Practical Paper

Virtual Reality Applied to User Interfaces for Digital Photogrammetric Workstations

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Abstract

The use of an all-photogrammetric mouse as an alternative to other input devices for softcopy photogrammetric systems is proposed. With this interface, the operator's hand movements are linked to the floating mark by means of a real-time hand monitoring system. Two cameras positioned underneath the operator's hand locate and track one or more light spots attached to the hand. Through a feedback loop, the user has the feeling of directly manipulating the floating mark by hand in the stereomodel. Besides being more intuitive than the existing interfaces, the proposed one offers the possibility to measure distances as well as terrain facets in only one operation. Time savings of up to 45 percent are reported for DEM *collection.*

Introduction

Since the introduction of stereoscopic plotting instruments, different types of human-machine interfaces have been invented. A brief historical review of them may be useful in the present context. The main purpose of plotter interfaces was (and still is today) to manipulate a measuring mark in the photogrammetric model space. With early plotters, such as the Kelsh, an illuminated dot on the platen supported by a tracing table was used to materialize the floating point. This table could be freehand manipulated in the projection plane. It also included an additional screw to raise or lower the platen. Since then, *X*- and *Y*-handwheels have become very popular in optico-mechanical instruments. Connected to gear boxes, they generate planimetric displacements of the floating mark in the stereoscopic model. The elevation of the floating index is generally modified using a footwheel. With analytical stereoplotters, despite the fact that handwheels are connected to encoders, the same kind of interfaces are utilized. Although they have the advantage of providing finer movements of the floating mark, they significantly reduce the natural approach and feeling that characterize the manipulation of the mark by hand. The cause of this drawback is the breaking down of the displacements of the floating point into their three spatial components. Hence, some training is always needed before being able to generate fluid movements of the floating mark.

With the arrival of softcopy photogrammetry systems, new devices, such as computer mice, digitizing tablets, and keyboards, have replaced mechanical interfaces. These provide considerable improvement in comparison to mechanical hand and footwheels for a couple of reasons. First of all, they are physically less demanding to operate, and secondly, the planimetric displacements are, as they were originally, freehand generated. Nevertheless, the altimetry manipulation is still decoupled from the planimetry and, consequently, another height control must be operated. Of course, with a little practice, operators can overcome this situation and they develop an almost natural habit. However, as Koenderink (1993) mentioned, with the evolution of the technology, it is now the machine that must adapt to the human being and not the converse:

> In many complex systems the human operator remains a vital link. In practice it is often the weakest in the chain. Now, it is no longer realistic to train a human to fit to a machine. Since machines have become so flexible, they can be tailored to exploit human abilities to the full extent.

With respect to this philosophy, a new photogrammetric input device is introduced in this paper. It is based on the tracking of an operator's hand using a digital photogrammetric measuring system. Preliminary tests demonstrate the user-friendliness and the new possibilities offered by this input device.

Photogrammetric Mouse Concept

In today's high-tech world, an increasing number of teleoperated devices are utilized. Examples of these are deep-water exploration submarines or police robots for bomb destruction or other dangerous missions. As the word says, the concept of teleoperation can be simply defined as the manipulation of a given device from a distance (a more rigorous definition can be found in Held and Durlach (1993)). With stereoscopic plotting instruments or with softcopy photogrammetric systems, the manipulation of the floating point can be viewed as the teleoperation work if the floating point is assimilated to a device having the potential of moving in the model space. Teleoperations are possible provided that a feedback loop exists between the command and the action generated. In stereophotogrammetry, this feedback is supplied by the operator's visual perception of the mark relative to the ground.

In the quest of developing a better interface to teleoperate the floating point, the criterion of user-friendliness is of prime importance. There is no doubt that this requirement would be perfectly fulfilled if the interface would allow the operator to "grab" the floating point and move it to the feature to be measured in the model space. This way, the operator's natural psychomotor abilities would be employed without any conscious effort. A good example of this kind of natural interface can be found in restaurants where waiters generate bills by simply touching a computer sensitive screen. To reproduce that kind of natural and intuitive user-computer interaction in the context of softcopy photogrammetric systems, a close-range photogrammetric measuring system has been modified (Boulianne *et al.*, 1992). This sys-

