

A 2D-3D Integrated Environment for Cooperative Work

Kosuke Nakashima^{*}, Takashi Machida^{*,}, Kiyoshi Kiyokawa^{*,**} and
Haruo Takemura^{*,**}**

^{*}Graduate School of Information Science and Technology, Osaka University,
Yamadaoka 1-5, Suita, Osaka, 565-0871 Japan

^{**}Cybermedia Center, Osaka University,

Machikaneyama-cho 1-32, Toyonaka, Osaka, 560-0043 Japan

nakasima@lab.ime.cmc.osaka-u.ac.jp, {machida, kiyo, takemura}@ime.cmc.osaka-u.ac.jp

Abstract

In the present paper, we propose a novel cooperative modeling environment that integrates both two-dimensional (2D) and three-dimensional (3D) modeling environments. The cooperative 3D environment is realized by employing an IllusionHole, while its mask region is used to provide a cooperative 2D environment onto which a 2D GUI is projected. A pair of 6DOF mice is provided to allow users to seamlessly switch between 2D and 3D workspaces. In addition, a palette-like operation plate is provided for seamless input and output in both 2D and 3D environments. A prototype modeling system was developed in order to demonstrate the potential of a workspace that is characterized mainly by an adaptive 2D GUI based on user position and the interoperability between 2D and 3D environments. A subjective evaluation supports the effectiveness of the developed system.

Key words: 3D user interface, 2D GUI, collaboration

1. Introduction

Traditional CAD/CAM systems allow users to design 3D objects using a 2D graphical user interface (GUI). In such a 2D modeling environment, the limitation in terms of the number of dimensions available for display and manipulation enhances usability. For example, a standard orthographic three-way (front, top, and side) view or a cross section is helpful in identifying the precise dimension of a 3D model. Manipulation of a 2D pointer (using a mouse or a light pen) on a 2D screen is supported physically and stably by either a desktop or the display surface. However, intuitively understanding the 3D geometry through 2D representation is difficult.

On the other hand, immersive modelers that use VR technology allow users to design 3D objects via stereoscopic viewing and direct manipulation. In such an environment, users can easily and intuitively understand and manipulate 3D objects, because the 3D information itself is accessed in three dimensions. However, manipulating three or six degrees of freedom

simultaneously in mid air without proper physical support is often difficult.

Since both 2D and 3D modeling environments have distinct advantages, it is expected that a workspace should integrate these environments in such a way as to make use of all of these advantages. ErgoDesk [1] and NIME [2] are good examples of an integrated modeling system that provides both 2D and 3D user interfaces for 3D design. Using these modelers, users are able to draw 2D shapes on a tilted display as a physical support and then extrude the drawn shapes as 3D geometric models in space using a 3D user interface.

Collaborative design is quite common in 3D modeling because collaboration allows the exchange of ideas between designers and/or customers. Although most traditional modeling systems are implemented as a single-user environment, a number of multi-user collaborative modeling systems have been developed. In such systems, several users can share the same environment and work together. Collaboration is classified into two types: (a) co-located collaboration (also known as face-to-face collaboration), in which users share the same workspace at a single location, and (b) remote collaboration, in which user audio-visual information is exchanged via a network between distant locations. In a co-located environment, users can easily communicate with each other using nonverbal communication cues such as gestures and facial expressions.

Co-CAD [3] and Teledesign [4] are typical 2D-GUI-based CAD systems that support remote collaboration, and VLEGO2 [5] is an immersive modeler that supports co-located collaboration. In VLEGO2, two users, each wearing a see-through HMD, face each other and build objects by assembling several simple 3D shapes.

In summary, 3D modeling environments are characterized by three features: a 2D user interface, a 3D user interface and multi-user collaboration (see Table 1). However, to our knowledge, no existing system has all

Table 1 Comparison of typical 3D modelers.

