

Sketching Images Eyes-free: A Grid-based Dynamic Drawing Tool for the Blind

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ABSTRACT

In this paper we describe one method of transforming a mouse-based graphical user interface into a navigable, grid-based auditory interface. We also report the results of an experiment that tested the effectiveness of a drawing tool for the blind called IC2D that uses this interaction style. The experiment included eight visually impaired participants and eight blindfolded sighted participants. The results show that auditory interpretation of graphics is an effective interface technique for visually impaired users. Further, the experiment demonstrates that visually impaired users can develop meaningful drawings when given adequate technological support.

Keywords

Drawing, visually impaired, graphics, auditory user interfaces, graphical semantic enhancement, grid, IC2D.

INTRODUCTION

The increased popularity of graphical user interfaces (GUIs) makes what is possible for the sighted virtually impossible for the visually impaired. In earlier systems with character-based user interfaces, simple accessibility media, such as screen readers, braille output, and speech synthesizers, were effective [1]. Current systems now run GUIs that render these simple aids almost useless for the blind, preventing them from accessing, comprehending, and sharing graphical information readily available to sighted users, or creating their own computer-based graphics for communication or self-expression.

Drawing programs are designed with sighted users in mind; they depend on sophisticated GUIs that involve *direct manipulation*, a term that describes the emphasis on continuous visual representation of objects and physical actions between computer users and graphical objects [25]. These visually based interfaces often lack sufficient non-visual feedback to allow vision-impaired users to construct a mental image of the graphical output. Therefore, blind computer users can only utilize these picture-based interfaces in a limited fashion.

GUIs create a number of obstacles to blind users' ability to access or create computer-based graphics. Specifically, the

challenges of mouse-based data input are compounded by the inability of traditional drawing software to translate graphical data output to the screen access programs on which blind computer users commonly rely. Although tactile and haptic displays are available to visually impaired users as special purpose external devices, the usefulness of these devices is significantly offset by their bulkiness, cost, and ambiguous output. Our main goal is to present a portable and accurate feedback device that will allow for increased mobility as well as ease of use.

In this paper we describe the Integrated Communication 2 Draw (IC2D), a system that transforms geometric information into an auditory format to address the problems encountered by visually impaired users of computer-aided drawing tools. Based on the results of drawing studies carried out with visually impaired participants [13], we employ a 3×3 grid as the basis for IC2D's interface. IC2D takes input using the keyboard and gives feedback using speech and non-speech audio. It also provides a descriptive labeling feature that enhances the semantics of the image created. A recent innovation, not discussed in this paper, allows visually impaired users to create and view animated graphics [11].

The rest of this paper is organized as follows. In the next section, we give an overview of the related work. Then we describe the IC2D system in detail. This is followed by an evaluation of the system and a discussion of the results. Finally, we present our conclusions.

RELATED WORK

A number of research projects have tried to translate visual information into either tactile or audio information.

Tactile Displays

Tactile displays are one approach to bringing GUIs to the blind that has received much attention from the research community. These systems, such as dynamic Braille displays [1, 2, 16, 23, 24], have several drawbacks. For example, Braille labels have been used to help convey a tactile version of an image. Unfortunately, these labels often occupy space that is not available on the image, not all blind people can read Braille, and frequently, not all the information of an image (e.g., colors or distances between objects) is recorded in a tactile picture [13].

Recent research has used the tongue and the skin as routes for transmitting visual information through the nervous

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system. Bach-y-Rita [26] developed a system that uses electrodes placed on the tongue of a blind person to enable her to sense shapes, motion, and other visual stimuli. The system employs a camera connected to a control box that in turn is connected to the electrode array. The electrode stimulates the nerves in the tongue, producing a “tingling” sensation that the blind person can then translate into a visual cue. The researchers found that with brief training 12 first-time users scored 20/860 in visual acuity. Legal blindness is defined as 20/200 with corrected vision.

