# Augmented Viewport: Towards precise manipulation at a distance for outdoor augmented reality wearable computers

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**Abstract** In this chapter we present our research directions on the problem of action at a distance in outdoor augmented reality using wearable computers. Our most recent work presents the augmented viewport technique to enable interactions with distant virtual objects in augmented reality. Our technique utilizes physical cameras to provide real world information from the distant location. We examine a number of factors required to achieve an efficient and effective solution for precise manipulation at a distance for outdoor augmented reality using wearable computers. These include the improved usage of physical cameras, collaboration, viewpoint visualization, alignment of virtual objects, and improved input devices. We particularly focus on the collaboration aspect of the technique, with the utilization of remote cameras from multiple users of wearable computer systems and mobile devices. Such collaboration supports precise manipulation tasks by allowing viewing from different perspectives, directions, and angles, as well as collaborative precise triangulation of virtual objects in the augmented environment.

## 1 Introduction

Our investigations into augmented reality (AR) have focused on wearable computers in an outdoor setting [1]. We are motivated to find solutions to the problem of precise action at a distance for outdoor AR [2]. One of the main challenges is the requirement of mobility. Users of an outdoor wearable computer system require freedom of movement and wearability comfort. Indoor tracking systems with complex setups can provide high precision operations, such as the FastTrak's Polhemus magnetic tracking [3] or the Vicon motion system for visual tracking [4]. However, such solutions cannot be applied outdoors because they restrict user's movements and require complex setup at a fixed location. The main envi-

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ronmental constraints of the outdoor environment are its inherently large scale and dynamic nature. Therefore, it is common for users to interact with virtual objects that are out of arm's reach. Action at a distance (AAAD) technique is one of the approaches of handling these outdoor constraints. Solutions to the AAAD overcome these environmental constraints and offer the users of outdoor AR systems an efficient and effective way of interacting with distant virtual objects in the augmented outdoor environment in a collaborative manner.

## *1.1 Action at a distance problem*

AAAD is a well researched problem in the VR domain. The two main approaches are: bringing distant objects closer to the user and bringing the user closer to distant objects. There are many interaction techniques belonging to those categories, such as: world-in-miniature, voodoo doll, image plane techniques, and ray casting, cone selection, Go-Go arm, HOMER, and teleportation techniques.

World-in-miniature (WIM) [5] is an interaction technique that supports multiple interactions including object selection, manipulation, navigation, and visualization. The virtual world and its contents are scaled down into a miniature version and placed on one of the user's virtual hands. By manipulating the miniature objects in the WIM, the user is able to change the position, orientation, and scale of the corresponding objects in the virtual environment. The user may also navigate around the virtual environment by manipulating their representations in the virtual world [6]. With a similar scaling approach, the scaled world grab technique brings the world closer to the user, by scaling the world centered to the user's head [7].

A variation of this approach is to scale down only the distant object to be manipulated. The Voodoo doll technique [8] places a miniature version of the distant object of interest in the user's hand for manipulation. The two-handed technique supports translation and rotation of virtual objects by performing relative movements and rotations with two Voodoo dolls on both hands. The creation of Voodoo doll uses the image plane technique by pinching the projection of distant objects on the user's viewing plane. The image plane technique enables interaction with the projection of the world. Distant objects are projected onto the user's two-dimensional viewing plane [9]. Image plane interaction supports various gestural selection techniques, such as pinching, pointing, and framing, as well as affine transformations, such as translation, scale, and rotation [10].