	2D	3D	Collaboration
ErgoDesk [1], NIME [2]	✓	✓	
Co-CAD [3], Teledesign [4]	✓		Remote
VLEGO2 [5]		✓	Co-located
Proposed system	✓	✓	Co-located

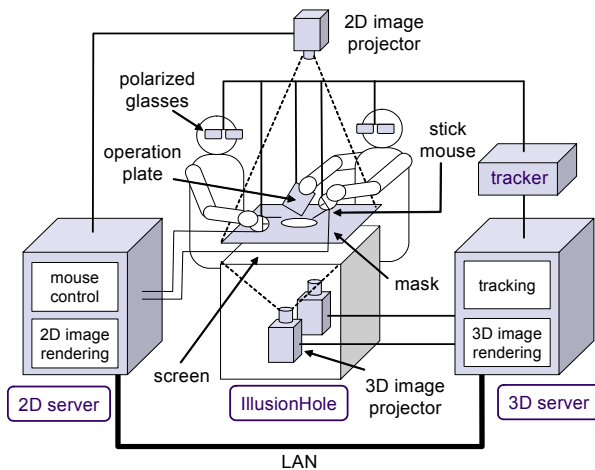


Fig.1 System configuration.

three of these features. A modeler that integrates these three features would enable users to discuss and exchange ideas and cooperatively design 3D objects intuitively and accurately.

In the present paper, we propose a novel modeling environment that provides a seamless 2D/3D user interface and supports co-located collaboration. The remainder of this paper is organized follows. Section 2 describes the basic design and concepts of the workspace. Section 3 illustrates a prototype modeling system. Section 4 describes ongoing studies, and concluding remarks are presented in Section 5.

2. Collaborative 2D-3D Integrated Workspace

The proposed system consists of an IllusionHole [6], to provide a 3D workspace, and a projector, to display a 2D workspace onto a mask panel of the IllusionHole. The configuration of the system is shown in Fig.1. Two Windows machines, namely a 2D server and a 3D server, manage the 2D and 3D workspaces, respectively.

2.1 3D workspace

A pair of stereoscopic images is displayed using a 60-inch IllusionHole, the hole diameter of which is 26 cm. Since the mask panel of the IllusionHole shows a pair of stereoscopic images exclusively to one user and hides these images from other users, multiple users (up to four) can simultaneously observe the same 3D scene



Fig.2 Display device.

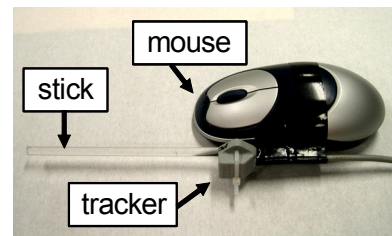


Fig.3 Stick mouse.

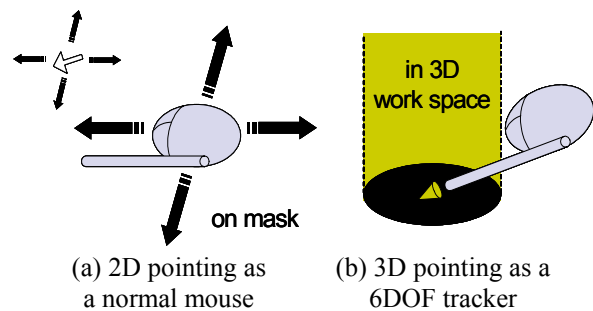


Fig.4 Seamless 2D-3D input.

from their respective viewpoints through a pair of polarized glasses with head tracking capability. The 3D server (Pentium 4, 2.4-GHz, 512-Mbyte memory, nVidia GeForce4 4600) renders the 3D scene and controls the Polhemus Fastrak six-degree-of-freedom (6DOF) information tracker of the polarized glasses and the custom input devices (stick mice and operation plates, as explained later herein).

2.2 2D workspace

A 2D user interface is displayed on the mask panel and projected onto the operation plates from an overhead projector placed above the IllusionHole (see Fig.2). The 2D server (Pentium 4, 3.06-GHz, 1-Gbyte memory, nVidia GeForce4 4600) renders 2D images and controls the stick mice. Using raw Windows APIs, several USB

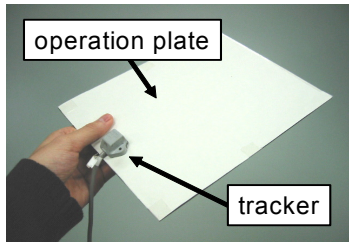


Fig.5 Operation plate.