Auditory Displays

Although research using these other senses has been promising, many researchers have recognized that hearing is a more natural substitute for vision. A number of GUIs have been adapted into auditory forms based on the use of synthetic speech and non-speech sounds [4, 9, 10, 15, 21].

Mynatt’s Mercator system [21] uses everyday non-speech sounds to transform graphical information to a non-visual environment. Mynatt makes distinctions between the lexical, syntactic, and semantic levels of a visual interface to understand how best to break it down into a non-visual format. The lexical level comprises the low-level graphics consisting of lines, dots, and text, which, when assembled, form functional objects. The syntactic level of an interface, at a higher level, is the buttons, menus, scrollbars, etc., that provide a particular function. The semantic level, the highest level, provides a meaning or interpretation of the syntactic objects in terms of what the on-screen objects allow us to do. Mynatt argues that transforming a graphical interface at the semantic level is the best approach for creating usable and efficient non-visual interfaces. Mercator is a screen reader that provides access to the semantics of X-Windows applications.

One of the most frequently used methods of representing graphical information non-visually combines touch panels with auditory feedback in the form of speech and non-speech sounds [10, 17, 18]. The Nomad Mentor [4] first introduced the concept of Audio-Tactile Graphics as an input/output tool for the blind by connecting a touch pad to a computer with a voice synthesizer. The touch pad grid has 9,600 points, each of which is associated with an identifying label that can be recorded. A tactile graphic may be placed on the touch pad, and the user can explore, edit, or create labels for it. When a stylus comes into contact with the touch pad, the voice synthesizer verbalizes the label associated with the point. For more effective navigation, the user would need directional or relational feedback to move from point to point [13, 15] or markers signifying that the point has already been explored [10, 14, 17]. Without such feedback, the Nomad Mentor does not provide a mechanism to efficiently reach specific positions of graphical information. Also, it does not allow a visually impaired user to interpret and label a printed image.

Kamel and colleagues developed the GUESS system [15], which uses a touch tablet and non-speech sounds to allow

blind users to explore patterns of images. The system sonifies simple geometric objects and employs three feedback techniques to map and locate different patterns of these objects onto the tablet. The first technique provides sound feedback when the stylus touches inside the boundary of an object. The second technique maps a 3×3 virtual grid onto the tablet. The user hears unique tones when the stylus crosses a gridline. The third method uses a sound localization technique that is manipulated by the relative position of a stylus. To test the relative efficiency of these three techniques, three groups of users were assigned one location technique each and asked to explore and then relocate a specific object. The experimenters measured how quickly users were able to relocate the objects a second time, and found that the participants who used the second technique (the grid) took 51% less time on the second trial, followed by the third group (sound localization technique) using 22% less time, and finally the first group (absolute position technique) using 3% less.

Kennel represented diagrams to blind people using audio feedback and a touch panel [17]. Touching particular diagram frames and applying different pressures triggered three types of feedback via speech sound: information regarding the frame, the interrelation between frames, and the textual content of the frame. Jacobson used a similar technique to represent maps to blind users [10]. However, he designed the feedback functionalities, both speech and non-speech sounds, as different sectors surrounding the area of the represented map on a touch-sensitive screen. Depending on the sector selected, the blind user is able to obtain different types of information while exploring the map. For instance, by selecting the non-speech functionality, then touching any of the structured areas (e.g., a building), a corresponding non-speech sound is produced. The user can then obtain more detail, such as a verbal explanation, by choosing the corresponding sector.

T-Draw [18] was one of the first tools used to study how blind people perceive the world they live in. Kurze used a Thermostift digitizing tablet and heat-sensitive swell paper as a method of input. The swell paper is placed on the top of the tablet. The drawing is constrained to two geometric objects: polygons and lines or sequences. A polygon is recognized when a line ends near the beginning of another line and a voice command is given. While the object is being drawn, the user gives its attribute verbally. The drawing can be explored by using a tablet and a special pen. When the pen approaches a line or is inside a polygon, the associated attributes are described using text-to-speech. This method does not allow drawings to be altered later, and most importantly it does not compensate for lack of visual feedback. For example, drawing two parallel lines is hard to achieve using T-Draw.