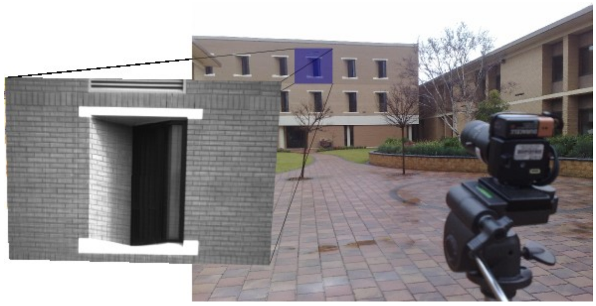
A second approach of covering the distance between the user and the virtual objects is to bring the user closer to the objects. Ray casting and cone techniques extend the user's pointing gesture for selection of distant object. A virtual ray is fired from the user's virtual hand or pointer to select distant objects [11]. These techniques are suitable for object selection from both a close range and at a distance. The user can translate the object by moving the virtual ray to change the position of the object which is attached at the end of the ray. Extending arms is another popular approach for bringing parts of the user's body to distant objects. The virtual hand metaphor is an intuitive technique supporting direct manipulation of virtual objects with the user's hand. A simple version of the technique implements a one-to-one mapping of the movements between the user's hands and the virtual ones, limiting it to close body interactions [12]. The Go-Go arm technique [13] allows the user to extend their virtual hands by non-linearly increasing the mapping ratio as the physical hand reaches away from the body. The HOMER technique [14] is a combination of both ray casting and hand extension techniques that allows a seamless transition between selection and manipulation tasks.

Teleportation instantly transports the user to remote locations in the virtual environment in order to perform close body interaction with distant objects. This technique is typically considered a travel technique in virtual reality [15], which could be utilized to overcome distance in the task of manipulating distant virtual objects. Teleportation has the visual advantage over hand extension techniques, as the user visually interacts with distant objects at a close range.

## *1.2 Augmented viewport technique*

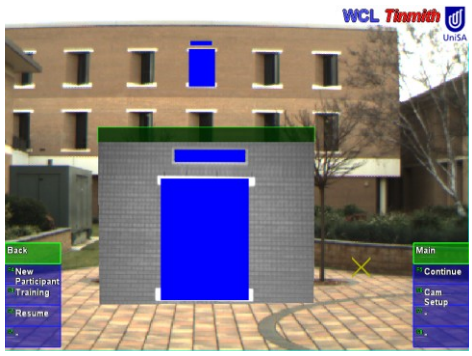
Our recent work presents the augmented viewport technique [2], a new AAAD technique for outdoor AR systems. The augmented viewport is the AR version of the virtual viewport technique in VR research [16], which brings a view of a distant location closer to the user. The augmented viewport takes the form of a virtual window, showing both the virtual and real world information of a distant location. The real world information is provided by physical cameras, which are either 1) located at the distance outside or 2) within the user's field of view, or 3) located near the user and equipped with an optical zoom lens to zoom further into the distance. Fig. 1 shows an example of the augmented viewport using a zoom lens camera. The camera is mounted on a tripod and zoomed in on a physical window on a building at a distance (Fig. 1A). The inset figure is the view as seen through the zoom camera. The view for the user without the augmented viewport through the standard head mounted display (Fig. 1B) indicates virtual objects (blue boxes) overlaying on the same window of the physical building. Combining those views results in an augmented viewport with a window display, showing distant virtual and physical objects. The viewport offers a closer view, and is located near the user (Fig. 1C). Currently the augmented viewport technique is implemented on the Tinmith wearable computer system. Tinmith is an outdoor AR wearable computer system [1], consisting of a belt-mounted computer and a wearable helmet. Tinmith employs a video see-through head mounted display, located on the helmet together with a head orientation sensor and a GPS antenna unit.

The outdoor environment is naturally large and open. The augmented viewport technique overcomes this aspect of the outdoor environment and enables the user to perform direct manipulation operations on distant virtual objects. The user is able to interact with distant virtual objects through the viewport using close body interaction techniques, such as ray casting or image plane techniques. The possible placements of the augmented viewport are in three coordinate systems relative to the user's view: world, body, and head relative. World relative placement has the viewport in a fixed position and orientation in the world coordinate system. Body relative places the augmented viewport attached to the user's body, so that the viewport stays at a fixed position and orientation from the location of the user's body. And head relative placement fixes the viewport to the user's head orientation.