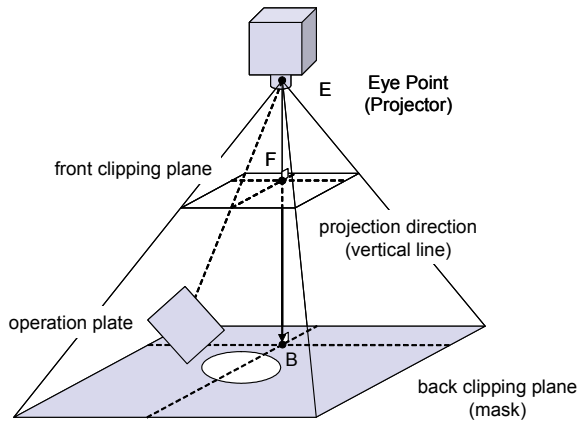


Fig.6 Projection frustum for an operation plate.

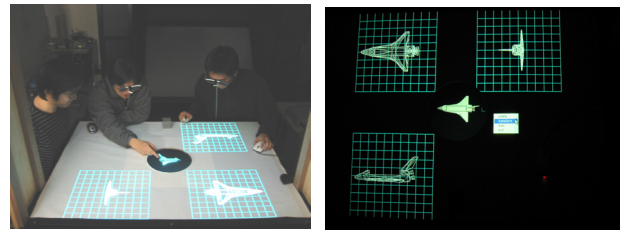
mice can be connected to the 2D server and controlled independently. Tracking information is sent from the 3D server to the 2D server, while information from the mice is sent from the 2D server to the 3D server in order to maintain consistency.

2.3 Stick mouse

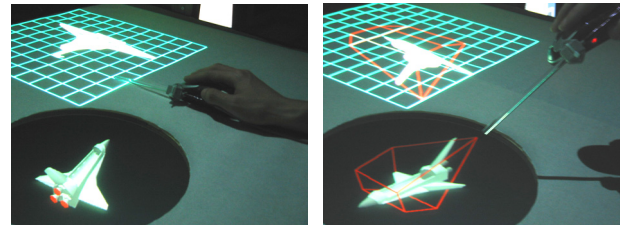
If different devices are provided for 2D and 3D environments, users will have to switch devices repeatedly, increasing both physical and cognitive burdens. The stick mouse (Fig.3) provides a seamless input device for use in both 2D and 3D environments. The stick mouse works as a normal mouse when manipulated on the mask panel on which the 2D pointer appears, as shown in Fig.4 (a) (2D mode). When manipulated inside a cylinder-shaped 3D volume above the mask hole (3D mode), the stick mouse works as a 3D pointing device using a Polhemus tracker, as shown in Fig.4 (b). In the 3D mode, an arrow-shaped 3D cursor appears at the tip of the stick in the 3D workspace.

2.4 Operation plate

The operation plate (Fig.5) which is a plastic board and a Polhemus tracker is attached on the plate, via which a variety of 2D-3D coordinated functions can be performed. The operation plate is considered to be a second, independent 2D workspace that acts as a bridge between 2D and 3D workspaces. For example, users can invoke and operate a 2D hierarchical menu on an operation plate or select a 2D cross section of a 3D model for 2D editing at an arbitrary orientation by

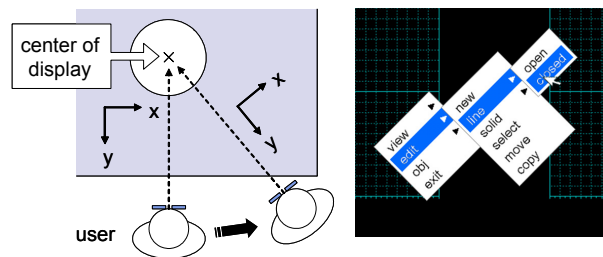


(a) Prototype modeler in use (b) Orthogonal views



(c) 2D manipulation (d) 3D manipulation

Fig.7 Prototype modeling system.



(a) Rotating mouse coordinate system (b) Rotating mouse cursor and menu

Fig.8 Adaptive 2D GUI.

placing the plate inside the model. Users can also pick a 3D object to move to the 2D workspace, similar to the use of a palette.

For a 2D image on the plate, a projection frustum is precisely adjusted to a real frustum defined by the overhead projector and the mask panel (see Fig.6). The 2D image to be shown on the operation plate is rendered as a virtual plate in space at the position and orientation of the actual operation plate and is transformed with this perspective projection. As a result, 2D images are projected onto the operation plate without distortion.