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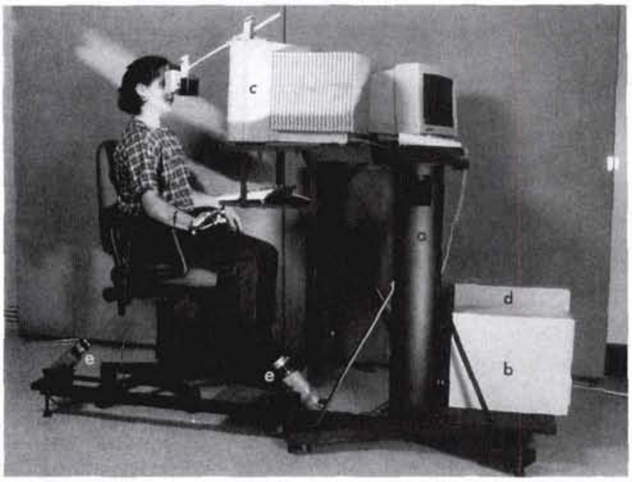
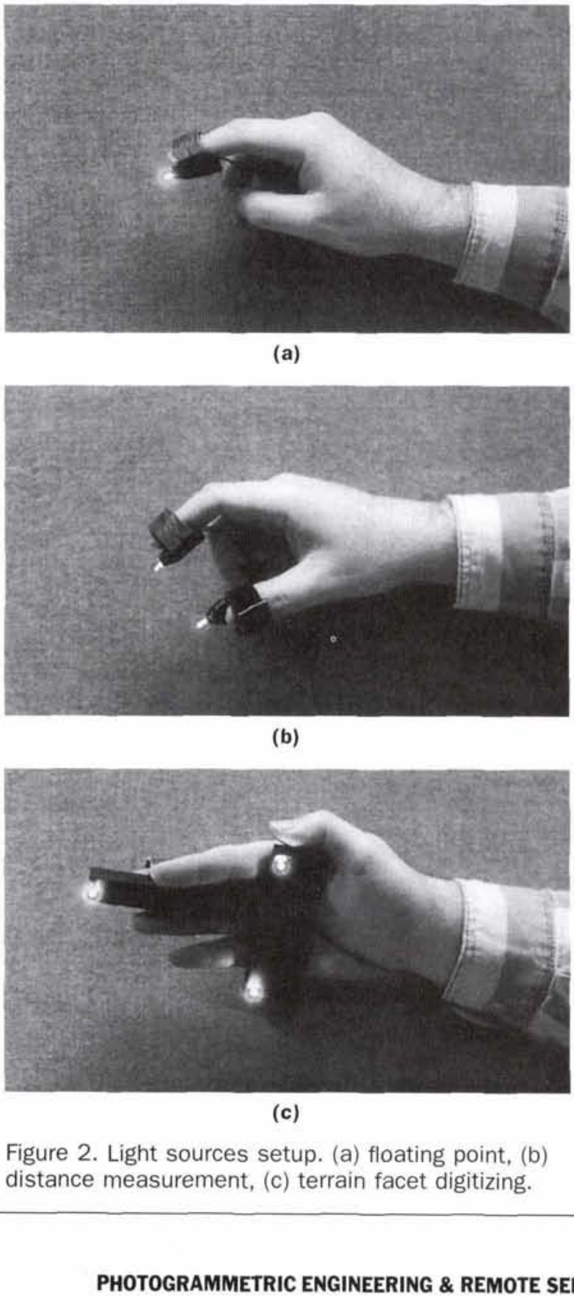


Figure 1. Global view of the photogrammetric workstation. (a) central pillar, (b) main computer, (c) stereoscopic display, (d) photogrammetric mouse computer, (e) CCD cameras, (f) light apparatus.

tem, based on two digital cameras, has been transformed into a "photogrammetric mouse" (the term mouse has been kept because of its wide acceptance in the computer science community, even though the photogrammetric hand-tracking system has little resemblance to a real mouse). Its main function is to position and keep track of a light spot attached to the operator's hand. With this approach, the operator can manipulate the floating mark with natural hand movements. Apart from the fact that the operator does not have the feeling of being present in the model (something known as telepresence), this approach shows certain similarities to virtual reality systems.