**A: The zoom lens camera setup on tripod. Inset: the view through the zoom camera of a distant physical window**


**B: The view through the user's head-mounted display (blue boxes indicating distant virtual objects overlaying the physical window)**




**C: = A + B: The augmented viewport, combining the video stream from the zoom lens camera and distant virtual objects**

**Fig. 1 The augmented viewport technique**

### *1.3 Collaboration for action at a distance*

The augmented viewport technique supports collaboration for action at a distance problem. User of the augmented viewport technique can benefit from the head-mounted or mobile cameras from other users of wearable computer systems and mobile devices. A network of mobile devices and wearable computers are interconnected to provide multiple viewpoints of the augmented environment. Different viewpoints can be shown through the augmented viewport windows to assist with manipulation tasks of virtual objects at a distance.

There can be several camera sources to form a network. Head-mounted cameras worn by users' of wearable computer show direct first person perspectives of the world. Cameras attached to mobile devices can be used to offer more flexible and dynamic viewing angles. Outdoor wearable computer user can also extend manipulation to indoor settings with desktop webcams.

The collaboration network of remote cameras offers various benefits. The user has multiple viewing angles, directions, and aspects of the environment, including the views that physically impossible for other users to achieve. Triangulation of virtual objects can be achieved from multiple camera sources, in order to precisely determine virtual objects' positions.

The augmented viewport is our first step towards achieving the research goal of precise manipulation techniques for AAAD in outdoor AR environments. For future research directions, we analyze various factors that are posing challenges to the open research question of AAAD for outdoor AR.

## 2 Required factors

The required factors to improve AAAD technique for outdoor augmented reality are fivefold: 1) improved usage of remote cameras, 2) collaboration between users of wearable computers and mobile devices, 3) better visualization of views from these cameras, 4) the automatic alignment (snapping) of virtual objects to physical objects, and 5) improved user input devices.

### *2.1 Remote cameras*

The augmented viewport technique can be applied to different types of cameras, such as CCTV cameras, remote wireless cameras, or even static imagery from satellites. We are also interested in the collaborative potential of using the AR cameras from multiple users of nearby AR systems, and/or cameras mounted on automatic robots. There is a requirement to better perform the discovery and selection of existing cameras in the user's world, as well as to understand their locations and placements.

A CCTV camera provides a fixed viewpoint at a particular distant location. If the camera is located at a location that is not visible to the user, possibly due to physical constraints, the augmented viewport offers a telepresence mode of interaction. Considering that the viewport appears as a virtual window not covering the entire field of view, the user still retains their physical presence in the augmented world, which is one of the main characteristics of the outdoor AR system. We propose increasing the flexibility to the augmented viewport solution by providing the user with the ability to control the orientation and/or the position of the remote camera. ARDrone[3] is a wireless controlled flying quadrotor, with a VGA camera mounted at the front. The ARDrone can be connected to via an ad-hoc wireless link, through which the flying commands and the video stream of the front-mounted camera are transmitted. A potential implementation can have the user control the ARDrone with either an onscreen menu or a separate orientation sensor attached to the hand. This allows the user to remotely control the ARDrone and to use the video source from the camera as an augmented viewport. With this combination, the user can selectively perform manipulation of virtual objects from various distant locations. A similar source of remote cameras are remote controlled robotic vehicles, which have been utilized in an AR X-Ray system [17].

Static satellite imagery has been shown to improve precision of virtual object placement. The work by Wither and colleagues [18] overlays static satellite images of the user's surroundings in a God's eye immersive view, in order to assist the user with the placements of virtual annotations. The augmented viewport can take advantage of this approach and be used to provide a top-down map view of the user's location, while still allowing the user to maintain the immersive view of the augmented world.