3. Prototype Modeling System

We have implemented a prototype modeler (Fig.7 (a)) through which two or three users can collaboratively design a 3D object using four orthogonal views (top, side, front and optional) in the 2D workspace (Fig.7 (b)) and a stereoscopic view in the 3D workspace. The orthogonal views are manipulated using stick mice in 2D mode (Fig.7 (c)), whereas the 3D image is directly manipulated using a stick mouse in 3D mode (Fig.7 (d)). In this section, we describe a number of functions of the prototype modeling system as well as examples of the

operations.

3.1 Adaptive 2D GUI

Generally speaking, users tend to orient the mouse in the direction of their body. If the user moves from the front of a horizontal display to the side or back of the display, his/her mouse orientation against the display is likely to change as well. This causes difficulty in using a mouse as its direction of movement does not match that of the 2D pointer. For example, the 2D pointer might move to the left of the user when he/she moves the mouse forward.

To solve this problem, the prototype system employs a mechanism to adaptively rotate the coordinate system of each mouse based on the position of the corresponding user (see Fig.8 (a)). That is, the mouse coordinate system, along with every GUI component, is rotated such that the Y axis remains oriented toward the center of user's eyes from the center of the display (Fig.8 (b)). As a result, users can easily manipulate the 2D GUI from any position around the IllusionHole display.

3.2 2D-3D Interoperability

In the prototype modeler, object manipulations performed in the orthogonal views are simultaneously reflected in the stereoscopic view, and manipulations in the stereoscopic view are simultaneously reflected in the orthogonal views.

This interoperability enables 2D-3D coordinated operations (Fig.9). To create an extrusion object, for example, the user first draws a cross section on the 2D workspace (Fig.9 (a)), and then specifies a path of the extrusion in the 3D workspace (Fig.9 (b)). To create a revolution object, the user first draws a cross section on the 2D workspace, and then specifies the axis of revolution in the 3D workspace.

3.3 Plane selection

Optional views can be used to show cross sections of the object. The cross sections are interactively selected using an operation plate. In the plane-selection mode, a cross section of a 3D object is dynamically shown on the operation plate and on the optional view area, based on the position and orientation of the operation plate in the 3D workspace. During selection, a grid is projected onto the operation plate as a visual cue (see Fig.10 (a-1)). The same functions can be performed on the optional view as on the top, side and front views (Fig.10 (a-2)).

In this way, the operation plate allows users to intuitively select a plane and manipulate an object. For example, the user is able to select a plane in an arbitrary direction, onto which he/she can create a cross section using the plate. The user can then draw the section on the optional view.

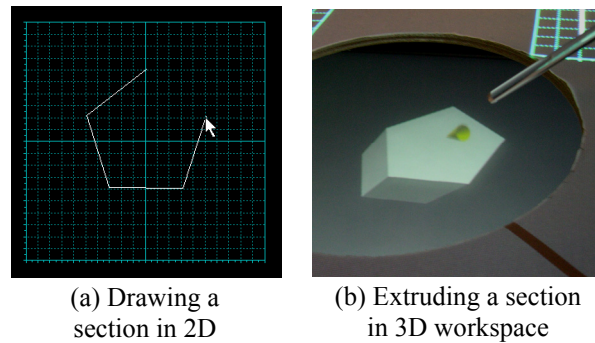


Fig.9 2D-3D Interoperability.

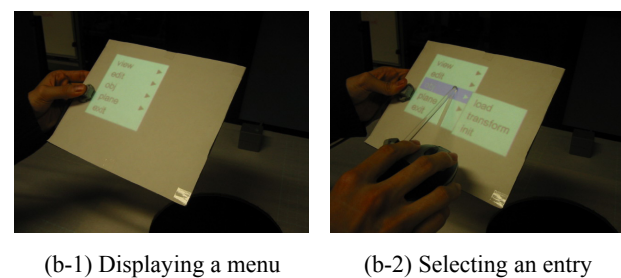
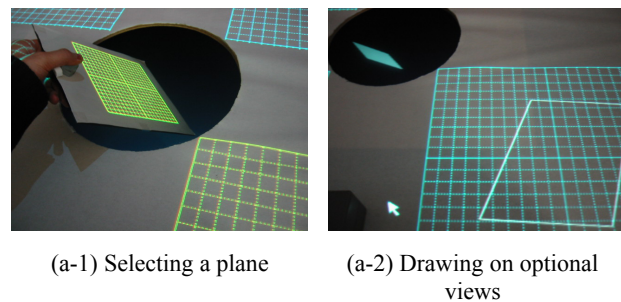


Fig.10 Operation plate functions.

