Communicating through Gestures without Visual Feedback

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ABSTRACT

Human-machine interaction by gestures helps to improve communication: it utilizes means of communication which are common to humans but alien to machines. We consider ergonomic, functional and semantic issues in gesture-based interfaces without visual feedback. Such situations arise with the unobtrusive usage of wearable devices but, more importantly, with interfaces for visually impaired persons. We consider the latter scenario – that of blind users – in view of forthcoming haptic interface technology and investigate properties of gestural interaction models.

Categories and Subject Descriptors

H.5 [**Information Systems**]: Information Interfaces and Presentation; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Haptic I/O, Input devices and strategies, Interaction styles*

General Terms

Experimentation, Theory

Keywords

Gestural interaction, Visually impaired, Nonvisual communication, Haptics

1. BACKGROUND

Typically, communication involving humans is highly multimodal. When specific information channels are unavailable substitute means of communication are used, resulting in an increased use of alternate channels or in a loss of information or both. In multi-directional communication, the modes may vary according to the respective parties involved. In this paper we report on research concerning the communication of a blind person with a computer and, in particular, on how to use planar gestures as a means of computer input.

For a human communicating with a computer the predominant means are still as follows: Human-to-computer communication (computer input) uses keyboard, voice and pointing devices; in all cases including ones not mentioned, there is usually a feedback, mainly visual and supported by sounds. For computer-to-human communication (computer output) there is a very large variety of visual and acoustic modes available. The distribution of modes between human and computer is quite unbalanced. Some important channels available to humans, like those corresponding to the senses of touch, smell or taste, are only used rarely if at all in human-computer-communication; the heavy reliance on just vision and hearing incurs an inevitable loss of information. This situation is acerbated when the human's ability to use vision or hearing is impaired or absent.

For a blind computer user the visual feedback as well as the visual output have to be substituted, and this is mainly achieved by haptic and acoustic devices together with some kind of keyboard and voice used for input.

Common classifications of human interaction with a computer or a machine are according to types of tasks or interface media. We assume the reader to be familiar with the relevant literature (see [4, 34], for example; for gestures see [25]). Devices and tools typically available to a blind computer user are as follows:

- For computer input: standard keyboard, Braille keyboard, voice (spoken language).
- For computer output: refreshable Braille display[1], embosser, voice (synthesized speech), sound. Among these, mainly a refreshable Braille display, voice or sound are

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[1]This is a single line of Braille cells, usually 40 or 80, each of which can display one Braille character.

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used for feedback. Screen readers provide some of the required software support for output.

Simple text documents can be accessed with acceptable effort by these means. Creating or manipulating text documents including their layout is severely impeded by the limitations of the devices – imagine writing a well-structured letter with a single line of output as feedback. Accessing a complicated document, involving, for example, hyperlinks, mathematics, tables, diagrams or other graphics, usually requires that the document be 'printed' first – for instance on an embosser; this implies that direct manipulation of such an object, creating or changing it or observing its changes in real-time is impossible. Specifically, information processing in environments like those of Internet Explorer, Word, Excel, PowerPoint, Photoshop or LaTeX (or their respective counterparts) is extremely cumbersome, if at all possible; even the seemingly simple task of writing a software program or a device specification is very hard. For a comprehensive survey concerning communication for the blind see [30]; that survey reflects the state of the art in early 2008.

In this paper we focus on access to and manipulation of, information which, by its very nature, is best rendered in 2 or $2\frac{1}{2}$ dimensions[2]. We distinguish two scenarios: (1) the information is static, does not change, and will not be manipulated; (2) the information is dynamic, short-lived, changed frequently, and might have to be manipulated. These are extremes, and other scenarios exist; for our purpose this limited view suffices to explain the relevant issues.

The static case is essentially that of traditional books. A 'printing' by embosser or a similar process will create a 'permanent' document. Reading by touch can be enhanced using a device like the Talking Tactile Tablet [16, 17], for instance, or the framework for talking diagrams proposed in [5, 27], thus supplementing the haptic information by acoustic information. However, many features of such an approach are unacceptable in a dynamic setting like that of browsing through web pages. To render haptic information, a refreshable planar haptic display is required; the rendering may then be supported by additional acoustic information. One such display, the Metec DMD 120060, has been available since about 1985[3]; it is shown in Figure 1. A successor prototype, referred to as the BrailleDis 9000 in the sequel, is being developed in the HyperBraille project [8]; it is shown in Figure 2 and described in [36]. Both versions, though quite different with respect to technology, performance and interaction capabilities, have the following features in common: The displays consist of 60 rows of 120 dots each at roughly the usual Braille dot distance horizontally and vertically, which can be raised or lowered; moreover the positions of some or all fingers on the display are available as input through sensors. In the older device the sensors are two moveable rings as seen in the figure; essentially, their positions are reported back to the computer as co-ordinates of the dots inside the rings. In the new model, the sensors are embedded in the modules of the display and activated by touching.