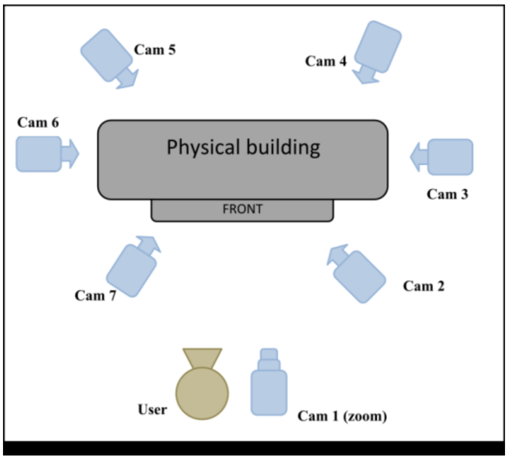



**Fig. 2 Camera viewpoint scenario**

Considering that there are various sources of cameras for the augmented viewport technique, a question arises as to how an AR system performs the discovery of available cameras in the vicinity? How to properly present their existence, as well as their locations and orientations, to the user in order to make a selection of cameras for the manipulation task? Will a top-down map view of the vicinity suffice to provide effective visualization of the camera cluster? Each camera is characterized by their location in the physical world and their intrinsic parameters, especially their viewing frustum. Fig. 2 outlines a scenario for possible locations of physical cameras. Camera no. 1 has a zoom lens to zoom closer to distant location while situated near the user, and cameras no. 2 and 7 are looking from similar views to the user's perspective. Other cameras, however, are looking from either the sides (cameras no. 3 and 6) or the back (cameras no. 4 and 5) of the physical building, which cannot be seen from the user's location. What are the effective visualizations to indicate to the user that those cameras exist and they can provide augmented viewports covering cer-

[3] http://ardrone.parrot.com

tain areas of the physical building? We suggest color-coded shading, in which colored regions are overlaid on the physical building corresponding to the areas seen by each of the remote cameras. For each remote camera, a virtual model of the viewing frustum is created with separate colors. The virtual frustums are placed at the locations of the respective cameras, so that the frustums can cast color-coded shades onto physical building. However, this technique does not cater for cameras in occluded regions, such as camera no. 4 and 5 in the illustration. Is it possible to utilize X-Ray vision [17] to assist the occluded visualization?

## 2.2 Collaboration

One of the many sources of remote cameras can be the head-mounted camera of another wearable computer user. When there is other wearable computer users (*remote users*) located closer to the remote location, the view from their head-mounted cameras be displayed in augmented viewports of the wearable computer user who is located further away from the desired location (*local user*). This setup supports collaborative virtual object manipulation, in which the *remote user* can directly manipulate virtual objects through the wearable computer interface, and the *local user* can perform manipulation through the augmented viewport.

An example scenario is when multiple architects are examining a large architectural site with virtual models of buildings and/or structures. The architects can collaboratively manipulate parts of the models while observing from different viewpoints and locations. Such a collaboration feature is also useful in situations where the participants cannot visually communicate with one another, such as a collaborative repair or inspection scenario in outer space.

An important factor to be considered for collaboration is the support of simultaneous manipulation. There needs to be a sharing mechanism to prevent multiple users from interacting with the same virtual object at the same time. When a user is manipulating the virtual objects, extra visualizations, such as virtual hands or onscreen cursors depicting their current operations, can be shown to other users in the network.

## 2.3 Viewpoints

Once the availability and the locations of remote cameras have been presented to the user, the next step is to select a suitable camera to perform the required manipulation task. What are the selection criteria to? The following factors should be taken into consideration regarding their effects on task performance: the angle the camera is looking at the distant area of interest, the level of details provided by the camera, and whether the user can intuitively comprehend the alignment between their viewpoint and the camera's viewpoint. The extent to which these factors affect task performance is still open to further research. A study by Zimmons and Panter [19] suggests that the quality of the rendered virtual environment does not affect the user's task performance, possibly due to the physiological condition of threat to personal safety, which was set up in the study.

