# Wearable Laser Pointer Versus Head-Mounted Display for Tele-Guidance Applications?

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## Abstract
Wearable camera and display technology allow remote collaborators to guide activities performed by human agents located elsewhere. This kind of technology augments the range of human perception and actuation. In this paper we quantitatively determine if wearable laser pointers are viable alternatives to Head-Mounted Displays for indicating where in the physical environment the local agent should direct her/his attention. The potential benefit of the laser pointer would be reduced eye fatigue, due to the fact that the documented refocusing challenges associated with HMD use would be completely eliminated. 10 participants where asked to perform a short tele-guided pick-and drop task using both approaches. The quantitative analysis indicates that user performance in the laser pointer condition is higher than the HMD approach (P $=$ .064, $\alpha = 0.1$). While all 10 participants found the task easy in both conditions, 8 of 10 participants found the laser pointer system more convenient.

## Author Keywords
Remote collaboration, tele-presence, tele-pointing, head-mounted display, laser pointer, wearable computers.

## Introduction

Tele-presence technologies facilitate collaboration over distance by allowing domain experts to oversee and guide work processes in cases when they do not have the possibility to be physically co-located. Healthcare, mining, and maintenance are classical applications. In this paper we compare one of the most investigated approaches for presenting information to the person being guided (the HMD approach) with one much less explored: the use of wearable motor controlled laser pointers. Instead of presenting information on a semi-transparent display in front of the human agents eye(s), information is instead projected directly into the physical environment.

*Head-Mounted Displays for telepointing applications*

Wearable tele-guidance systems allow remote users to have a situational awareness of the current task environment also in mobile settings, while traditional stationary tele-conferencing systems tend to constrain activities to fix locations. A typical mobile setting includes, on the local side (the location where someone needs support), a head-mounted display (HMD), a head-mounted camera that captures the field of view of the wearer, and a small wearable processing unit connected wirelessly to a remote computer. This specification adequately describes state of the art HMD solutions offered by for instance Vuzix and Google. As HMDs become smaller and less obtrusive, they become interesting candidates for a growing set of mobile interactive applications including tele-presence and tele-pointing.

However, the new emerging HMDs still suffer from known limitations and challenges. Social acceptance, eye fatigue, and focusing problems are well documented (e.g. [8]). Laser pointers could be an interesting alternative for certain kinds of remote collaboration. While HMD tele-pointing solutions often rely on a video see-through Augmented Reality approach where the pointing cursor appears together with a video image of the local environment pictured on the HMD, laser pointer solutions show the remotely controlled pointing cursor directly in the real world environment. Thus, there is no need for the user to change focus depth or perform cognitive work to align the streamed image with the real world. However, the display of more complex content (beyond a point cursor) can be more challenging than when using the pixel matrix offered by HMDs.

*Laser pointer Versus Head-Mounted Display?*

Previous studies on remote collaboration systems have mainly focused on evaluating just one of these technologies in isolation or in combination [8]. We argue that the laser pointing approach alone could be an interesting alternative for tele-pointing applications. If performance on isolated single-person tasks such as the one investigated in this paper turns out to be comparable, laser pointer solutions could potentially outperform HMD-based solutions for a) very intense telepointing tasks where HMDs would cause fatigue, and b) for tasks where sharing of the remotely provided tele-guidance information with co-located peers is an advantage.

## Related Work

Remote guidance technologies fall into three main categories: (1) stationary systems, (2) robot-mounted technologies, and (3) wearable solutions. In the stationary approach, a remote expert provides guidance to a local user by drawing or pointing to a specific object in the task space. This graphical information could be displayed on a monitor over the video streaming from the local side, or it could be overlaid on the physical objects by a stationary laser pointer [10]. In the robot-mounted systems, the combination of a camera and a laser pointer on a movable machine [12] or on a robot [7] allows a remote user to control laser pointer and point to any particular object. Wearable tele-guidance systems have typically been designed to support mobile users. A head-mounted camera carried by local users share their view of the real world and what they are doing with a remote collaborator. The remote instructor provides some graphical instructions, which could be visible for the local user through a HMD [1] or using a combination of HMD and laser pointer [8].

