The Stringed Haptic Workbench: a New Haptic Workbench Solution

N. Tarrin, S. Coquillart, S. Hasegawa, L. Bouguila and M. Sato

1 i3D - INRIA Rhône-Alpes - Gravir-Imag(CNRS-INPG-INRIA-UJF)
nicolas.tarrin/sabine.coquillart@inria.fr

2 Tokyo Institute of Technology
hase/laroussi/msato@pt.titech.ac.jp

Abstract
The workbench is an interesting semi-immersive configuration for interactive tasks. However, haptic feedback, i.e. force and tactile feedback, is one important cue which is missing. To the authors’ knowledge, the sole proposed solution consists in installing an arm force feedback device on one-screen workbenches. This solution, however, has several drawbacks. The arm can perturb the stereoscopic display, cross virtual objects or hide parts of the visualization space. Furthermore, the interaction space is limited by the size of the arm, which may also damage the screen or perturb the electromagnetic tracking system. Some of these difficulties may even be worth with a two-screen workbench. This paper discusses an alternative solution, which consists in integrating a stringed haptic device on a workbench. This approach is less invasive, more flexible and well-suited to a two-screen workbench.

1. Introduction

The workbench (see Figure 1) is an interesting semi-immersive configuration for interactive tasks. Many applications require interactively manipulating data located in front of the user. For that purpose, the bench specificity of the workbench is very attractive. In this way, it is similar to the FishTank approach but provides a larger manipulation/visualization space and consequently a better immersion. It can also accept several users.

A large number of interactive applications, like virtual prototyping, modeling and virtual sculpting or scientific visualization have been proved to benefit from the addition of haptic feedback to the visual cue.

The workbench provides stereoscopic display, large screens, and head-tracking, but usually no force feedback. The lack of this important feedback cue was already stressed by W. Krüger et al., designers of the first workbench.

Adding force feedback capabilities to workbenches is not an easy task for two major reasons. First, there are not many types of force feedback devices and most of the existing ones are either heavy, invasive, expensive, or only work within a limited space. The second difficulty comes from the configuration itself. Most of the greatly appreciated benefits of the workbench turn out to be a constraint or even a difficulty for the integration of force feedback. The large size of the visualization space is very important to increase presence and immersion but few force feedback devices work in large spaces. Furthermore, the superposition of the visualization and the manipulation spaces made possible thanks to head tracking allows direct manipulation but complicates the integration of force feedback devices. The device has to be op-
rerational inside the display space, no scale factor is allowed, sufficiently accurate calibration must be provided, and the parts close to the hand and/or the handle have to be small enough not to hide the scene.

1.1. Previous Work

Lecuyer et al. experiment a portable system which could follow the user’s displacements in front of a two-screen workbench. The Wearable Haptic Handle (W2H) developed by CEA is made of two parts. The upper one is a small platform which moves in 6 Degrees of Freedom (DoF) according to the base one. The motion of the upper part is actuated by a wire-driven Stewart platform. The user feels the displacements of the platform inside his/her hand while interacting with the virtual environment. As indicated, the choice of the W2H is dictated by two important characteristics which differ from arm haptic devices like the PHANToM. First, the W2H has a wide workspace which can match the large visualization space of the workbench. Second, the W2H is small enough not to hide the user’s field of view and thus not to perturb the stereoscopic display of the workbench. Furthermore, the W2H is non intrusive, light, safe and cheap.

However, unlike a fixed-base haptic interface, the W2H cannot stop the user’s motion and does not prevent the user’s hand from penetrating inside a virtual object. In addition, Lecuyer et al. show that within the context of the experiment, the directional information of the W2H is difficult to understand and to use. The authors also show that the haptic information provided by the W2H does not have a positive impact on the completion time of the insertion task under study. According to this experiment, we believe that, at least for insertion-like tasks, a fixed-base force feedback interface is desirable.

To the authors’ knowledge, only two attempts to add fixed-base force feedback to workbenches have been proposed so far. The first one from the University of North Carolina and the second one from the University of Utah. Both approaches are in fact quite similar. Both consider a one-screen workbench and propose installing an arm force feedback device, in both cases a PHANToM, on it. Guaranteeing the largest manipulation space is an important concern in both cases. For that reason, they have decided to fix the PHANToM upside down, above the workbench screen. However, this haptic device does not offer a sufficient coverage of the large workbench’s visualization space, and several difficulties or limitations remain such as the risk of screen damage, occlusions, or possible perturbations of the electromagnetic tracking system.

