Investigating Phicon Feedback in Non-Visual Tangible User Interfaces

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Abstract
We investigated ways that users could interact with Phicons in non-visual tabletop tangible user interfaces (TUIs). We carried out a brainstorming and rapid prototyping session with a blind usability expert, using two different non-visual TUI scenarios to quickly explore the design space. From this, we derived a basic set of guidelines and interactions that are common in both scenarios, and which we believe are common in most non-visual tabletop TUI applications. Future work is focused on validating our findings in a fully functioning system.

Keywords
Tangible User Interface, Visual Impairment, Phicons

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation: User Interfaces - *Interaction Styles*.

General Terms
Design, Human Factors.

Introduction
Visually impaired and blind computer users face significant hurdles in accessing computer-based data. Screen-reading software is useful for textual data, but

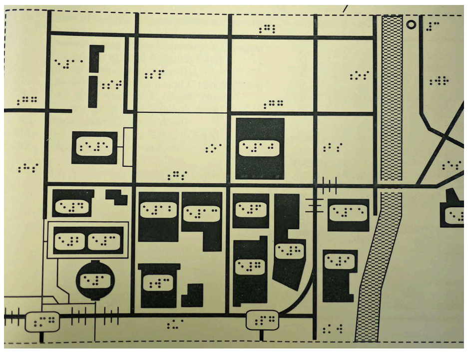

Figure 1. An example tactile map printed on swell paper. Passing the print out through a heat printer causes the surface to rise up creating a tactile relief.

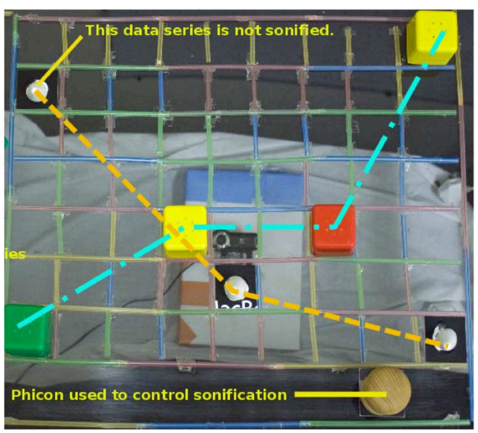

Figure 2. An example of the tangible line graph builder TUI by McGookin, Robertson and Brewster [1].Shown with two data series.

less so for the millions of charts, graphs, maps and other commonly used visualizations produced each year. In order to make this data accessible it must be specially formatted, usually by hand, and printed onto swell paper – special paper that causes the print surface to raise up when subjected to heat – to create a tactile diagram which can be explored through touch (see Figure 1). Such diagrams are inflexible and cannot be modified after creation or interactively manipulated [1]. They do, however, allow the user to employ both hands and the rich human tactile sense when exploring the diagrams. This allows the user to mark and spatially reference features. Much research has been carried out to present and allow manipulation of visualizations without the need to create these diagrams [2, 3]. Whilst successful, most of this work introduces new problems, such as the loss of two-handed interaction or impoverished tactile feedback [3]. More recently, researchers have begun to look at how tabletop tangible user interfaces (TUIs) can be employed non-visually, allowing the advantages of tactile diagrams to be retained but with the advantages of dynamic data display and modification.

Similar to visual tabletop TUIs, non-visual TUIs involve the user placing computer-tracked Phicons (physical icons) on a physical table. Manipulating Phicons [6] on the table surface controls a computer-based model of some data visualisation. Where non-visual TUIs differ, is that the model, rather than being visually displayed on the tabletop, is presented aurally through a sonification (a direct mapping between data parameters and sound, usually pitch) [5]. For example, Figure 2 shows a non-visual TUI to allow the interactive creation of simple line charts, such as might be the case at school [1]. Phicons represent control points for two data series and are placed in a physical grid. The system interprets these and infers the graph. This graph can be sonified when the user interacts with a special Phicon at the base of the graph or saved and restored at a future date.