Dragon NaturallySpeaking [3] takes a different approach to making GUIs accessible to physically challenged computer users. The system retains the GUI, but allows users to

control the cursor with speech input. It provides navigation control through the MouseGrid, a 3×3 grid that users can overlay on the entire desktop or an active window. The grid provides reference points for voice-activated cursor movements and the location of objects. Like the system we propose, a recursive grid scheme allows users finer navigation control. Speaking a particular grid cell number places a smaller 3×3 grid over that cell. The user could then, for example, select an icon contained within one of the smaller cells. Unlike the technique we describe here, Dragon's interface requires users to be sighted.

THE IC2D GRID-BASED DRAWING SYSTEM

IC2D differs from most of the systems described above in that it does not make use of any external devices, such as tablets or adapted graphical displays. The IC2D interface relies on keyboard input and provides auditory feedback. Even though IC2D makes use of external voice synthesizer hardware, this need not be a barrier, as voice synthesizer software is increasingly available.

One of the main obstacles for blind computer users when interacting with graphical output is identifying or locating the exact position of the cursor on the screen. For example, it is of little use for a blind person to control the cursor by holding the mouse, as this does not provide adequate non-visual feedback. Drawing programs have a related problem, that of finding the way back to a previously selected point, a process that usually requires the user to look at the screen. In addition, a visually impaired user must be able to accurately find parts of previously drawn objects for modification. One of our main goals is to allow a blind person to select a desired point on the screen, move the cursor to perform another task at a new location, and later relocate the cursor back to the original position.

The design of any new method for accomplishing a task should adapt the method to the intended user's intuition [22]. This sometimes means adopting designs already internalized by users for other tasks. For example, a clock face is a familiar interface that can be used by visually impaired users as a tool for giving the relative location of different types of food on a plate. The vegetables, for instance, might be described as being located at "6 o'clock" (closer and in front of the person), and the meat may be located at "12" (farther away from the person).

Grid-Based Navigation

The first step of our approach in solving the problem of providing adequate feedback is to divide the screen into a smaller, more navigable workspace [5]. The primary feature of the IC2D graphical interface system is a 3×3 grid composed of nine fixed, non-overlapping screen regions. These regions, or cells, are assigned numbers corresponding to the numbers on a telephone keypad. Most blind users have already learned this schema. The system is arranged so that users can use the keyboard to move to and from any of the nine cells as follows:

- 1) By using four user-assignable keyboard keys that behave as directional keys (e.g., i, ",", j, and l) which are up, down, left and right, respectively.
- 2) By using the numbers (1–9) on the top row of the computer keyboard, with each number representing the respective cell location.

When the user moves to a cell, the cursor is located at the center of that cell. Thus, the center is a unique point of reference for the given cell. Pressing the k key selects the current position. Moving to a cell and then selecting it by pressing k is analogous to pointing and clicking with a mouse to select an object.

Keyboard Input

The IC2D interface relies entirely on keyboard input to enable users to select and relocate points as well as produce final drawings with meaningful labels. The keyboard has proven a successful input device for blind users manipulating graphical data [20, 21]. In IC2D, all function keys are placed around the home row. This allows blind users to quickly and efficiently perform tasks because they are not required to move their hands between the numeric keypad and the keyboard. Forcing users to stop and relocate their hands after each command reduces their productivity.

Although all of IC2D's functions are too numerous to list here, Table 1 gives the keyboard commands necessary to produce recognizable drawings.

Key	Functionality
i	move cursor up
,	move cursor down
j	move cursor left
l	move cursor right
u	lower grid recursion
m	higher grid recursion
k	selects grid positions & palette options
e	activates labeling mode
s	shape palette
d	finalize drawing
x	unselect position or exit palettes

Table 1. Selected IC2D function keys.