[2]By $2\frac{1}{2}$ dimensions we mean that, in addition to the two dimensions defining the plane, a very limited amount of height information is made available. In the sequel this case is implicitly included in discussions of planar renderings when the technology supports it.

[3]Five copies of this display were produced; four of these are still in use in research projects.

Figure 1: The DMD 120060.

The analysis and proposals regarding communication by gestures discussed in the sequel do not depend on these specific devices, but exploit experience gained from their use. The abstract setting to be considered is explained further below.

Haptic computer interfaces are still very much a subject of ongoing research. In 2005 the ISO working group ISO TC159/SC4/WG9 was convened to define guidelines and standards for haptic interfaces. The current drafts include, in particular, detailed lists of relevant terms with their definitions and recommendations for their realization [9]; see also [2, 6].

Figure 2: Prototype of the BrailleDis 9000.

Why would one want to have gestures at all as input mode for blind computer users? A planar haptic display is usually explored (read) with both hands and several fingers of each hand. To use a keyboard for input requires that the hands be moved off the display; when they return to the display after completion of the input their original placements have been lost and must be found again through exploration of the display; this is a tedious process. Moreover, neither keyboard nor voice input provide a direct reference to the actual finger positions and the objects under scrutiny. On the other hand, a pointing device – a pen, a mouse or something similar –, when placed beside the display, leads to similar re-orientation problems or, when placed on the display, prevents the fingers from touching the display and, hence, from reading. Gestures performed by the hands directly on the display avoid the re-orientation problem, can provide reference to the objects being examined and could permit an interleaving of reading and input.

Concrete early proposals to use gestures as means of input for blind computer users are reported in [37, 38, 39, 40, 41]; see also [30] and [33].

2. SCENARIOS

We assume the following abstract setting:

- a haptic planar or three-dimensional display, possibly using virtual reality technology, to present both textual and non-textual information;
- sensors or cameras for recognizing the positions of hands or fingers or other body parts placed on or in the display;
- no visual feedback, but possibly haptic or acoustic feedback;
- alternate means for lengthy inputs like texts, pictures, sound etc.;
- possibly easily reached keys or other touch-sensitive areas on or close to the display area.

While we do not exclude three-dimensional explorations, for instance using data gloves or pressure sensitive devices in virtual reality, from consideration in principle, the scenario we envisage in this work is far more modest.

We assume that the sensors report time-stamped data concerning location (co-ordinates) and possibly also pressure.

The input tasks to be performed using the haptic channel include the tasks typically achieved by a pointing device like a pen or a mouse, such as pointing, selecting, dragging etc., and those achieved using special commands or special keys. Additional tasks would include drawing and following displayed information. In this paper we focus on 'simple' tasks to be performed using gestures. A more general discussion of interaction techniques involving a planar haptic display is presented in [29].

The haptic display DMD 120060 and its successor, the BrailleDis 9000, developed in the HyperBraille project serve as examples with which to test our proposals, keeping in mind, however, the more abstract setting. These two devices and others envisaged have in common that the display serves as both an input and an output device, simultaneously, and uses the same channel for all communication.

3. GESTURE CLASSIFICATION

In [24] a gesture is defined as any movement of an individual which shows a communicative intent. A classification of gestures based on function or rôle is proposed in [12, 23]; see also [7].

Levels of a gesture description model can be distinguished according to the following criteria linking technical issues with issues of signal processing, feature selection, information coding and user-centred issues related to perception and cognitive processes [33]:

- Signal level: Time-variant physical data as obtained from the device. The nature of these data is highly device dependent. For instance, the DMD 120060 issues a sequence of co-ordinates of the two rings, identified by their numbers, according to a cyclic scan of the device; the BrailleDis 9000 returns a sequence of touch-intensity data and co-ordinates from modules where touching has been detected. In a camera-based setting a different kind of data would be available. Interpreting the signals depends, of course, on their nature. This issue is crucial for the design of new devices. In this paper, we assume that the problem of interpreting the raw data has been solved[4].
- Feature level: From sequences of signals one extracts features like stroke types (see [21, 22]) which are the constituents of abstract gestures. The difficulty of this task depends not only on the type of signals provided, but also on the selection of features. In the case of manual gestures, this process depends on many parameters including: the number of fingers involved; other parts of the hand involved; multiple users' hands involved[5].
- Information encoding level: Features or sequences of features are mapped to meanings. The procedure is that of abstracting from concrete physical data to gesture types or 'abstract gestures'. In our context the main issues are those of distinguishing and recognizing gestures. Without visual feedback, the same abstract gesture can have vastly different actual shapes and these may not even be repeatable[6].
- User level: Here we deal with a variety of interaction issues including perceptive, cognitive and ergonomical ones like the following: resolution of the perception of a feature; reproducibility of a feature; complexity of information encoding; mental models of gesture types; matching gestures to models, etc. Different features of the device influence the user's behaviour.