Research Problem

Several examples of non-visual TUIs exist [1, 4, 5]. Whilst successful, there are not yet clear design guidelines in many areas. One important area is Phicon feedback. In visual TUIs, the sense of embodiment [6], that information is contained within the Phicon, is important. This means that data is projected, or otherwise visually shown, close to the Phicon. E.g. when placed on a map, a Phicon representing wealth may have the average salary of people living nearby to be displayed next to it. In non-visual scenarios this is not possible. In other examples, Phicons can visually alter their appearance in response to a query from the user (e.g. Ljungblad *et al.'s* tangible/digital film festival planner [7]). In non-visual TUIs this information has been shown to be useful (mostly as it has not been provided, yet it is requested by users [1, 4]). However, how it should be supplied, and in what way, is not clear. What are the common interactions that users would need to perform with Phicons, and how should the Phicons support being located non-visually?

Investigation Method

We are trying to develop answers to these questions by creating a set of basic guidelines to drive future research into non-visual TUIs. Development of an entire system and Phicons is both expensive and time consuming, and might limit the general applicability of the guidelines. Therefore, we have adapted a low-cost prototyping approach for this initial stage, allowing us

Figure 3. Phicons as used by McGookin, Robertson and Brewster[1]. Top to Bottom: a polystyrene cone, a heavy plastic cube and a wooden door handle. All are attached to a 4x4cm cardboard square.

try many things quickly in order to develop candidate guidelines that we will later validate with real applications. We developed two application scenarios (see next section) where a non-visual TUI could be useful, and derived tasks users would need to perform with it. We coupled this with the construction of exemplar Phicons illustrating a range of multimodal feedback and sensing options. Brainstorming with a visually impaired usability expert then identified common user interactions.

Application Scenarios

Our application scenarios were derived from two common uses of tactile diagrams: graphs and maps.

Graph Construction

The first application scenario was based on our previous work in developing a non-visual TUI to support the construction and manipulation of simple mathematical charts and graphs [1]. In this scenario, users would construct a bar chart or line graph with up to two data series. Each data series was represented by a different set of Phicons. Graphs are constructed by placing Phicons in a physical grid where they acted as control points (either the top of a bar or a turning point in a line series). We assumed that the TUI would have some notion of the correct answer, and could offer support if a Phicon was misplaced. We considered users would want to know the name or value of a data series, find a particular named bar in the bar chart, as well as label a data series or bar. These are all tasks that are common when interactively drawing graphs in school.

Geographic Investigation

We chose this scenario as it involved less structured data. Unlike the rigid grid structure of the graph example, the map was assumed to be virtual, and could be interacted with by the user moving his or her fingers across its surface, causing features such as roads or houses to be read out. This meant that Phicons could be placed anywhere and would be (theoretically) harder to find. This is likely to be the case if an online map that could be panned and zoomed by users was employed. The dynamic nature of the data means that it would not be possible to have enough tactile overlays, or switch those tactile overlays rapidly enough, for them to be useful. When placed on the table, Phicons would calculate statistics in their immediate vicinity (e.g. education level, poverty, wealth, etc.). Each calculated statistic would be represented by a different set of Phicons, similar to the multiple data series in the graph example. Again, we assumed users would be able to query the placed Phicons to find the highest or lowest of a specific statistic, e.g. the area with the highest level of poverty or lowest life expectancy. The example problems we developed were again derived from the kinds of problems users might be asked to solve in school. They required understanding relationships between the Phicons, such as between economic wealth and life expectancy.

Technical Development

When exploring design solutions it is common to sketch or to create paper-based prototypes to support discussion and quickly evaluate possibilities. These allow multiple solutions to be quickly and cheaply compared. This is harder when considering non-visual TUIs. Interaction is through other senses and requires a physical object to give a proper sense of how a task might be achieved.