Palettes

IC2D uses the same 3×3 grid described above to support palettes, which offer a consistent way of accessing functionality that would normally be found on pull-down menus and in dialog boxes. There are four different palettes for shape type, colors, file commands and animation [11]. This paper discusses the first three palettes. The shape palette (see Figure 1) contains predefined shapes such as circles, rectangles, lines, and closed polygons. When a user selects a shape, it remains selected until a different shape is

chosen. The color palette (see Figure 2) contains the colors green, orange, yellow, etc., and the file palette contains commands such as “open” and “save” (see Figure 3). Voice feedback is also used when navigating these palettes.

Each palette provides nine options. Users navigate a palette using the same grid-based navigation described above. Starting from the center of the grid, the user can reach any other cell in the palette using no more than two navigation key presses, or by merely pressing one of the numbers 1-9 on the top row of the keyboard.

Grid Recursion

We previously explained how the 3×3 grid provides coarse navigation of the drawing area. Starting with this baseline interface, we use a recursive scheme to allow users to make more precise selections. Each of the nine cells can be further divided into nine cells, which in turn can each be divided into nine cells. In this manner, users can descend to two additional levels; our previous studies showed that after these two levels, it becomes difficult to conceptualize positions [12]. This gives users 27×27 cells for object positions and control points. Objects are drawn at full screen resolution. Although this schema of reference points is fewer than commonly found in drawing programs for the sighted, other work on drawing programs for the visually impaired has shown success with similar precision [7].

Each position in the 27×27 grid is easily identified, as its label corresponds with the telephone keypad numbering system. For example, suppose the user is at the top level and chooses cell 9. From this cell, the user presses the **m** key to descend to the second level grid, subdividing cell 9 into a smaller 3×3 grid. Then, by choosing cell 8, followed by **m**, the user subdivides cell 9-8 and descends to a third level grid. Here the user chooses cell 1. In this example pressing 9 **m** 8 **m** 1 takes the cursor to the final cell. This location is given as “position 9-8-1.”

The usefulness of grid recursion can be demonstrated by drawing a right triangle inscribed inside a circle inscribed inside a square (see Figure 4). At the top level we select cells (1, 3, 9 and 7). We then access the shape palette, select the rectangle object, and press the draw function key **d** to finalize the drawing of the square. We then move to cell 5, descend a level using the **m** key and select cells 5-5

and 5-6 and draw a circle. Finally, we move the cursor to cell 5-5 and descend a level to select cells 5-5-3, 5-5-9 and 5-5-7 to draw the triangle.

The above example gives some idea of what drawing in IC2D is like. In many cases, the order of selecting points matters. For example, consider drawing a square by choosing the four cells 1, 3, 7 and 9 in this order and then connecting them with the multiline shape. This would not construct a square, but rather would look like the letter ‘Z’. On the other hand, in drawing a triangle the order of selecting positions does not matter.

To find information about all the objects within a cell, we move the cursor to the desired cell and press the object information key (**o**). This gives audio feedback describing all shapes and their relative locations within the cell (e.g., “Shape square, positions 1, 3, 9, and 7”).

The Use of Labeling to Enhance Semantics

Graphical displays offer computer users a vast amount of information all at once. Sighted users visually scan an image to get a quick overview of its important attributes. This technique must also be supported for blind users of drawing systems to allow them to easily explore an image, focusing on different pieces of it as well as conceptualizing it as a whole. Since auditory information is transitory, blind users must also be provided with special navigation, repeat, and overview functions when interacting with graphics in a non-visual environment. Annotations can be used to give meaningful semantics to images so blind people can accurately build a mental model of graphical information.

The Blind Information System (BIS) [19] is an XML-based picture description browser for the blind. This system uses a hierarchical labeling scheme similar to what we describe here. The main difference is that BIS uses visual interaction techniques to create the labels. Therefore, although it allows blind users to comprehend graphical information, it does not allow them to create it.

Structuring and reordering graphical data and assigning them meaningful labels allows blind people to easily conceptualize a given image [8, 14]. Using IC2D’s label mode, the user can navigate through a drawing, query the existing labels of the drawing, and assign meaningful textual labels to objects or groups of objects.

