_reality_meets`.

[13] R. Wetzel, L. Blum, and L. Oppermann. Tidy city: A location-based game supported by in-situ and web-based authoring tools to enable user-created content. In *Proceedings of the International Conference on the Foundations of Digital Games*, FDG '12, pages 238–241, New York, NY, USA, 2012. ACM.

[14] F. Zünd, M. Ryffel, S. Magnenat, A. Marra, M. Nitti, M. Kapadia, G. Noris, K. Mitchell, M. Gross, and R. W. Sumner. Augmented creativity: Bridging the real and virtual worlds to enhance creative play. In *SIGGRAPH Asia 2015 Mobile Graphics and Interactive Applications*, SA '15, pages 21:1–21:7, New York, NY, USA, 2015. ACM.