In the present research, the photogrammetric mouse concept has been implemented in the DVP™ softcopy system, but could be easily adapted to other systems. With the DVP, stereovision is provided by a simple mirror stereoscope placed in front of a split screen (Gagnon *et al.*, 1990). Figure 1 shows the different parts of the workstation prototype equipped with the photogrammetric mouse interface. A mobile central pillar supports (1) a computer dedicated to the photogrammetric processing; (2) a split screen with a mirror stereoscope; and, finally, (3) a second computer driving two CCD cameras. These cameras are positioned underneath the operator's hand (front or rear) looking upwards. A light bulb, linked to a power supply unit, is attached to the operator's hand using velcro bands (Figure 2a). This light apparatus neither restrains movements nor causes discomfort. To facilitate the detection of the incandescent light spot, infrared filters are placed in front of the CCD camera lenses (Boulianne *et al.*, 1995). Real-time video signal digital conversion is obtained using a Meteor™ RGB frame grabber from Matrox, Inc.. Basic ergonomics rules were seriously considered when designing the photogrammetric workstation. This has led to a very relaxed operator position. Also, to reduce operator fatigue, the chair armrest provides a complete forearm support.

As with any teleoperation system, manipulation of the floating mark by hand monitoring can be affected by systematic distortions. In general, such distortions produce movements of the teleoperated device not congruent with the operator's commands. Regarding distortions, Grunwald states that: "*The success of a teleoperated device depends on whether and to what extent the human is able to adapt to these distortions*" (Grunwald, 1993). Among these are rotations, translations, and scale factors between the operator's coordinate system and the one in the device space. To illustrate the distortion problem, it is easy to imagine the difficulty that one operator would encounter during the teleoperation of the floating point if a hand displacement to the right produced a displacement to the left in the model. Such distortions are easily handled by establishing an adequate correspondence between the space surrounding the operator's hand and the stereoscopic model. This is achieved (1) when hand displacements along the direction defined by the operator's shoulders are translated into horizontal movements of the two indexes on the display; (2) when horizontal movements perpendicular to the preceding direction produce vertical displacements on the screen; and, finally, (3) when upwards and downwards movements raise and lower the floating point in the stereomodel. In addition, because of the feedback loop and because of human adaptability, the operator will naturally compensate if small systematic errors still remain. This compensation will be automatically realized by correcting the hand position until the floating mark is displayed at the location which the operator judges to be the right position in the model.



(a)

(b)

(c)

Figure 2. Light sources setup. (a) floating point, (b) distance measurement, (c) terrain facet digitizing.

Time delays between the operator's command and the reaction of the remote device can be a more critical distortion in the present context. Indeed, it has been shown that delays longer than 300ms significantly degrade the quality of a teleoperation (Held *et al.*, 1966). With the vision system presented in this paper, the feedback loop involves the digital conversion of two video signals, the detection of one or more light sources in the images and, the computation of the spatial position. Among the different commercial frame grabbers, the Matrox Meteor™ RGB card has been chosen for its capability to digitize a video signal in real time. In this application, real-time capability represents a digital conversion rate of 30 frames per second at a resolution of 640- by 480- by 24-bit color pixels. When black-and-white images are used, up to three monochrome cameras can be connected to each individual channel, allowing the simultaneous digital conversion of multiple video signals. For the prototype photogrammetric mouse, two COHU monochrome cameras were connected to the red and green input channels, respectively, of the frame grabber. This scheme implies that the cameras have to be synchronized for the grabber to operate properly, as if only one color camera were used. Therefore, a synchronization signal is supplied by the front camera to the rear camera and to the synchronization input of the grabber (Figure 3). In addition, to improve acquisition time in comparison to employing two sequential grabs, this strategy insures that the front and the rear frames are taken at exactly the same moment. This is important to determine accurately the position of the light source(s) in the hand space.

The Meteor frame grabber has no existing memory and instead uses the host computer memory to store the images. Providing that enough host memory is available, several image buffers may be allocated to the process. The implementation of the photogrammetric mouse described here uses two RGB image buffers. A very interesting characteristic of the Meteor grabber is its capability to work asynchronously with the computer CPU. This means that the frame grabber can digitize and store an image in one buffer while the CPU accesses the other buffer to perform some image processing operations (detection of one or more light sources in the images and space intersection). Because the image processing time is shorter than the grab time, the CPU waits until the Meteor card indicates the grab completion. The processor then sends to the frame grabber the order to start a new grab in the just-processed buffer, and begins to process the just-filled buffer. After each concomitant grab and processing cycle, the mouse system verifies if there is a request for data from the photogrammetric application computer. If so, the most recent computed data are immediately transmitted. Information exchange between the two computers is done via serial ports at a 19,200 baud rate. This process runs continuously until the photogrammetric application system emits a stop command. With this combination of hardware and software, the hand location system can provide a position roughly once every 38 ms, or eight times faster than the minimum feedback response time mentioned earlier.