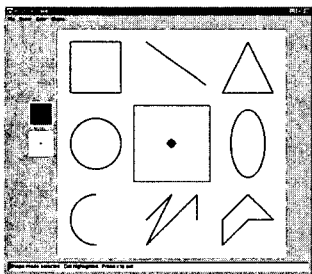


Figure 1. The Shape Palette.

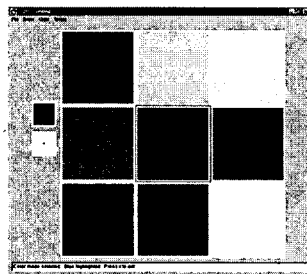


Figure 2. The Color Palette.

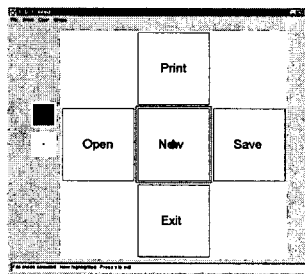


Figure 3. The File Palette.

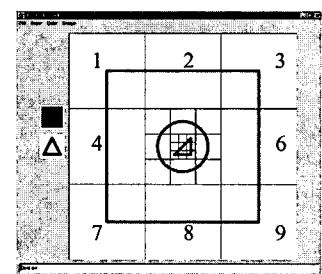


Figure 4. Grid recursion.

The labeling mode offers three basic types of information in a hierarchy: labels, object types, and positions of the primitive objects. Users navigate through the hierarchy using the keyboard, with voice synthesis reading the labels back to users as they navigate the grid in draw mode. Users can assign labels to objects as soon as they create them and may request a summary of their current level or current label, type, or position. This feedback can be toggled on and off, and requested on demand for all objects.

EVALUATION OF IC2D

We previously conducted two pilot studies of IC2D that revealed blind computer users are able to successfully draw recognizable figures [12] and recognize drawings done by both sighted and blind users [14]. Here we present an evaluation of IC2D that included more participants, including both blind and sighted users.

In this experiment, we had a total of 16 participants, eight sighted, five partially sighted and three congenitally blind. Their ages ranged between 19 and 49 years. All partially sighted participants normally required some sort of assistive device to use a computer (e.g., Closed-Circuit TV, or voice or Braille output [1]). We presented each participant with three tasks to complete and measured their performance.

Method

Each participant had approximately 25 minutes of tutorial on how to use IC2D. This session was split across the three experimental tasks and included:

- Introduction to the IC2D interface, including all the function keys necessary to complete drawings.
- Familiarity with the IC2D help menu.
- Hands on practice using the interface and the different palettes.
- The steps to draw simple objects (e.g., a square)
- Practice with labeling and grouping.

The sighted and partially sighted participants were blindfolded at the start of the experiment, before the tutorial. No hints were given at any time. However, if participants needed assistance during testing, we referred them to the IC2D help mode. We asked all participants to verbalize what they were trying to do while performing all tasks. All of the participants' output and comments were recorded for further analysis. We used both the participants' performance and verbal responses to draw conclusions about the usability and effectiveness of the system.

Tasks

The first task was divided into two parts. In the first part we asked the participants to draw three circles in three different grid positions of their own choosing. After drawing each circle, we asked them to verbally describe the location they had attempted to draw it for later comparison with the actual drawing. Upon completing the three circles, we asked them to describe the overall picture. The goal of this part of the task was to see if participants could describe

their own non-instructed drawings. In part two, we asked participants to draw the smallest triangle possible in the bottom right cell of the grid, then draw a rectangle inside the top left cell, and finally draw a line connecting the top vertex of the triangle with the top left vertex of the rectangle. The goal of this part was to see if participants could carry out instructed drawing with precision.

In the second task, we presented participants with three pictures that each contained a different arrangement of a man, a tree and a house. We gave them one image at a time and asked them to explore it, and then verbalize their mental model of it. The goal of this task was to see how well participants could use IC2D to visualize different spatial representations of objects.