The types of remote guidance found in literature can be classified into four categories [5]: (1) cursor pointer (the local pointer follows the remote instructors mouse pointer); (2) laser pointer (the local laser pointer rests at a location determined by the remote instructor through a mouse click), (3) sketching [2] (the instructor draws figures, not just points), and (4) hand gestures (a representation of the instructors hands are shown to the local user). While previous studies have proved the superiority of the digital sketches over cursor pointer [3], and faster performance of hand gestures, no significant difference has been reported between user performance when receiving information projected directly onto physical objects vs. information displayed on an external monitor [6] such as the study presented in this paper. Finally, a combination of laser pointer and HMD has been proven to lead to a significant improvement in task completion time [8].

Another alternative to the laser pointer technology for Augmented Reality systems is using pocketsize Pico projectors [4], but the luminance of the state of the art projectors is less than laser pointers which limits the applications of portable projectors to indoor and low-light conditions. However the complexity of the content that can be projected by Pico projectors is much higher than laser pointers.

Stationary laser pointers have also been explored as an alternative to HMD for Augmented Reality applications [9] but our study is the first attempt to develop and evaluate a wearable laser pointer as an alternative to HMD for remote collaboration.

## Research Question

Given the known challenges of HMDs such as eye fatigue, is motor-controlled laser pointer technology a viable alternative to HMDs for mobile remote guidance applications? We intend to answer this question by measuring user performance in both cases given the same tele-pointing task.

## Experimental Design

To compare the task performance of users wearing both the head-mounted display (HMD) and wearable laser pointer, we conducted a comparative within subjects study. The study explores the response times of participants for a simple pick and drop task while being instructed by a remote instructor.

The experiment design was inspired by previous work in tele-guidance systems and special care was taken to reduce uncontrollable noise and to not bias the experiment in favor of any of the two conditions. For both conditions, no image/pointing stabilization system was used and only nearby objects were pointed at.

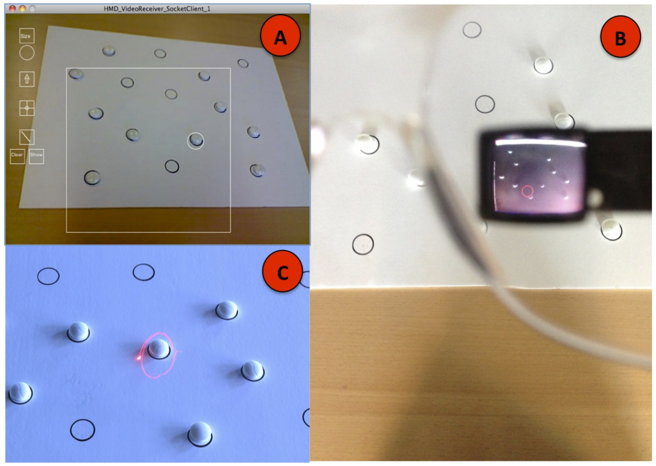


**Figure 1:** The user interface of the helper station (A), HMD-based system (B), and Laser pointer system (C).

## Technical Setup

Both of the wearable remote guidance systems consist of two main components: a wearable system for the local user and the separate helper station which is controlled by the remote instructor. Both the user interface (UI) of the helper station (Figure 1A) as well as the remote instructor using it remained identical for both the laser and HMD condition throughout the whole experiment. The white square-shaped border in the UI (Figure 1A) indicates the area of the local environment to which the remote instructor can point remotely. Since the motor-controlled laser pointer did not cover the whole field of view of the camera, the same limited square-shaped pointing area was enforced also for the HMD condition. Although four different symbol presentations are supported by both systems (dot, circle, line, and polygon) we only made use of the circle symbol. The helper station communicated to the wearable systems through a WIFI network over the UDP protocol with very limited latency.

*HMD-based system*

In order to build a video-see-through HMD, we attached a webcam (1.3 MP) previously embedded in a laptop and a HMD (MicroOptical SV-9, 640×480 pixels) to an ordinary laptop (Macbook Pro 13 inches) residing in a backpack (Figure 2E).