Multi-Input Device

In addition to the more natural way to teleoperate the floating point, the most important advantage of the photogrammetric mouse concept is to offer the possibility to maneuver more than one index at the same time. For example, if two light sources are placed on two opposing fingers (Figure 2b), distances can be directly measured in only one operation. Extending this idea, terrain facets can be digitized in a one-step operation by using a T-shape pointing tool with three light sources (Figure 2c). The operator's duty is then to put his or her hand in virtual contact with the ground surface in the stereomodel while the vision system is monitoring the hand position and attitude. To avoid data redundancy, a special triangular distribution and measurement strategy must be followed. As shown in Figure 4, only dark triangles have to be measured; the other triangles are derived from the collected information. In theory, the possibility to measure more than one floating point at a time should significantly reduce the data acquisition time. However, this strategy rests on the hypothesis that one operator can manipulate, in an efficient manner, two or three points simultaneously. Some practical tests presented later on will shed some light with respect to that.

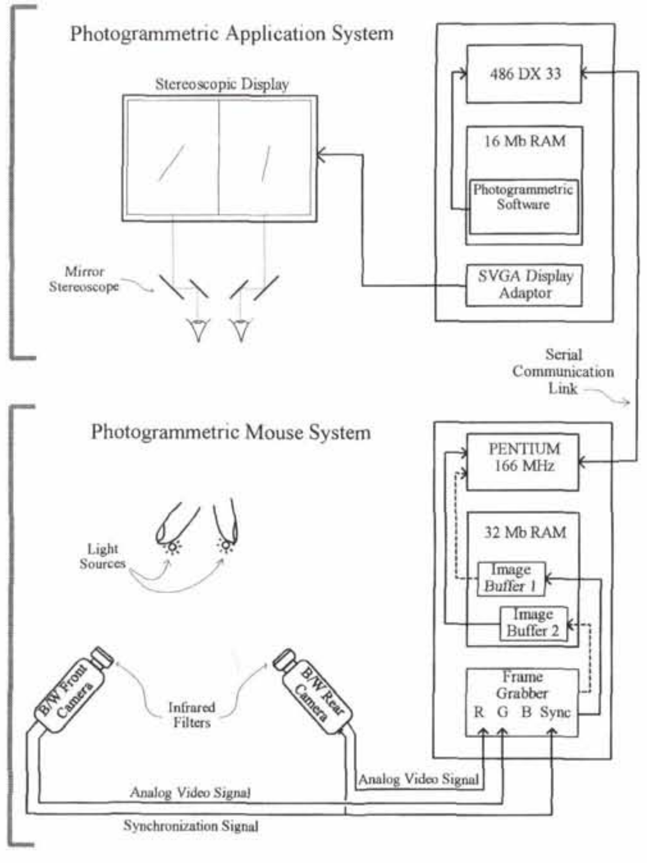


Figure 3. Photogrammetric mouse interface.

Stability Considerations

Hand manipulation of the floating mark(s) is affected by some stability problems. Despite the fact that the operator's elbow rests on the chair armrest, it is almost impossible to hold the hand perfectly still. This generates constant changes in the position of the floating point(s). To avoid this disturbing effect, a stabilization scheme has been implemented in the proposed interface. It consists of monitoring the hand stability over a short period of time (e.g., 1 second). When the hand displacements stay within a certain volume during this preset period, it is assumed that the movements are not intended and that a measurement is about to be performed. At this moment, the vision system sensitivity is automatically lowered, leaving small trembling movements undetected. To regain the original sensitivity, the operator only needs to move the hand a distance that exceeds the stability criteria.