We refer to [9, 25] for further details. The specific issue of gestures without visual feedback is not addressed there, however.

4. GESTURE RECOGNITION

The recognition of gestures is a special case of scene analysis. Events are recognized as such and then interpreted. The recognition of gestures is simpler than the general task of scene analysis as gestures have a limited 'vocabulary'. This is true even for non-standardized gestures like those supplementing speeches, but even more so for gestures in structured settings like conducting (see [14]) or sign language (see [28]).

We assume the existence of a vocabulary of gestures in which abstract gesture types and their associated meanings can be looked up. Such a vocabulary can be pre-defined or user-defined or generated on the fly through a learning process. We also assume that a device or algorithm for the translation of concrete gesture data into gesture types is available. However, we also consider the consequences of a lack of visual feedback. This imposes a limitation on the physical aspects of gestures which must not be ignored.

[4] Clearly, it would be useful to obtain more and better structured data for processing than are provided by current technology.

[5] Neither scenario is uncommon as observed with both the DMD 120060 and the BrailleDis 9000.

[6] Training or learning programmes might meet their limits in this context.

5. GESTURE FUNCTIONS

We assume a bounded (small) set of functions related to abstract gestures as looked up in a vocabulary. This means that concrete gestures are subsumed into equivalence classes. Distinguishing between these is a matter of the 'feature level', but will also be considered further below.

Many functions of gestures can be drawn from the ISO documents [9]: *Pointing, selecting, moving, tracking, tracing, entering, dragging, pushing, pulling, displacing, directing, grabbing, releasing, hitting, rubbing.* Others, like *sweeping,* arise from the specifics of haptic displays without visual feedback [36]. Speed and direction of movement have been proposed to control scrolling (see [13]). There is a large variety of functionalities to be distinguished by very few abstract gestures.

Various types of gesture-based menu selection schemes have been discussed in recent years. Most of them were motivated by special input features like pens or by display constraints (see [15, 35, 43], for example). These proposals, like marking menus, provide interesting paradigms to be investigated in our setting. There are some key differences however: The sensorical resolution of both the user and the display are far less than what is considered in that work. Executing gestures on a haptic display with fingers and recognizing such gestures is quite different from doing so on a pen-based display. The resolution of both the user's fingers and the display is far less than the resolution of any of the common video displays. Thus it is much harder to distinguish features on a haptic display than on a video display. This is not a matter of technology, but a matter of principle.

6. INITIATING AND FINISHING A GESTURE

As the display is used for both, output and input, it is necessary to distinguish between these modes. This kind of problem is familiar from various system interfaces: during keyboard input using an editor one needs to switch between actual text input and controlling commands; a similar situation is encountered with voice input or in document processing with markup. In all such cases a special escape construct is used to indicate the switching of modes. In traditional editors this is achieved by a special key; in voice input special command words surrounded by pauses are often used; in markup one uses a special character sequence. The success or failure of the switching is often indicated through visual feedback.

For our setting, the following escape methods for switching between modes are being discussed:

- Voice input: Objections to this proposal have been overwhelming. The main reason given was that voice input cannot be used in a multi-person environment, like an office or the public. The annoyance caused by users of cell phones would corroborate this argument. This does not rule out voice input as a means for switching, but limits its applicability.

- Special gestures: Such gestures would have to be significantly different from all expected hand movements to be distinguishable. We have considered certain kinds of tapping with fingers or rolling the hand as options. Whichever form is chosen, the gesture needs to be extremely special so as to avoid accidental confusion with normal movements. After initial considerations we have postponed pursuing this option in favour of first conducting a series of experiments.

- Special keys: Such keys would be easily reachable with hands placed on the display, hence in close proximity of the display area. It would be sufficient for them to be reachable with a single finger, and preferable if this did not require the movement of any other fingers[7]. Taking into account the nature of the exploration of a haptic display, the design and placement of such keys needs to take ergonomic criteria into account: The keys should not only be easily reachable, but it should be close to impossible to activate them during normal use. This rules out keys at positions where hands would normally rest or work and keys which are triggered with little resistance. On the other hand, as mentioned, the keys should be in easy reach and easily found. Experiments will be conducted to guide the design; our present and rather naïve proposal is to provide a touch-sensitive strip to the left and right and at the top of the display area, to serve as such an escape key or a set thereof; the bottom should be avoided as this is where hands might rest.