For the third and final task, we gave participants a physical cube and asked them to draw it preserving the 3D effect as much as possible. We asked them to draw it from any angle they wished. We also allowed them to feel it at anytime while drawing it. We informed them that drawing just a square to resemble the cube was not acceptable. The goal of this task was to see if the grid-based interface would allow participants to visualize and draw real world objects

Performance Measurements

We evaluated the results of the experimental tasks by the task completion time, the participants' self-assessed level of confidence in what they had drawn, and the quality of the drawing. Level of confidence and quality of the drawing scores use a scale of 1 (low) to 10 (high).

A sighted individual visually evaluated the drawings to rate their quality. This outside judge was not present while the participants worked with IC2D, but had access to the recorded comments the participants made about what they were attempting to do. We filtered these comments prior to playing them for the judge to insure that the judge would have no indication of whether a participant was sighted or visually impaired. The judge evaluated the drawings based on whether the participant had been able to successfully execute what they had been trying to do, as described in their comments, and whether the participant had been able to meet the goal of the task. In the case of the cube-drawing task, for example, the highest score was given for rendering a perspectively-accurate cube (i.e., a drawing with parallel lines, fully connected lines, and accurate angles). A drawing with errors such as not connecting two lines properly, drawing inaccurate angles, or producing an overall effect of incorrect perspective, was given a lower score.

Results and Discussion

The visually impaired participants performed as well or better than the sighted participants on all three tasks for all of our metrics, although there was not a statistically significant difference in most cases. This is possibly due to our relatively small sample size ($n=16$).

There were no significant differences in time, user confidence, or the judge's rating for Tasks 1a, 1b and 3

(Mann-Whitney ranked-sums). In Task 2 the visual impaired group was significantly faster ($U=13$, $p=0.05$), more confident ($U=11$, $p=0.03$), and was rated higher by judges ($U=7$, $p=0.007$).

The visually impaired participants completed tasks using the system at least as quickly as the sighted participants did, regardless of previous computer experience (see Figure 5). Overall, sighted participants averaged 8.5 minutes per task compared with an average of 7 minutes for blind participants. Although these times might seem long compared to the time it might take sighted participants to complete the tasks using standard drawing packages, these are tasks that blind participants would simply be unable to even attempt with existing technology.

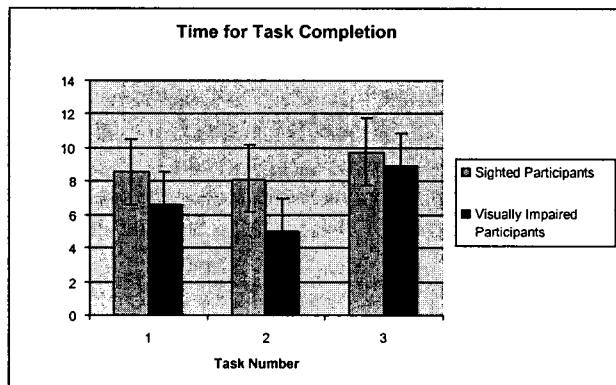


Figure 5. Average task completion time in minutes for sighted and visually impaired participants.

Blind participants' own responses indicated that the grid interface was intuitive. The 38-year-old congenitally blind participant commented, "I can understand the grid concept abstractly, but not in a visual sense, because I have never been able to see." He successfully drew the three circles in Task 1, described their locations on the left side of the grid and was able to recognize that two circles were inside the third one (see Figure 6). A 21-year-old sighted participant said, "I can almost visualize everything on the screen without having to look at it."

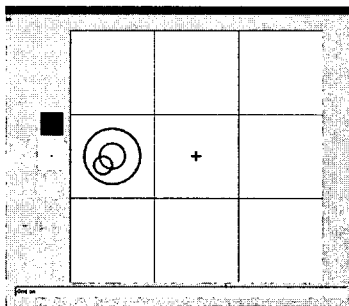


Figure 6. The three circles drawn and described by a congenitally blind participant.