Practical Results

Three preliminary tests were conducted to verify the performance of the photogrammetric mouse interface relative to

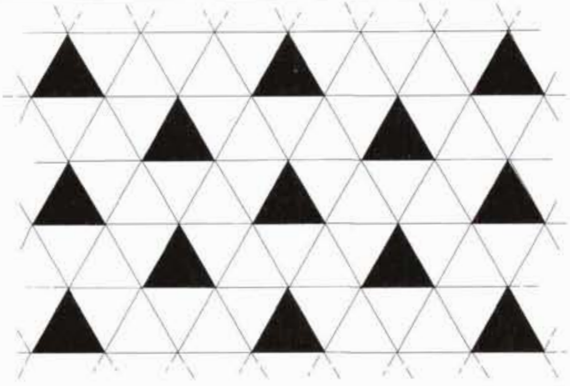


Figure 4. Triangles in staggered rows.

the conventional one. The first test targetted the estimation of the precision of the photogrammetric mouse when a unique floating point is manipulated. For this test, a pair of 1:6,000-scale photographs of a residential sector was selected. The photographs had been previously scanned at a resolution of 600 DPI, giving a planimetric pixel size of 24 by 24 cm and, considering the height-to-base-ratio, a pixel height of 40 cm at ground scale. After a complete model orientation with the DVP photogrammetric softcopy system, a set of five arbitrary points were measured ten times, in a round of operations, with the conventional mouse/keyboard interface and, subsequently, with the photogrammetric mouse. With the new interface, a root-mean-square error (RMSE) of ± 5 cm in X, ± 6 cm in Y, and ± 7 cm in Z at ground scale was calculated. This corresponds approximately to one-fifth of a pixel. Also, knowing that the usual DVP accuracy is about one-half of a pixel, it may be concluded that the photogrammetric mouse interface is equivalent to the conventional one in terms of precision.

Regarding time, the measurements took 13 minutes 2 seconds using the photogrammetric mouse compared to 11 minutes 7 seconds with the standard interface. This longer time may be explained in part by the fact that all of the selected points were at approximately the same height, which does not allow the new interface to show its real potential. Nevertheless, considering this fact and with further refinements to the photogrammetric mouse piece of software, it is safe to conclude that the new interface is a viable solution to manipulate the floating point.

For the second test, the same stereoscopic model was used. This time, the purpose was to evaluate the efficiency of the direct-distance measurement capability. The diameter of nine circular swimming pools was measured using the conventional technique and also the proposed one. In comparison to the results obtained with the usual interface, an RMSE of ± 21 cm was calculated, which is smaller than the planimetric pixel size at ground scale (24 cm). In addition to proving the possibility of direct-distance measurements, this experiment shows a gain in terms of time of 25 percent (2 minutes 2 seconds against 1 minute 30 seconds).

Finally, the possibility of digitizing terrain patches was tested. A stereoscopic model of a terrain showing slopes up to 30 percent was used. The ground pixel size was 85 cm in planimetry and, considering the base-to-height ratio, 1.43 m in altimetry. A network of 560 triangles had been previously established respecting the regular planimetric distribution of Figure 4. The elevation of each vertex of the triangles was first measured with the conventional interface. Subsequently, the photogrammetric mouse was used to digitize the terrain triangle-wise, and the accuracy of the results was compared. An RMSE of ±1.45 m in height was obtained. As this corresponds to the height of a ground pixel, this result is again acceptable. Furthermore, the operation realized with the photogrammetric mouse resulted in a gain of time of 45 percent (6 minutes 57 seconds against 13 minutes 6 seconds).

Conclusions and Recommendations

To the authors' knowledge, this work represents the first time that a close-range digital photogrammetric system has been used in conjunction with a stereoplotter to serve as an input device. Like virtual reality systems, the proposed photogrammetric mouse gives the operator the natural feeling of directly moving the floating point by hand. If one considers the fact that softcopy photogrammetric systems are now reaching non-photogrammetrists, this kind of user-friendliness becomes more and more relevant when it comes to design a new interface.

Even though more practical tests should be carried out before establishing the exact performance of the photogrammetric mouse, the preliminary tests described in this paper showed a definite potential. This is especially evident for distance measurement and for digital terrain model generation, where time savings of up to 45 percent were noted without any significant loss of accuracy.

In the near future, the possibility to add some voice recognition capabilities to the photogrammetric mouse interface will be considered. This addition should respect the same strategy maintained in this paper, that is to say, human-machine interactions must be as natural as possible. In this regard, voice command is certainly the most intuitive way to communicate with a computer. By implementing only a few commands like Accept, Reject, Pen-Up, and Pen-Down, the operator's second hand could be completely free during data collection.

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