1.2. The steps toward our approach

The work presented in this paper has been conducted on a TAN Holobench, which provides two 1.1m by 1.8m screens (one horizontal and one vertical) and a Polhemus FastrackTM electromagnetic tracker. For the reasons explained above, from the very beginning, one of our main concerns has been to add force feedback. Anecdotally, it is also amazing to note that during demonstrations on the two-screen workbench, about one person in two tries to touch displayed virtual objects with his/her free hand (the one which does not manipulate) no matter what the application is. Some persons even ask: “can’t we touch it?”.

The PHANToM approach was quickly abandoned for the reasons mentioned previously. In addition, we can anticipate that the limitation due to the size of the manipulation space is even worse with the two-screen workbench where the visualization space is much larger than with a one-screen configuration. The size of each screen is 110x180cm while the size of the manipulation space of the largest PHANToM device is approximately 42x52x82cm (0.18m³). Fixing the PHANToM above the horizontal screen of the two-screen workbench would also lead to worse occlusion problems as the arm would almost systematically pass in front of or even intersect the objects visualized in the upper part of the vertical screen.

Our interest lies in direct manipulation with force feedback, which requires to superimpose the space where forces are provided with the visualization space. Thus we also quickly abandoned all the force feedback systems which do not allow direct manipulation in the visualization space, such as joysticks or mice.

1.3. Stringed Force Feedback Devices

Several Stringed Haptic Interfaces have been proposed. They are composed of actuators providing a force through a set of strings adequately linked together or to a manipulation tool. A quick look at Stringed Force Feedback interfaces shows that most of them satisfy the desired properties i.e. fixed-base (but for the Haptic Gear), large workspace, and low intrusion. Additional properties like lightness, safety, or low cost are also satisfied. One of our main concerns was the perturbation of the stereoscopic display. Will the strings be visible on the workbench and would they perturb the stereoscopic display?

This paper introduces a new approach to perform virtual direct manipulation with force feedback. A Stringed Haptic Interface, the SPIDAR is proposed. Section 2 briefly describes the SPIDAR system. Section 3 presents the adaptation of the SPIDAR system on a two-screen workbench and Section 4 describes the software platform developed. The Stringed Haptic Workbench is proposed for a virtual prototyping application in Section 5. Finally, this configuration is discussed in Section 6.

2. The SPIDAR

The SPIDAR (SPace Interface Device for Artificial Reality) was chosen for its flexibility and its completion but other
The SPIDAR 2 allows force feedback on two distinct points, like the thumb and index finger, with 3 DoF each (3 translations). Four motors are necessary for each point. They are positioned on non-adjacent vertices of a cubic frame.

The SPIDAR for both hands extends this configuration to four distinct points (two fingers of each hand for instance) with 3DoF each. For this configuration, sixteen motors are needed (four for each point).

The SPIDAR G allows 6 DoF force feedback on one point (3 translations, 3 rotations). This point has to be materialized by a physical object such as a handle to deal with the 3 rotations. This configuration involves eight motors, one on each vertex of a cubic structure.

Finally, the SPIDAR provides 2 1/2 DoF force feedback on 8 points, with 3 motors per point. The points are associated to four left hand fingers and four right hand fingers. The missing 1/2 DoF corresponds to forces directed toward the space between the hands. This configuration is well adapted to two-hand manipulation of small objects like a Rubik’s cube.

Up to now, most SPIDAR systems have been proposed as desktop configurations. The only test with a large manipulation space offers a SPIDAR 2 installed in front of a one screen display wall. But, to the authors’ knowledge, a Stringed Haptic Device has never been installed on a workbench nor with head-tracked and stereoscopic display allowing direct manipulation of virtual objects.

3. Adapting the SPIDAR system to a two-screen workbench

Both hardware configuration of the SPIDAR 2 and of the SPIDAR G use eight motors. Offering a flexible system seems important to us, so we have chosen an 8-motor configuration. This allows to provide 3DoF force feedback on two points (SPIDAR 2) or 6DoF force feedback on a physical object (SPIDAR G) using the same hardware configuration.

As previously stated, one of our main concerns is to provide force feedback for direct manipulation within a sufficiently large space. More precisely, we want to fill as fully as possible the workbench manipulation space with the SPIDAR manipulation space (the space where the SPIDAR returns forces in every direction), also called SPIDAR space.