The present version of the BrailleDis 9000 has keys, the usability of which is not obvious and needs to be tested. We have proposed that a new version of the display be built on which the ideas suggested above can be experimented with. We hope that this modified version will be available for testing soon.

Finishing a gesture seems less difficult: Lifting – of a finger, of fingers, of a hand, of both hands – could be enough to indicate that a gesture has ended. This could be achieved with practically no displacement when the hands are moved back onto the display. This and other options will be tested on the BrailleDis 9000.

7. GESTURE FEEDBACK

Feedback to user actions is a standard requirement; it is normally provided visually or acoustically or by a combination thereof. Feedback is to be distinguished conceptually from computer output as carrying a different kind of meaning. Typically, feedback may indicate which action has been activated, the status of its execution, its success or failure, reasons for failure, or access to help information. When visual feedback is unavailable, other means have to be substituted.

- Acoustic feedback: In the presence of visual feedback, acoustic feedback is usually limited to a few sound patterns. Without visual feedback, much of the task could be performed by sound or voice output. In contrast to voice input, acoustic output is less intrusive as the sound can be kept local, for instance by earphones.

- Haptic feedback: It is conceivable to use vibration patterns or changes in the haptic output to indicate the status of an action. With respect to the low resolution of haptic devices this is, most likely, confusing rather than helpful.

[7]This idea is, of course, similar to that of the escape key on a normal keyboard.

Of course, it is possible to combine these methods to various degrees. There are, at present, no experimental data to support either view. General issues of non-visual feedback which would need to be considered have been studied in [1, 26, 35, 42]

Among the purposes of feedback that of reporting a mistake is particularly important. Even for sighted users this issue is handled badly in most commercial systems. Without visual communication, supplying critical information about interaction failures and supporting corrective measures is even more difficult. As far as we know, this aspect of interaction has not been studied systematically at all.

8. GESTURE FORMS

Gesture forms can roughly be described by the following criteria – restricted to gestures produced with hands:

- Single-finger gestures: These resemble input produced by a mouse, by a pen or on a touch pad.

- Multiple-finger gestures, single-person gestures: The fingers could work toward a single functionality or a combination of functionalities. For instance, rhythmic tapping with alternating fingers of one hand could indicate a musical theme as performed on a piano to initiate a specific action. Combined movement of fingers could indicate grabbing or zooming.

- Multiple-person gestures: For the DMD 120060 and also the BrailleDis 9000, we have frequently observed several users exploring the display simultaneously, thus sharing information; this type of interaction can be useful in a teaching environment, for example.

- Tapping: This can be with or without a specific rhythm; it can involve a single finger, several fingers and even other parts of the hands. Mouse clicks are analogous to tapping with little or no rhythm. As rhythmic tapping we mentioned 'piano playing' above. Using Morse code, which can be done with a single finger, is another example (see [21]). The Morse code is pre-defined, but may be too complicated to learn in its entirety for the purpose; it could be substituted by a simpler and more restricted code, however.

- Drawing a shape: This comes to mind first when one thinks about gestures. Typical gestures would include check marks, circles, underlining. The shapes will have meanings attached to them.

- Chording: By combining spatial, temporal and multiplicity information about finger or hand contact, complex information can be transmitted using a very simple encoding scheme. Certain cases of tapping or drawing can also be considered as chording. As a simple example to illustrate the concept, consider a five-bit binary code, such that each of the 31 non-zero code words is represented by the corresponding combination of fingers of one hand placed at appropriately selected positions on the display. Also the communication system of *finger Braille* uses the method of chording [19, 20].

- Lifting: Removing fingers or hands from the display can also be made to carry a meaning and thus be interpreted as a gesture. This might be used to indicate the end of a drawing for instance.

- Gestures with fixed locations relative to the display space: This assumes the perception of a feature to which to move in the display space. The gesture is then performed relative to that feature. Pointing is an example of such a gesture.

- Gestures without fixed locations relative to the display space: The gesture is performed anywhere in the display space. A typical example could involve issuing a computer command.

- Gestures involving fingers vs. gestures involving other parts of a hand: The latter could be performed by placing the palm of the hand on the display or by rolling the hand on the display.

This list is by no means complete, nor is the classification orthogonal. We selected some of the main criteria for distinction and presented these in a simplified form. The selection should indicate the complexity and diversity of the issues which need to be addressed. A more detailed taxonomy is being prepared in [33]. Some of these gestures require specific technical support. All of them are possible in principle on the new BrailleDis 9000; the older DMD 120060 is limited to gestures with one or two fingers and mainly to drawing, slow arrhythmic tapping and lifting.