There is a requirement to better understand how the augmented viewpoints from remote cameras align with the user's physical view of the world. The effects of the misalignment between the viewpoints of the remote cameras and the users on their task performance and sense of presence remains an open research question. In outdoor AR systems, it is important for the user to maintain the first person perspective throughout. Remote cameras, however, may be looking at different angles and directions. For example, the user is currently looking directly in front of a physical building and the augmented viewport uses a CCTV camera pointing to the side or the back of the same building, completely out of the user's field of view. This scenario may affect the task performance. If the remote cameras and the user are looking in opposite directions, such as cameras no. 4 and 5 in Figure 2, the translation task will be affected by the mirror effect, such that when the user translates the object to the left through the viewport, the object ends up moving to the right. How can such errors be prevented? What are effective techniques to help the users visualize the locations and directions of the remote cameras, especially when they are different from the user's perspective? One suggestion is to perform ray tracing technique to select camera. A set of rays are cast from the location of interest towards the camera cluster to determine which camera can provide coverage for that area. However, this technique requires a virtual model of the physical building to determine the area that the cameras are viewing.

Regarding the viewpoint misalignment, we plan to apply planar homographies to generate a view of the distant location from multiple remote cameras so that it matches with the user's first person perspective. We expect that this approach will enhance the intuitiveness of the augmented viewport, but this must be evaluated.

Multiple viewport interaction is an interesting research topic regarding the viewport window interface in VR. The work by Hirose and colleagues [20] supports object manipulation and user navigation through the use of multiple viewport windows. Virtual objects can be translated from one remote location to another by travelling through the viewports that are showing the corresponding remote locations. For the augmented viewport, a question arises as to how the user can effectively interact with multiple viewports from multiple physical remote cameras. The cameras show either different angles of a single remote location or separate remote locations.

## *2.4 Precision by snapping*

We also question the precision aspect of the AAAD problem. What does precision mean in the context of an AR environment? One of the most important aims in AR is to align the physical world and the virtual information, and merge them into a unified reality. Therefore, precision is said to be achieved when virtual objects are correctly aligned with the physical worlds and/or other virtual objects. Currently, sensor and tracker errors are still existent. What are the approaches to further improve precision, within the limitations of the current state-of-the-art registration and tracking technologies? We seek to reduce freehand errors and reinforce physical-virtual object alignments.

Snapping is a proven technique for improving precision by reducing freehand errors, as widely implemented in desktop-based CAD applications [21]. A typical implementation of snapping is grid-based snapping. It is an open question as to the proper approach of rendering a grid-based visualization in an outdoor augmented reality environment to improve precision in virtual object manipulation. Such rendering may be obtrusive and could interfere with the tasks.

A pixel is the smallest displayable element on the head mounted display. The larger the distance from the camera to the physical object, the fewer the number of pixels the physical object occupies on the screen. The augmented viewport uses cameras that can have a closer view of the object, and increases the number of pixels representing the object on the head mounted display; thus increasing the granularity in precision for the task of aligning virtual objects to the physical world. Fig. 3 illustrates the difference in pixel granularity between the zoom lens camera and the HMD camera. Both images show the same physical window, with the left hand side being seen through the viewport and the right hand side through the HMD camera. With the viewport, the top and bottom white edges of the window can be clearly distinguished, while they are very blurry in the HMD camera. We propose using feature and edge snapping to improve the alignment between physical and virtual objects, through the pixels of the video stream of the augmented viewport. A selected image-based edge and feature detection algorithm is applied to the video stream provided from the remote cameras and appropriate visual cues are displayed through the augmented viewport. User's manipulations of the virtual objects can be snapped to detected features or edges, if required. Once the virtual objects are aligned to the features in the video stream, it is important to understand the correlation in transformation between the remote cameras and the physical world. What are the position and direction of the camera relative to the world? How does such information affect the proper alignments between the virtual objects and the physical world?