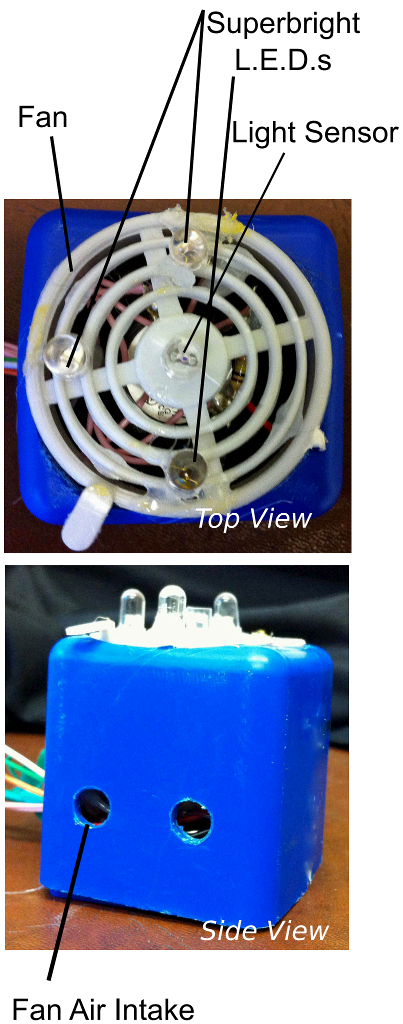

Figure 4. An illustration of the exemplar Phicon, illustrating its sensors and actuators.

To overcome this, we choose a hybrid approach using pre-existing Phicons from a previous study [1]. These Phicons (see Figure 3) are inert, but do vary significantly in physical properties such as size, material, shape, texture and weight. In addition, we constructed an exemplar dynamic Phicon. This contained a number of different sensing and output modalities that we could use to quickly prototype ideas that arose in the discussion.

This exemplar Phicon was constructed from a 4x4x4 cm cube (see Figure 4). Within the cube we embedded a small fan, similar to those used to cool computer chips. A grill was embedded into the top of the cube to allow the fan to blow out. We also inserted a small vibration motor into the cube, and took care that the motor was not powerful enough to move the cube independently. This would be undesirable in a real system. Many visually impaired users are not fully blind and wish to retain as much use of their vision as possible. Therefore, we added three superbright LEDs to the top of the cube. We also added a light sensor that could detect variations in light intensity, such as if covered with a hand (see Figure 4 top). An umbilical cable ran from the base of the Phicon to an Arduino (www.arduino.cc) microcontroller. The Arduino was connected to an Apple Mac that ran software to control the components in the Phicon.

Prototyping with Blind Usability Expert

To identify the requirements, and how the Phicons could provide these, we carried out a session with a usability expert who is both blind and specialises in non-visual accessibility. We started the session by introducing the problem area and each of the scenarios that were developed. This was followed by exploration of the Phicons, including demonstrations of each of the modalities on the exemplar Phicon. The session then proceeded by working through each of the tasks identified for each scenario. Possible solutions were tried out using a "Wizard of Oz" approach. The blind expert attempted to carry out some of the tasks with the different Phicons, while the experimenter acted as the rest of the system, manually controlling the exemplar Phicon and providing speech feedback. The "Wizard of Oz" approach also allowed us to incorporate a "virtual" accelerometer within the Phicons. The experimenter determined if a particular gesture had been performed and acted accordingly.

Results

The results of the session yielded three main areas of consideration in non-visual Phicon embodiment: Dynamic vs. static physical properties, types of interaction and, modalities and sensors.

Dynamic vs. Static Physical Properties

In the initial demonstration of the Phicons, the expert was immediately drawn to their physical, material variations, and identified that the layout of the LEDs on the exemplar Phicon formed a triangle. Static physical properties such as material and texture offer graspable identification, and the richness of the human haptic system is able to quickly identify different shapes and materials [3]. Dynamic physical properties, such as those in our exemplar Phicon, allow greater flexibility, but these can take longer to identify. They are also subtler, such as a change in the pattern generated by the vibration motor. However, there was a strong preference towards the use of dynamic properties wherever possible, as these were felt to be more flexible. In our geography scenario, for example, we assumed that a Phicon with different material physical properties represented each statistic. This would require a set of Phicons for each possible statistic to be created. A set of Phicons which varied only in their dynamic physical properties, retaining the same form factor, material and other static properties, would require a smaller set and allow each one to represent any statistical quality that the user wished. In practical applications however, there is a limit to the number of dynamic components a Phicon can contain, but static properties should only be relied upon if they represent attributes of the data that are known not to change.