*Laser pointer system*

The wearable laser pointer system consists of a similar laptop computer connected to a microcontroller to control a pair of galvanometers. The galvanometers have two mirrors to change direction of the laser point in X and Y dimensions. The galvanometers, laser pointer, and a laptop webcam (1.3 MP) was mounted on a helmet (Figure 2D). The maximum angle of the galvanometer is $30°$ which is slightly less than the maximum range of the camera $(40°)$. Therefore, we limited the pointable area to the white-bordered square shown in Figure 1A. In laser pointer systems, there is always a potential displacement between the intended (clicked) points on the screen and the actual laser-highlighted position in the real world. One mitigation strategy is to calibrate the system for different distances and use a depth sensor to adapt. Our approach was to place the camera very close to the laser pointer (<1cm) and calibrate the system for an average distance (2m) resulting in an accuracy of <5 pixels of error in the range of 1 to 5m.

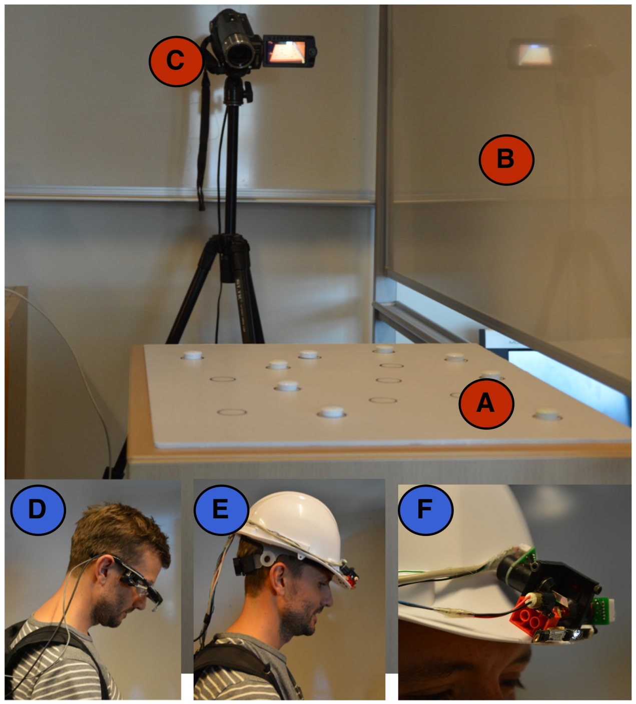


**Figure 2:** The experimental setup consisted of (A) a desktop with a number of magnets and indicators, (B) a separator to visually shield the remote instructor from the participant and (C) a high-resolution camera to capture the interaction between the participant and the board. The apparatus used for the experiment was a (D and F) custom-built remotely controlled laser pointer and (E) an off-the-shelf HMD.

*Participants*

10 participants (mean age=35, 1 female) were recruited to participate in the experiment. Participants were all highly skilled computer users ($\bar{X} = 5$, $\sigma = 0.7$). The setup consisted of a table with a white board containing a number of circular indicators and physical magnets (Figure 2A), a separation screen to visually separate the remote instructor from the participant in an effort to emulate remote guidance (Figure 2B). The entire experiment was captured in 1080 60p full HD video (Figure 2C) which was manually post-hoc annotated to measure the response times of the users.

*Apparatus*

In the laser pointer condition (Figure 2D), a custom-built remotely controlled laser pointer projected information directly into the real world environment. In the HMD condition, a head-mounted monocular display was used onto which the remote pointer information was displayed, blended with a video image of the environment in front of the participant. Both conditions included a wearable camera that allowed the remote instructor to see what the participants had in front of them.

In both conditions, the remote instructor could point to a specific magnet on the board (see Figure 2A) using a physical (in the laser pointer condition) or a digital (in the HMD condition) tele-pointer. The guidance system running on a computer at the remote end allowed the remote instructor to use four types of pointers, but only the circle was used in this experiment:

*Procedure*

The experiment started with a short introduction to the purpose of the experiment and the use of the apparatus. After participants were prepared for the experiment (for both conditions), they were asked to use the system until they felt comfortable. This usually took 1-2 minutes. Next, the participant was asked to complete the main task. The task consisted of picking up and dropping the magnet that was indicated by the remote instructor. The participant sees this indication either through the laser physically pointing to the board (in the laser pointer condition) or through the video overlay in the HMD (in the HMD condition). Participants were requested to return to a fixed starting point after picking up or dropping each magnet, in order to reset the experiment in between each pick-and-drop operation. After the tasks were completed for both conditions, the user was asked to complete a short questionnaire with 5-point likert scale questions polling their experiences completing the task and using the system. The experimental setup was randomized to balance conditions.