3.4 Plate menu

Normally, a pop-up menu appears on the mask panel when the user clicks the right-hand button of the stick mouse (i.e., 2D mode). A pop-up menu can also be invoked and shown on an operation plate when the user clicks the right-hand button of the stick mouse in 3D mode (see Fig.10 (b-1)). The pop-up menu on the operation panel can be manipulated using the 2D pointer appearing at the tip of the stick mouse, as shown in Fig.10 (b-2).

3.5 Modeling examples

The prototype modeling system provides a number of basic functions found both in typical existing 3D CG modeling with orthogonal views and in immersive modelers with head-tracked stereoscopic viewing. Some modeling examples using the prototype modeling system are illustrated below.

Currently, the Wavefront OBJ format is supported as a file format for import/export. Users are also able to create new objects in a number of ways, including revolution and extrusion.

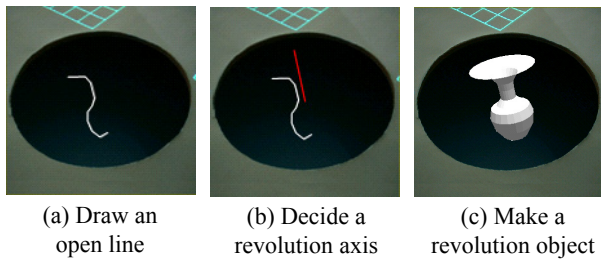


Fig.11 Revolution.

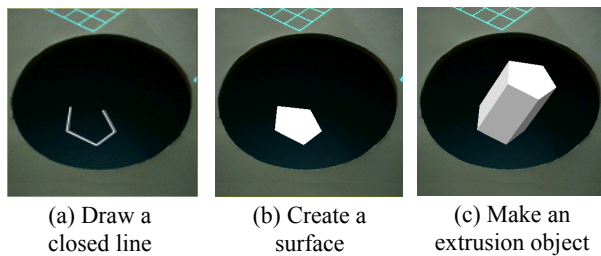


Fig.12 Extrusion.

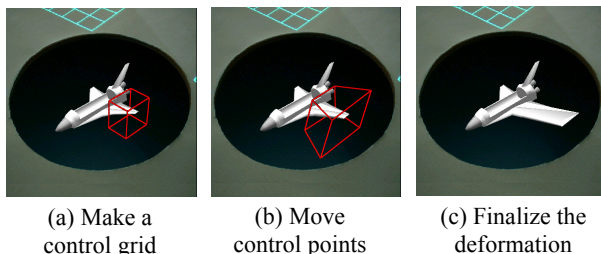


Fig.13 Deformation.

To make a revolution object, the user must first draw an open line segment as a cross section. A single click of the mouse adds a vertex, and a double click ends the operation (Fig.11 (a)). Note that the open line segment can be drawn both in the 2D and 3D workspaces. The user must then decide the revolution axis, which is rendered in real-time by a mouse drag (Fig.12 (b)). The revolution axis is fixed by releasing the mouse button. The revolution axis can also be drawn in both the 2D and 3D workspaces. Once the axis is fixed, an object of revolution is made by rotating the open line segment around the axis (Fig.11 (c)).

To make an extrusion object, the user must first to draw a closed line segment as a cross section. A single click of the mouse adds a vertex (Fig.12 (a)), and a double click makes the line segment into a surface (Fig.12 (b)). A closed line segment can only be drawn in the 2D workspace. The user must then decide an extrusion axis. By performing a mouse drag, an extrusion object (not an extrusion axis) will be rendered in real-time. The object shape is finalized by releasing the mouse button (Fig.12 (c)). The extrusion axis can be specified in either the 2D or 3D workspace.

Each object can be translated, rotated, scaled and deformed. Translation and rotation can be performed by

a mouse drag in either the 2D or 3D workspaces. When in the 2D workspace, the user is able to easily perform these transformations using the physical support of the panel surface. To deform an object, the user first creates a box-shaped control grid by dragging the mouse to include the entire object or a part thereof (Fig.13 (a)). The control grid can be made either by mouse drags on two different orthogonal views, or by a mouse drag in space. Then, the user moves its control points by mouse drags in the 2D and/or 3D workspaces for deformation (Fig.13 (b), (c)).