9. GESTURE ERGONOMICS

For general issues regarding the ergonomics of haptic human-machine interaction we refer to [9]. Specific issues regarding the nature and placement of interaction areas on a device like the BrailleDis 9000 have been discussed earlier in this paper. For the ergonomics of gestures as such, there is no comprehensive framework at present.

10. EXPERIMENTS AND FACILITIES

Several experiments were conducted as a preliminary study of simple forms of gestures without visual feedback [31]. Parameters under consideration included the degree of accuracy achieved in the shape of the gesture, the variation in the act of performing the gesture and the confidence and preferences regarding various types of gestures. Special movements, with body parts different from the hand performing the gestures were noted when they seemed relevant.

These experiments were conducted with six blindfolded sighted subjects having significant experience with computers and pointing devices (like mouse, touch pad). Finger paint was used to draw the gestures on separate sheets of paper[8]. This was repeated in a random order of gestures by each subject several times. The shapes to be drawn were first explained verbally and then performed once by guiding the subjects' hands. The subjects were to use one finger according to their preferences for the actual drawing; some used additional fingers or the other hand for help. Typical shapes requested are shown in Figure 3: The set shown is

[8]The gesture input on the DMD 120060 is too slow. On the other hand, the prototype of the BrailleDis 9000 was still under construction when the experiments were performed.

just a sample; for instance, the gesture ‘north’ is also present in other directions. The dot indicates the intended starting point; the arrow indicates the intended direction. Although obviously limited in many ways, these experiments achieved their intended purpose of providing some first insights in the parameters involved, the phenomena to look for and of giving some guidance for the design of a more comprehensive set of tests.

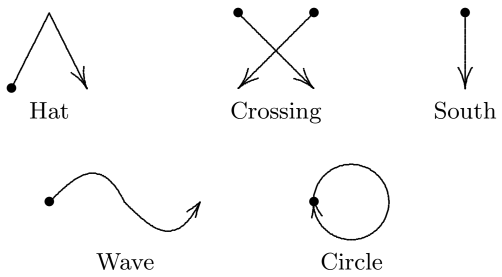

Figure 3: Examples of pre-defined shapes of gestures used in the test.

In Figure 4 we show a few typical drawings selected from the more than 200 sheets of paper. The actual starting points and the directions can be observed from the varying thicknesses of the lines. For instance, the ‘hat’ was started at the bottom right end, moving up to the left and then down again; this is the opposite of the required direction as shown in Figure 3.

- Regarding the shapes of the drawings, one finds many of the characteristic features of drawings by blind persons as reported repeatedly in the literature (see [10, 11], for instance): objects not shaped correctly; lines shaky; lines not meeting where they should meet; objects not closed; etc. Typical problems with the closure of an object, that is, with finding an earlier point again, are seen in the two circles. With simple gestures these ‘mistakes’ turn out to be less pronounced than with complicated scene drawings. In part this may be due to the speed at which simple gestures can be drawn; in part also the fact that all subjects had prior visual knowledge of the expected shapes may need to be taken into account.

- The starting point and direction were often incorrect: With the single stroke, often ‘east’ and ‘west’ were confused, less often ‘north’ and ‘south’; this also happened when descriptions different from compass directions were used. The ‘hat’ and ‘cross’ in Figure 4 are both incorrect in this respect. The ‘wave’ starts and moves correctly (but is too long). One of the circles is drawn counter-clockwise.

- The number of repetitions can be wrong: This is visible in a very large number of drawings of the ‘wave’. We have also observed the wave upside down.

- For a complicated shape like the circle, sometimes the respective other hand was used to provide a reference point or a measurement.

- Subject-specific preferences regarding the directions of movements and the choice of hand were observed. This concerned not only ‘east’ and ‘west,’ where a correlation between direction and choice of hand could be suspected on the basis of our data, but also ‘north’ and ‘south’, where the latter was preferred.