## Results

*User Performance*
We measured the completion time for single pick-and-drop operations for each participant. In order to calculate the time needed for a participant to grab or drop a magnet, we annotated the video of the experiment and extracted the completion time for each pick and drop operation in both conditions. Start and stop time for each operation was determined by the entrance/exit of the hand into the video frame captured by the camera shown in Figure 2C. Three of the ten participants at times used both their hands to move the magnets. Those data samples were removed. After removing outliers the sample size of the HMD condition was 138 while we had 137 pick-and-drop samples for laser pointer. For the HMD condition, the average time for a pick-and-drop operation was about 0.81 seconds with a standard deviation of 0.23. For the laser pointer condition, the average completion time was 0.77 seconds for each operation, with a standard deviation of 0.16.

The statistical t-test indicated that the pick-and-drop completion time in the laser pointer condition is significantly less than task completion time in the HMD condition (P = .064), confidence interval 90 percent.

*Questionnaire*
8 out 10 participants preferred using the laser pointer over the HMD, as they argued that using the HMD was significantly more tiring for their eyes (HMD $\bar{X} = 4$, $\sigma = 0.81$ see Table 1) than using the laser pointer (laser $\bar{X} = 1.5$, $\sigma = 0.52$). Completing the task was perceived as slightly easier using the laser pointer ($\bar{X} = 4.3$, $\sigma = 0.48$) than the HMD ($\bar{X} = 3.4$, $\sigma = 0.85$). Finally, participants argued that the visibility of the indicator was higher in the laser pointer condition ($\bar{X} = 4.5$, $\sigma = 0.70$) than the HMD (HMD $\bar{X} = 3.9$, $\sigma = 0.99$).

**Table 1:** The questionnaire results

| Questions | min | $\bar{X}$ | Max | $\sigma$ |
|---|---|---|---|---|
| Completing task using HMD was easy | 2 | 3.4 | 4 | .85 |
| Completing task using laser was easy | 4 | 4.3 | 5 | .48 |
| Using laser pointer was, eye-tiring | 1 | 1.5 | 2 | .52 |
| Using the HMD was eyes-tiring | 3 | 4 | 5 | .81 |
| Indications on HMD were easy to see | 2 | 3.9 | 5 | .99 |
| Indications by laser were easy to see | 3 | 4.5 | 5 | .70 |

*Open Comments*
Application ideas provided by participants included telemedicine, technical assistances for car repairment, guidance of art students to learn how to paint, or even remotely guided shopping.

## Discussion and Conclusion

We have investigated the use of laser pointers as an alternative to HMDs for tele-guidance applications because 1) previous studies [11, 8] have reported on a number of challenges connected to HMDs such as focusing problems, eye fatigue and etc.; 2) no previous adequate comparative study could be found. The results of our experiment showed that laser pointer solutions can perform better than HMDs for simple tele-pointing tasks (P = .064; confidence interval 90percent). During our experiment, participants needed to switch only once between the digital image shown on the HMD to the surrounding physical world. For tasks with higher frequency of focus shifts, we expect a higher difference between two conditions; however, the complexity and amount of information that can be displayed by laser pointer is still much less than HMDs. Such an example would be the case of remote guidance during surgery (future investigation), in which the surgeon in the HMD condition would need to keep looking at the patients internal tissues, switching from digital view on the HMD to the real world and vice versa. Moreover, the visibility of the laser point depends on many factors such as lighting condition, distance, color, and texture of the projected surface which is a limitation for the laser pointing approach. More empirical studies are needed to determine the strengths and weaknesses of both pointing approaches given certain application contexts. For future work we intend to design a more complex experiment to further investigate the performance of the two approaches and also add performance accuracy to the set of measured parameters. Both systems will also receive a pointing stabilization component in order to become directly useful in real world tasks outside the lab.

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