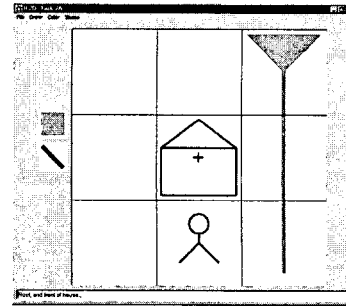


Figure 7. One of the figures used in Task 2. As the participants navigated the cursor around the figure, they heard "top of tree", "bottom of tree", "my man", etc.

Most participants found it easy to visualize the IC2D output and identify patterns. For example, another 21-year-old sighted participant drew three circles across the top three cells, and then described his completion of the task as resembling "a tic-tac-toe."

When attempting to interpret more complex images, such as those used in Task 2 (see Figure 7), visually impaired participants found the labeling mode useful. One participant commented, "I liked when it told you what the picture was, and where it was. It was very easy to picture that in my mind." The participants' comments indicated that the labeling mode is a suitable method for allowing blind users to build mental models of IC2D images.

Most of the sighted participants reported that trying to complete the tasks while blindfolded was an "intense" experience. Sighted users found that having to listen to instructions and output rather than being able to see it increased their cognitive load. One blindfolded sighted participant commented, "when you are using your eyes, it does not really take brainpower, but trying to map an image in your head from memory is more difficult." Sighted participants mentioned that they tried to use the help menu to prevent them from feeling disoriented, or used the "where am I" key (w), which provides current cursor position as well as color and type of the figure to be drawn, to allow them to regain their orientation.

In contrast, the visually impaired participants found it easy to use the keyboard to locate and execute commands. On average, they used the help mode less than the sighted participants did. Most of them remarked that they appreciated the interface because it allowed them to know where they were at all times. One blind participant commented, "once you started spending a few days with this, the way this grid is laid out is not complicated, you will be able to know exactly where you are all the time." The average self-reported confidence levels for both groups were statistically similar for Tasks 1 and 3. The visually impaired participants gave themselves higher ratings than the sighted participants did for Task 2 (see Figure 8).

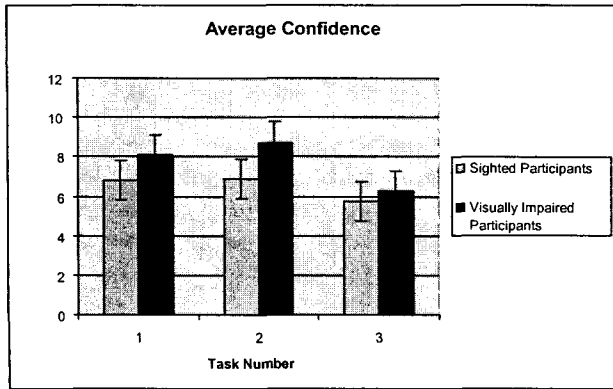


Figure 8. Average (self-assessed) confidence rating for sighted and visually impaired participants.

The results show that vision impaired participants on average performed at least as well as sighted participants and both groups performed quite well on the first two tasks (see Figure 9). For example, in Task 3, a blindfolded partially sighted participant, who spent 10 minutes on the task, drew the replica of the cube that received the highest quality rating. The visually impaired participant was able to recognize the location of the vertices to produce the 3D perspective, and when asked how she did so, she replied, “I counted squares at the smallest [recursion] level” (see Figure 10a). A sighted but blindfolded participant, who spent 9 minutes, drew the second-highest rated cube (see Figure 10b). This participant commented that he was trying to visualize the cube in his mind rather than with reference to the grid. These results show that a grid-based model is a useful schema for allowing users to create graphics in a non-visual environment. The grid allows visually impaired users to identify relative and absolute positions. It is essential to provide visually impaired users with a mechanism for determining perspective when interacting with graphics [5, 13].