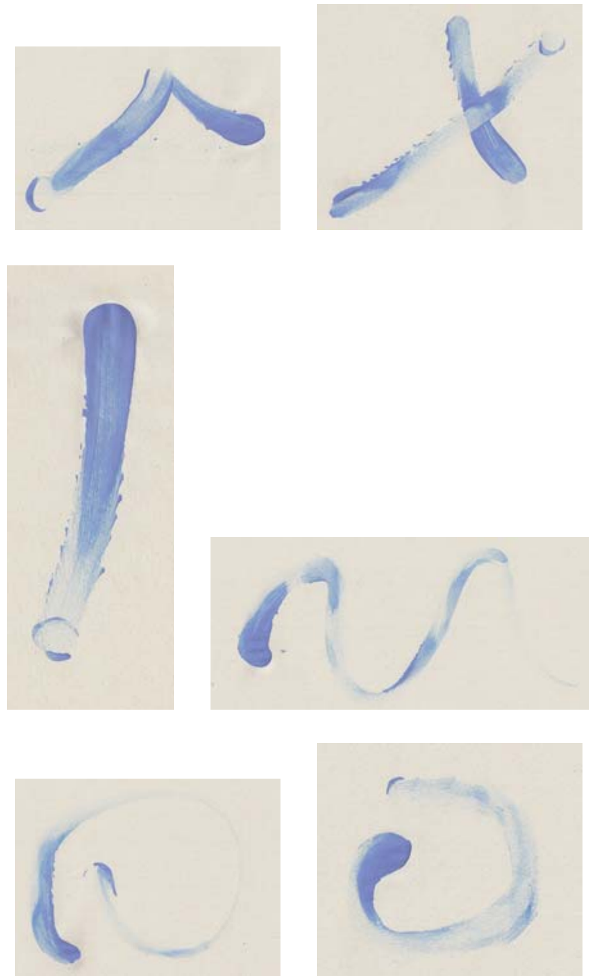

Figure 4: Examples of experimental gestures.

It is obvious that, without visual feedback, gestures are usually formed with a great deal of variation and that, consequently, the abstraction from physical data to abstract gestures must be very robust. Gesture shapes have to be quite different so as to avoid confusion and incorrect classification. Shapes need to be simple; specific features like peaks, hills or crossings can have quite a large range of appearances; repetition in a drawing as in the ‘wave’, which could be proposed to carry meaning, may actually not be useful. Direction of movement and temporal sequence need not be meaningful as criteria for distinguishing gestures. Using the second hand to enhance accuracy may be counterproductive in general as this requires moving that hand away from its current (exploration) task.

There were noticeable preferences of shapes. Moreover, a few additional shapes were suggested by the subjects. These and gestures not based on drawings will be included in a set of follow-up experiments.

11. CONCLUSIONS

There are specific problems for gestural interaction in the absence of visual feedback. These include: (1) determining a meaningful taxonomy of gestures; (2) selecting gesture types which are acceptable from a user's point of view with respect to ergonomics, perception and cognition, and which can be implemented efficiently with concrete displays; (3) determining appropriate mode switches (escape sequences); (4) choosing non-visual methods for feedback; (5) developing test criteria and test methods by which to evaluate gesture-based interaction. We have provided some recommendations and preliminary test results above. A more comprehensive study of test methods regarding gesture forms is being prepared and will be conducted using the BrailleDis 9000 of which a prototype has just become available to us a few weeks ago. Some related experiments regarding the ergonomics and learnability of gestures, which were recently conducted using the BrailleDis 9000, are reported in [32].

While there are many situations in which non-visual interaction with a computer-based device can be helpful and adequate for every type of user, a key situation is certainly that of blind persons working with an interactive haptic display. Experience shows that we cannot expect application programs to provide accessible interfaces themselves; substituting the visual channel by the haptic channel (supplemented by other senses) on a haptic planar display suggests the usage of gestures to simulate the typical features of a graphical user interface. As new refreshable haptic displays become available, developing a usable gesture-based non-visual interface seems to be a reachable goal.

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13. REFERENCES

[1] S. Brewster, J. Lumsden, M. Bell, M. Hall, S. Tasker: Multimodal 'eyes-free' interaction techniques for wearable devices. In G. Cockton, P. Korhonen (editors): *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI 2003, April 5–10, 2003, Ft. Lauderdale, Florida*. 473–480, ACM Press, New York, NY, 2003.

[2] J. Carter, J. van Erp, D. Fourney, S. Fukuzumi, J. A. Gardner, Y. Horiuchi, G. Jansson, H. Jürgensen, R. Kadefors, T. Kobayashi, M. G. Kwok, M. Miyagi, K. V. Nesbitt: The GOTHI model of tactile and haptic interactions. In Carter and Fourney [3], 93–95. Available at `http://userlab.usask.ca`.

[3] J. Carter, D. Fourney (editors): *Proceedings of GOTHI '05, Guidelines on Tactile and Haptic Interactions, October 24–26, 2005, Saskatoon, Saskatchewan, Canada*. USERLab, University of Saskatchewan, Saskatoon, 2005. Available at `http://userlab.usask.ca`.

[4] A. Cooper, R. Reimann, D. Cronin: *About Face 3: The Essentials of Interaction Design*. John Wiley & Sons, Indianapolis, 2007.