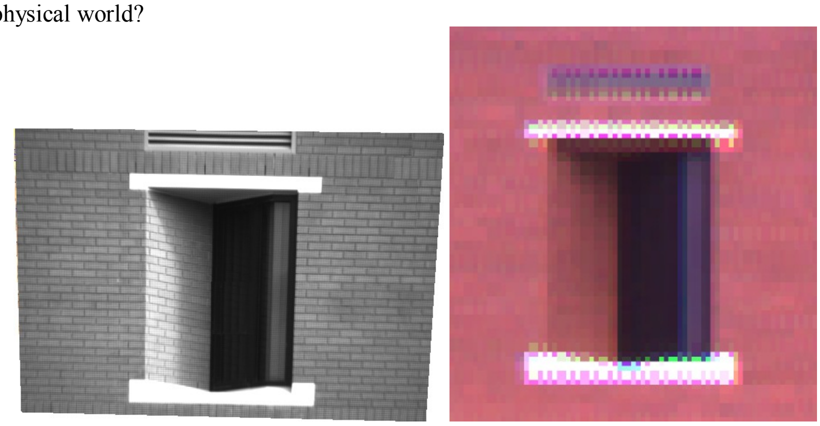
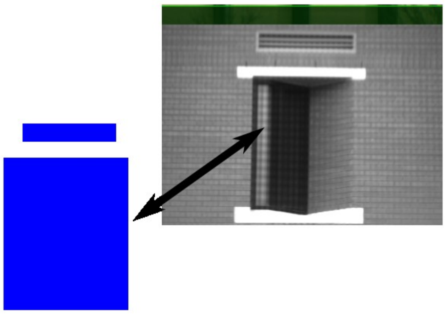


**Fig. 3: Pixel granularity: Top: seen through the viewport. Bottom: seen through the normal HMD on the wearable computer system. Both are pointing at the same physical window**

Snapping improves the alignment between virtual objects and the video stream from the augmented viewport (Fig. 4A). Through camera discovery, the intrinsic parameters of the physical camera are known, as well as its locations relative to the physical world (Fig. 4B). Combining both improvements will lead to a more precise alignment between the virtual object and the physical world at a distance. Fig. 4C illustrates such improvements with more precise alignment of the virtual blue boxes to a distant physical window. The process involves different coordinate systems. The first step is the alignment of the virtual objects within the window coordinate system of the augmented viewport. The second phase is to translate the position of the virtual objects into the global world coordinate system, based on the alignment of the contents of the augmented viewport within the global coordinate system. Lastly, the process is concerned with how to precisely render the location of the virtual object to view in the user's head-mounted display. This last stage includes the position and head orientation of the user within the global coordinate system.

Such improvements also lead to another approach of reducing free hand errors by specifying the physical-virtual objects alignment as constraints for manipulation tasks. Once a virtual object has been aligned to a particular feature in the physical world, it can be set to be constrained to that feature throughout subsequent manipulation operations. For example, a virtual window is constrained to the left vertical edge of a physical window, so that any subsequent translations can only move the virtual window along the vertical edge.



**A: Proper alignment between virtual objects and augmented viewport's camera stream**

**B: Better understanding between the physical camera's location and the physical world.**


**C: A and B leads to more precise alignment between virtual objects and a distant physical building**

**Fig. 4: Combined alignment**

Further precision can be achieved through the application of image processing. Considering that the location of the user is known through the GPS tracker, and the position, orientation, and the intrinsic parameters of the remote cameras are obtainable, it is possible to perform image-based distance measurements. A mapping is formed between the pixels on the augmented viewport and the actual distance measurements of the physical features shown in the viewport. Therefore, based on the number of pixels the virtual objects occupy on the screen, we can specify or obtain the measurements of the virtual objects, or use known measurements to set constraints for manipulation, thus improving precision.