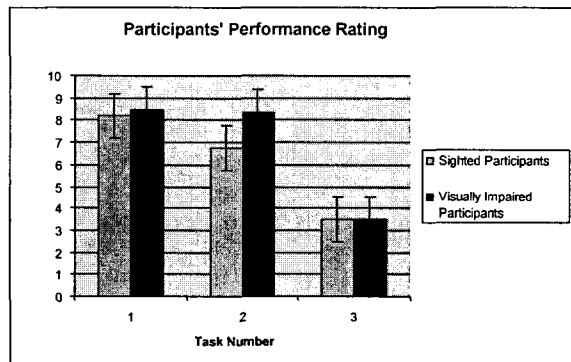


Figure 9. Average performance ratings, based on quality, for sighted and visually impaired participants.

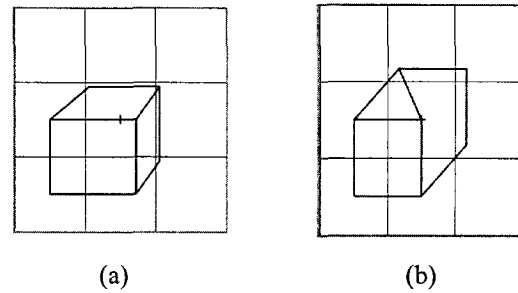


Figure 10. a) A blindfolded partially sighted participant replicated a physical cube by counting grid positions. b) A blindfolded sighted participant drew this representation of the cube by visualizing it in his mind.

CONCLUSIONS

Some visually impaired users who have worked with IC2D for more than four weeks have demonstrated that IC2D is a tool that can be used on a daily basis to communicate graphical information. In a previous study we conducted [13], a partially sighted participant drew a pig using a Sewell line drawing kit [6] (see Figure 11a). The same person blindfolded drew an accurate image of a pig after using IC2D for about four weeks (see Figure 11b). A totally blind user created the festive Christmas tree in Figure 12 after approximately five months of using IC2D. These two long-term IC2D users both possess some training in art.

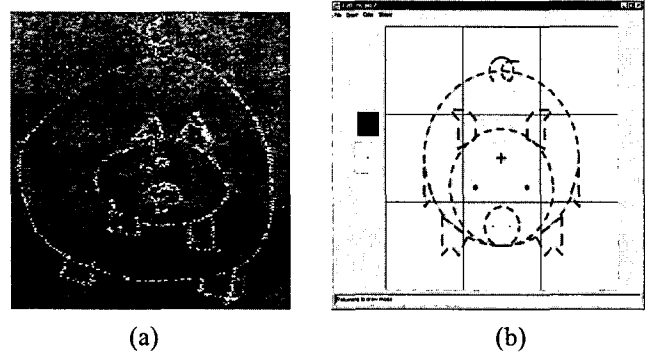


Figure 11. a) Drawing using a stylus and pressure-sensitive plastic sheet. b) Drawing by same participant using IC2D.

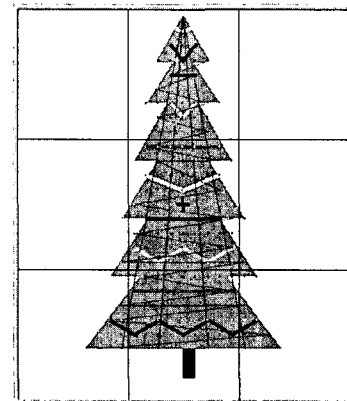


Figure 12. Drawing made by a totally blind IC2D user.

The use of picture-based computer interfaces has made computer use increasingly difficult for the visually impaired. One step in overcoming this accessibility gap is IC2D, a tool that combines a navigational grid and dynamic drawing with auditory voice output. Rather than force visually impaired users to adapt to a limited method for creating and accessing graphical information formatted for sighted users, we have attempted to analyze and overcome the disadvantages of current tools and implement methods more intuitive to visually impaired users. For example, all input for the IC2D interface is oriented around the keyboard. The use of this accessible input device allows blind computer users to create recognizable drawings, drawings which blind users can explore using IC2D, and through which they can graphically communicate with sighted people. Our evaluation of IC2D shows that visually impaired users can employ 2D drawing applications with the accuracy of sighted users.

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