3.6 User experience

A number of students in our laboratory have participated in two-user collaborative modeling using the prototype system. Through observation, we subjectively confirmed the practicality of the proposed approaches. Users voluntarily used both 2D and 3D workspaces and were able to create a variety of 3D objects in a short time. Using a physical support, users were able to stably and accurately manipulate objects in the 2D workspace on the mask panel. In addition, users were able to specify a point in space intuitively in the 3D workspace. Combining 2D and 3D workspaces enhances both usability and efficiency.

4. Ongoing Work

In the prototype modeling system, each workspace is always accessible by all users. Such a public workspace encourages users to discuss the design and come up with new ideas. On the other hand, personal workspaces located near a public workspace are said to be important in terms of independent activity and collaboration efficiency [7]. We are now implementing a new feature to provide a personal workspace to each user. Similar to the work reported in [8], this personal workspace provides a standard Windows desktop environment using the texture mapping feature from OpenGL (see Fig.14). All existing applications, e.g., modeling applications for 3D design, text editors for writing notes, and web browsers for Internet access, are available in the personal workspace.

In the prototype modeler described in the previous section, the mouse coordinate system is automatically rotated according to the location of the user. In addition, the user may want to translate his/her Windows desktop workspace freely [8, 9], in order to show his work to other users for example. Therefore, in the developed system, the Windows desktop workspace can be arbitrarily translated, rotated, and scaled using the stick mouse [9].

The software architecture for the personal workspace is shown in Fig.15. VNC technology is employed to realize the personal workspace feature. Although originally developed for remote controlling computers, VNC can also be applied for co-located collaboration [10]. An OpenGL window process and VNC client processes run

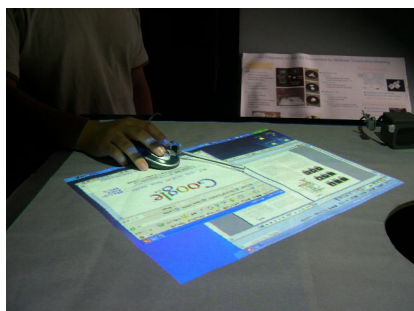


Fig.14 Texture mapped adaptive Windows desktop environment.

on the 2D server. When the OpenGL window process accepts a connection request from a VNC server that runs on a remote computer, a new VNC client is invoked. The VNC client sends the OpenGL window process a remote desktop image received from the VNC server. The image is then transformed properly and rendered on the mask panel as a texture mapped rectangle.

The prototype modeler can handle multiple USB mice with a single 2D server using Windows' raw APIs. In addition, we plan to make multiple keyboards available with a single 2D server. All of the mouse and keyboard events received by the OpenGL window process need to be dispatched to the correct VNC client (and through it to the VNC server) properly. Since the OpenGL window process knows all of the client information, implementing a direct manipulation interface for data exchange among personal workspaces will not be difficult [11].

5. Conclusion

In this paper, we have proposed a 2D-3D integrated modeling system for multi-user cooperative design. An IllusionHole provides a shared 3D workspace, and a mask panel is used as a versatile 2D workspace. Users are able to seamlessly manipulate shared 3D objects in both the 2D and 3D workspaces with special input devices such as a stick mouse and an operation plate. Through user-participation experiments in collaborative design, we subjectively confirmed the effectiveness of the prototype system. Further studies are being conducted in order to provide personal Windows desktop environments to users. In the future, we would like to extend the functionality further and conduct a rigorous user study.

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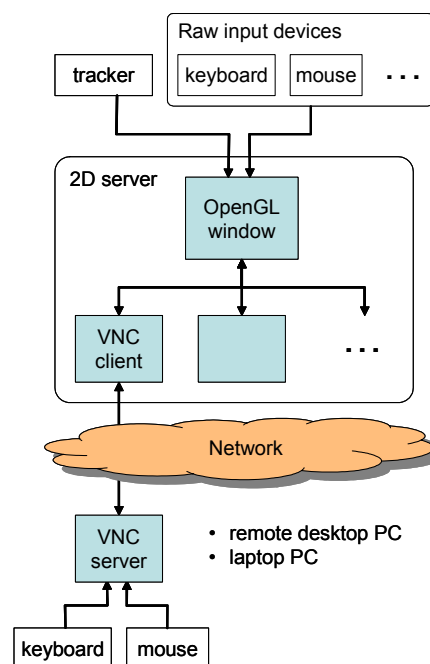


Fig.15 Software architecture for the personal workspace feature.

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