The combination of using various remote cameras can be utilized to support better physical-virtual objects alignment, with a focus on dynamic physical objects. Outdoor environments are dynamic with physical moving objects. In the situation where viewpoints of the user and the remote cameras overlap, it is possible to perform triangulation to track the locations of dynamic physical objects. Dynamic see-through is a method proposed by Barnum and colleagues [22] to visualize physical dynamic objects that are obstructed from the user's viewpoint, using remote cameras. By matching the vanishing point in the remote camera and the user's camera and applying a 2D image homography between parallel planes, called image homology, the dynamic see-through method enables tracking and rendering of remote moving objects. Similarly, the augmented Earth map visualization [23] utilizes live camera feeds to track and reconstruct virtual representations of dynamic real world objects, such as cars and people. The virtual representations are then correctly overlaid on a planar map-view plane of the environment, matching the location of their physical counterparts in the physical environment. We suggest applying similar techniques to the augmented viewport, by utilizing the remote cameras. The positions of dynamic objects can be triangulated from overlapping remote cameras or the user's viewpoint. Once the locations of dynamic objects are known, we can increase the flexibility in aligning virtual objects to dynamic physical objects, to improve precision in object manipulation.

## *2.5 Input devices*

We plan to improve input devices to achieve higher task precision. Considering that even with close hand operations, manipulation tasks are still affected by freehand and sensor errors. We are motivated to design new input devices to support discrete movements for translation, rotation, and scale. The devices will be required to satisfy the guidelines for wearability design [24] such as body placement, appropriate shape, fitting, and most of all, supporting intuitive task execution. One of the most important constraints for input devices for mobile AR system is portability. On the one hand, new input devices should not encumber the user nor hinder with other tasks while not in use. On the other hand, we are interested in the design of new input devices to reduce freehand errors, thus requiring certain tactile feedback and discrete movements. How can a design of new input devices both support a high level of tactile feedback and be uncumbersome and highly wearable?

The augmented viewport technique may benefit from the design of new input devices to support data entry. Desktop-based CAD applications utilize menus, dialogs, or toolbars to allow direct input of exact measurement data from the user. This approach has the highest level of precision; however, it is the least supportive of direct manipulation and contextual visualization.

Text input is an ongoing research problem in the areas of wearable computing and mobile augmented reality systems. Over the years, we have seen solutions developing from physical devices such as belt-mounted mice, forearm keyboards, to virtual onscreen keyboards [25]. Design towards wearability achieves the solution of a glove-based text input mechanism, called the Chording glove [26]. The glove maps combinations of finger presses on one of the hands and a control button press on the other hand to a table of characters. Hand gestures have also been investigated for intuitive textual input. The work by Liu and colleagues [27] presents a technique to allow the user to form hand gestures or perform writing in midair to provide input into the system. Interest in speech recognition for hands-free text input for wearable computers is also prevalent. The various challenges for speech input are distortion and ambient/environmental noises, accuracy, and simultaneous cognitive load [28,29]. The requirements of specific outdoor AR applications, and the wearabiity and usefulness of the newly designed input devices need to be considered before deciding on the feasibility of new input devices for data entry.

Within the domain of text input for precise manipulation, however, the requirements are more confined. We are only required to support input of digits and common symbols for measurement inputs, instead of the whole alphabet. The Twiddler keyboard, a handheld input device with a 3 x 4 button matrix, achieves up to 60 words per minute in typing speed [30]. Typing speed is not a requirement for measurement inputs, considering that the input task is only conducted on as-needed basis. It is required, however, to be convenient and effortless, so as not to interfere with the current manipulation task at hand. Therefore, the focus on high wearability, such as comfort of use, as mentioned previously, is more important.

## 3 Conclusion

We have presented our research position in the problem of precise action at a distance for outdoor AR systems. Based on our technique of the augmented viewport, we have identified current research challenges, including the utilization of various types of remote cameras, collaboration features, better visualization of the cameras' views, precision by snapping, and improved input devices.

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