3.1. Workbench manipulation space

The workbench manipulation space can be defined as the intersection of two volumes. The first volume, called reachable space, gathers every point users can reach with their hands. We approximate this volume by the parallelepiped shown in Figure 2a. Note that this volume extends forward (from the user’s point of view) to approximately 2/3 of the horizontal space, the arm not being long enough to reach the last 1/3 of that space. On the opposite side, the volume extends beyond the border of the horizontal space as a virtual object can stand outside the parallelepiped formed by the two workbench screens (also named workbench parallelepiped). On the left- and right-hand sides, the volume does not extend as far as the border of the workbench screens because it is uncommon for a user to move far enough to reach this space.

The second volume is the visualization space. For a given position of the user, the visualization space is the cone defined by the user’s head and the screens’ borders. Due to head-tracking, the visualization space is defined as the union of the cones for every possible head position of the user (see Figure 2b).

Consequently, the workbench manipulation space is approximately defined by the intersection of these two volumes, shown in Figure 2c.

3.2. SPIDAR spaces

The SPIDAR space is directly linked to the position of the SPIDAR’s motors. We label the motors as in Figure 3. In the two-point, 3-DoF configuration, each point is actuated by four non-adjacent motors, (1, 3, 6, 8) or (2, 4, 5, 7), which are situated on the vertices of a tetrahedron (see Figure 3a). To obtain force feedback in every direction, the point has to be located inside its motors’ tetrahedron.

If each point is to be operated independently, the SPIDAR space for each point is defined by each tetrahedron. But if
one wants to use two points at the same location, if they are attached to two fingers of the same hand for example, the boundary of well stimulated positions becomes the octahedron intersection of the two tetrahedrons, shown in Figure 3b. As we want a flexible configuration that allows different interaction methods, we will consider this octahedron as the SPIDAR space.

3.3. Fitting the spaces

Ideally, the SPIDAR space should include the workbench manipulation space but the larger the SPIDAR space is, the less accurate the manipulations will be. In addition, the size of the room may be limited and one does not want the SPIDAR interface to occupy too large a space.

The first approach which comes to mind consists in positioning the motors on the vertices of the workbench parallelepiped, as shown in Figure 4.

This approach has the advantage of offering six of the eight motors’ fixation points needed and of not making the configuration bulkier than the workbench itself. This configuration leads to a SPIDAR space of $0.3 \, m^3$. It is almost twice the size of the PHANToM space ($0.18 \, m^3$). But the size of the workbench manipulation space not covered by the SPIDAR space is $0.85 \, m^3$.

With this SPIDAR configuration, the octahedrons lower part lies on the center of the horizontal screen and is a point. This does not fit well with the manipulation space of the workbench. The SPIDAR space is not centered on the manipulation space and is far from being as large as desired in the manipulation space lower part. To provide better coverage of this part, we could imagine rotating the SPIDAR space so that one of the faces of the octahedron is supponed with the horizontal screen. Unfortunately, this solution is not realizable as it would require placing motors behind the screens.

The chosen solution consists in both widening the lower part of the SPIDAR space and stretching the SPIDAR space down and in the direction of the user. For that purpose, motors 1 and 4 are moved approximately 20cm lower, 50cm to the side and 1m backward. Motors 5 and 8 are placed respectively above motors 1 and 4 (see Figure 5). The new position of motors 1 and 4 does not guarantee that their strings will not touch the frame of the horizontal screen. If so, the strings may bend and lead to errors. Note that this problem is minimized by the sideways and backward placement of the 2 motors which move them away from the workbench frame. Furthermore, the strings touch the workbench frame only when the stimulated point comes close to the horizontal screen, which is usually avoided for screen safety reasons. The resulting SPIDAR space size is approximately $1 \, m^3$ and the size of the workbench manipulation space not covered by the new SPIDAR space is now $0.37 \, m^3$.

Figure 6 shows the hardware installation. Motors 2, 3, 6 and 7 are directly fixed onto the workbench, while motors 1, 4, 5 and 8 are firmly fixed on rigid pieces of furniture. In the figure, the strings have been highlighted manually because they were not visible in the photo.

Strings are linked together to a finger cap, as shown in Figure 7.

4. Software platform

The software platform developed for this configuration provides a framework that links together visual rendering, haptic rendering and physical simulation. As visual rendering, haptic rendering, and simulation have different needs in term
of computing, they have been separated into different threads (see Figure 8).