[5] M. Eramian, H. Jürgensen, H. Li, C. Power: Talking tactile diagrams. In C. Stephanidis (editor): *Proceedings of HCI International 2003, Volume 4: Universal Access in HCI, Inclusive Design in the Information Society*. 1377–1381, Lawrence Erlbaum Associates, Mahwah, New Jersey, 2003.

[6] J. B. F. van Erp, T. A. Kern: ISO's work on guidance for haptic and tactile interactions. In M. Ferre (editor): *Haptics: Perception, Devices and Scenarios. 6th International Conference, EuroHaptics 2008, Madrid, Spain, June 10–13, 2008, Proceedings. Lecture Notes in Computer Science* **5024**, 936–940, Springer-Verlag, Berlin, 2008.

[7] M. Fröhlich: *Ein wissensbasiertes Rahmensystem zur merkmalsbasierten Gestenerkennung für multimediale Anwendungen*. Dissertation, Universität Bielefeld, 1999.

[8] HyperBraille®. `http://www.hyperbraille.de/`.

[9] ISO 9241-9xx: Ergonomics of human-system interaction. Part 910: ISO/WD 9241-910, Framework for tactile and haptic interaction (working draft); part 920: ISO 9241-920, Guidance on tactile and haptic interactions (to appear); part 940: ISO/WD 9241-940, Evaluation of tactile/haptic interactions (working draft). Prepared by ISO TC 159/SC 4/WG9; for the general contents of these documents see [2], 2009.

[10] D. Katz: Der Aufbau der Tastwelt. *Zeitschrift für Psychologie, Ergänzungsband* **11** (1925). Reprinted by Wissenschaftliche Buchgesellschaft, Darmstadt, 1969.

[11] D. Katz: *Studien zur experimentellen Psychologie*. Benno Schwabe & Co, Verlag, Basel, 1953.

[12] A. Kendon: Current issues in the study of gesture. In Nespoulos et al. [24], 23–47.

[13] S. Kipke: Sensitive Braille displays with ATC technology (active tactile control) as a tool for learning Braille. In Miesenberger et al. [18], 843–850.

[14] P. Kolesnik, M. Wanderley: Recognition, analysis and performance with expressive conducting gestures. In *Proceedings of the 2004 International Computer Music Conference, ICMC '04, Miami, Florida*. 572–575, ICMA, San Francisco, 2004.

[15] G. Kurtenbach, W. Buxton: The limits of expert performance using hierarchic marking menus. In B. Arnold, G. van der Veer, T. White (editors): *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems, April 24–29, 1993, Amsterdam, The Netherlands*. 482–487, ACM Press, New York, NY, 1993.

[16] S. Landau: Tactile graphics and strategies for non-visual seeing. In *Thresholds 19*. 78–82. MIT School of Architecture, 1999.

[17] S. Landau, K. Gourgey: Development of a talking tactile tablet. *Information Technology and Disabilities* **7**(2) (2001).

[18] K. Miesenberger, J. Klaus, W. Zagler, A. Karshmer (editors): *Computer Helping People with Special Needs, 11th International Conference, ICCHP 2008, Linz, Austria, July 9–11, 2008, Proceedings. Lecture Notes in Computer Science* **5105**. Springer-Verlag, Berlin, 2008.

[19] M. Miyagi, M. Nishida, Y. Horiuchi: Conference system using finger Braille. In Carter and Fourney [3], 28–31. Available at `http://userlab.usask.ca`.

[20] M. Miyagi, M. Nishida, Y. Horiuchi, A. Ichikawa: Investigation on effect of prosody in finger Braille. In K. Miesenberger, J. Klaus, W. Zagler, A. Karshmer (editors): *Computer Helping People with Special Needs, 10th International Conference, ICCHP 2006, Linz, Austria, July 11–13, 2006, Proceedings. Lecture Notes in Computer Science* **4061**, 863–869, Springer-Verlag, Berlin, 2006.

[21] K. V. Nesbitt: A framework to support the designers of haptic, visual and auditory displays. In Carter and Fourney [3], 54–64. Available at `http://userlab.usask.ca`.

[22] K. V. Nesbitt: Structured guidelines to support the design of haptic displays. In Carter and Fourney [3], 65–74. Available at `http://userlab.usask.ca`.

[23] J.-L. Nespoulos, A. R. Lecours: Gestures: Nature and function. In Nespoulos et al. [24], 49–62.

[24] J.-L. Nespoulos, P. Perron, A. R. Lecours (editors): *The Biological Foundations of Gestures: Motor and Semiotic Aspects*. Lawrence Erlbaum Associates, Hillsdale, NJ, 1986.