The virtual coupling between the simulation and the haptic loop has been implemented following the spring/damper model. The haptic rendering loop gets the SPIDAR position, performs force computation according to simulation position, and sends commands to the SPIDAR via calls to the SPIDAR driver. Force feedback is enabled when collision occurs. As the simulation frame rate is variable, extrapolation is performed in the haptic loop.

The simulation loop computes collision detection and constraints applied to the objects. Objects’ positions are shared with the haptic and the visualization threads. The visualization thread displays objects on the workbench.

5. Application

Virtual prototyping (assembling and disassembling) benefits from the workbench direct manipulation and interaction fa-
It is one of the first applications we worked on and it motivated our wish to add force feedback to the workbench. The development of this first application on the Stringed Haptic Workbench is based on the software platform described above.

5.1. Simulation specificity

Among other things, virtual prototyping implies moving objects within encumbered areas. To provide users with the feeling of touching rigid objects, the simulation has to compute collisions between a point or an object representing the force feedback device and the objects of the virtual scene.

For this purpose we use CONTACT Toolkit, an interactive dynamics simulation library, which provides efficient continuous collision detection \cite{15, 17} and constrained motion computation \cite{16}. The continuous collision detection algorithms prevent the objects from any interpenetration during the interaction.

As a first approach, we used the one point 3DoF SPIDAR attached to the center of gravity of the manipulated object. For this example, we used a stylus linked to the strings instead of the finger cap previously described.

5.2. Example

The Renault car manufacturer provides us with a car door model, where an electric window winder motor has to be mounted. The user has to introduce the motor, move it in the door to its mounting location, and place it precisely (see Figure 9).

For this example, the update rate of the simulation goes from 10Hz to more than 1kHz, depending on collision complexity. The force feedback is updated at 250Hz, due to electronic command limitations. This is going to be brought up to 1kHz with new hardware.

6. Discussion and conclusion

First informal tests show that this insertion task benefits from the addition of force feedback. The fact that strings do not impact on stereo perception of the scene has also been verified in this application.

The main advantage of the Stringed Haptic Workbench is the size of its visual and haptic spaces. It allows direct manipulation on a far larger area than with previous haptic workbench solutions. Moreover, strings are extremely discreet. Users focus on the screens, and the strings do not ‘catch their eye’. Thus they appear blurred and are quickly forgotten while manipulating. The occultation is minimal and any part of the visualization space is visible. As concerns occultation, strings are no more, and perhaps less disturbing than the join between the screens.

The Stringed Haptic Workbench is a flexible configuration that allows the use of different interaction techniques. The 8-motors hardware setting gives the opportunity to use 3DoF force feedback on one point or 6DoF force feedback on a physical object. The SPIDAR does not perturb the electromagnetic tracking. Strings are metal free and the metallic parts of the system (motors, pulleys, and fixations) are situated far enough away from the tracking system.

Another advantage of this configuration compared to other haptic workbench solutions is that the hardware design of this system is safe. Mobile parts of the SPIDAR are so light (a few grams) that even in the worst situations, they cannot damage the screens. User safety is also improved for the same reason. In addition, the maximum returned force is limited by the strings’ resistance. If ever too strong a force is applied, the strings just snap, and the remaining part winds around their motor pulleys. Replacing broken strings is a fast and cheap operation.

As mentioned above, enlarging the SPIDAR space also reduces its precision. The precision problem is currently being addressed for medical applications which require high precision even with a smaller SPIDAR version. The results of this study should also be of benefit to the workbench version.

7. Future work

Further studies have to be undertaken to measure and improve the accuracy and the compliance of the system. Evaluations are currently being conducted and the virtual prototyping application is being tested on different industrial data sets. Other applications, like scientific visualization, are also under consideration.

This configuration makes it possible to try different new haptic interaction techniques and paradigms. Two hands, two fingers, 6DoF, or prop based haptic interactions are going to be studied.

The Stringed Haptic Workbench also offers new opportunities to better understand human perception and cognitive
For example, users no longer try to touch the virtual object with their ‘non-manipulating hand’. Furthermore, while only the tip of one finger is force stimulated, some users also tend to avoid objects with the rest of their hand, as if they believe it will also collide with virtual objects. Involved cognitive processes have to be studied in collaboration with psychophysicists specialized in visual and haptic integration.

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References