[25] M. Nielsen, T. B. Moeslund, M. Störring, E. Granum: Gesture interfaces. In P. Kortum (editor): *HCI Beyond the GUI: Design for Haptic, Speech, Olfactory, and Other Nontraditional Interfaces*. 75–106. Elsevier, Amsterdam, 2008.

[26] A. Pirhonen, S. Brewster, C. Holguin: Gestural and audio metaphors as a means of control for mobile devices. In D. Wixton (editor): *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI 2002, April 20–25, 2002, Minneapolis, USA*. 291–298, ACM Press, New York, NY, 2002.

[27] S.-P. Poh: Talking diagrams. Master's thesis, The University of Western Ontario, 1995. Report 459, Department of Computer Science, The University of Western Ontario.

[28] M. Potamias, V. Athitsos: Nearest neighbor search methods for handshape recognition. In F. Makedon, L. Baillie (editors): *The 1st ACM International Conference on PErvasive Technologies Related to Assistive Environments, PETRA 2008, July 16–18, 2008, Athens, Greece. ACM International Conference Proceedings Series*, 8 pp., ACM Press, New York, 2008.

[29] C. Power: *Multi-Modal Exploration*. PhD thesis, The University of Western Ontario, 2006.

[30] C. Power, H. Jürgensen: Accessible presentation of information for people with visual disabilities. *Univ. Access Inf. Soc.* (2009), 49 pages. To Appear.

[31] M. Schiewe, I. Sturm: Gesten in HyperBraille, Test 1; Auswertung des Tests 1, 5+2 pp. Manuscript, Potsdam, April 2008.

[32] M. Schmidt, H. Weber: Multitouch haptic interaction. In *HCI International 2009, 13th International Conference on Human-Computer Interaction, 19–24 July, 2009, San Diego, California, USA. Lecture Notes in Computer Science*, To Appear, Springer-Verlag, Berlin, 2009.

[33] I. Sturm: Non-visual communication with gestures, 9 pp. Manuscript, Potsdam, 2008.

[34] H. Thimbleby: *Press on: Principles of Interaction Programming*. MIT Press, Cambridge, Mass., 2007.

[35] D. Venolia, F. Neiberg: T-Cube: A fast, self-disclosing pen-based alphabet. In B. Adelson, S. Dumais, J. Olson (editors): *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Celebrating Interdependence, CHI '94, April 24–28, 1994, Boston, Mass.* 265–270, ACM Press, New York, 1994.

[36] T. Völkel, G. Weber, U. Baumann: Tactile graphics revised: The novel BrailleDis 9000 pin-matrix device with multitouch input. In Miesenberger et al. [18], 835–842.

[37] G. Weber: Gestures as a means for the blind to interact with a computer. In H.-J. Bullinger, B. Shackel (editors): *Human-Computer Interaction – INTERACT '87, Proceedings of the Second IFIP Conference on Human-Computer Interaction, held at the University of Stuttgart, Federal Republic of Germany, 1–4 September, 1987.* 593–595, North-Holland, Amsterdam, 1987.

[38] G. Weber: *Interaktive Dialogtechniken für blinde Rechnerbenutzer*. Dissertation, Universität Stuttgart, 1989.

[39] G. Weber: Reading and pointing – modes of interaction for blind users. In G. Ritter (editor): *Information Processing 89, Proceedings of the IFIP 11th World Computer Congress, August 28 – September 1, 1989, San Francisco, USA*. 535–540, North-Holland, Amsterdam, 1989.

[40] G. Weber: FINGER – A language for gesture recognition. In D. Diaper, D. J. Gilmore, G. Cockton, B. Shackel (editors): *Human-Computer Interaction – INTERACT '90: Proceedings of the IFIP TC 13 Third International Conference on Human-Computer Interaction, 27–31 August, 1990, Cambridge, UK.* 689–694, North-Holland, Amsterdam, 1990.

[41] P. Wetzel: Erkennen von Gesten im Dialog blinder Benutzer mit dem Rechner. Diplomarbeit, Institut für Informatik, Universität Stuttgart, 1988.

[42] G. Yfantidis, G. Evreinov: Adaptive blind interaction technique for touchscreens. *Univ. Access Inf. Soc.* **4** (2006), 328–337.

[43] S. Zhao, P. Dragicevic, M. Chignell, R. Balakrishnan, P. Baudisch: earPod: Eyes-free menu selection using touch input and reactive audio feedback. In M. B. Rosson, D. Gilmore (editors): *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '07, April 28 – May 3, 2007, San Jose, California*. 1395–1404, ACM Press, New York, NY, 2007.