Type of Interaction

Whilst carrying out the scenario tasks it became clear that there were three broad categories that Phicon interaction fell into.

Interrogation + response: This occurs where a user wishes to be informed of some attribute of the data represented by the Phicon. In our scenarios, this might be the name of a bar in a bar chart, the current statistical value of the map area around the Phicon, etc. The most straightforward way to accomplish this was through physical contact with the Phicon. In our prototyping we employed the light sensor, but any sensing technique to indicate the user is touching the Phicon would be suitable. This is distinct from gesturing with the Phicon using the "virtual" accelerometer, as this required the Phicon to be moved. Moving the Phicon made it difficult to replace in its original location. The response from the TUI does not need to, though it can, come from the Phicon directly. We tried both the vibration motor as well as speech feedback and both were felt to be equally useful. This allows feedback to be optimized through whatever modalities are available and appropriate given the task.

Attracting attention: This occurs when the system needs to alert the user to attend to a particular Phicon. This might occur due to a query, such as showing the area with the highest level of poverty, or alternately in the graph scenario, if a Phicon had been placed in the wrong location. There are few ways that grabbing attention could be achieved solely by the components within the Phicon. In the cases where we did identify solutions, these were dependent on user capabilities. For users with limited sight the LEDs are obvious solutions. Other than this, most of the devices within the exemplar Phicon require the user to be in physical contact. This cannot be guaranteed. Practically, this means that an auditory alert would need to be presented to indicate that a Phicon required attention. The user would then need to scan the area to find the correct Phicon (using localisation + homing). Confirmation could be provided by a vibration motor, or using the interrogation + response technique outlined.

Localisation + homing: This is closely related to attention. We separate them, as attention is more concerned with notifying the user about a Phicon rather than helping the user to find it. However, the differences between the two are subtle and may prove to be unimportant in time. A key point in exploring an unstructured data space is to gain an overview of what is around [3], as well as being able to find the relatively small Phicons. As our expert stated: *"You want something that is able to draw attention and receive attention when you are in the vicinity".* The fan in the exemplar Phicon could be felt from a height of 10-15cm. Therefore the user needs only to be in general proximity of the Phicon, rather than in direct physical contact. By moving his or her hand over the Phicons, such an indirect physical contact could provide a quick overview of where the Phicons are without the danger of knocking any over.

Modalities and Sensors

To gain the basic requirements outlined here, only the ability to sense that the user is touching a Phicon as well as having some way of interacting with the user when he or she is in proximity is required. We found little requirement for actuators that required the user to be in direct physical contact (e.g. the vibration motor or a hypothesized thermal interface). This means that such components could be used for other purposes, such as providing the rich feedback in response to queries previously outlined. There is a practical limit to the number of components that can be embedded within a Phicon, but we do not have enough information yet to suggest what those limits are.

Conclusions

Our aim is to reduce the large design space of non-visual tabletop TUIs by trying to quickly and cheaply identify basic, common requirements for Phicon feedback, and practical ways these can be implemented. The construction of an exemplar Phicon allowed us to show the practical design possibilities. This meant we avoided generating solutions that, whilst optimal, could not be implemented. We were able to play and try out different approaches and ideas in a way that would not be possible with fully constructed systems. Whilst we have made good progress in developing requirements, our next step is to validate them. This involves further prototyping sessions as well as implementing both of our application scenarios on a Microsoft Surface, and constructing Phicons that embody only the techniques we have identified. This will allow us to properly validate our findings, and allow us to significantly contribute to helping users more effectively connect with non-visual tabletop TUIs.

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References

[1] McGookin, D., Robertson, E., and Brewster, S. Clutching at straws: using tangible interaction to provide non-visual access to graphs. *In Proc. CHI 2010*. ACM.(2010), 1715-1724.

[2] Fritz, J.P. and Barner, K.E., Design of a Haptic Data Visualization System for People With Visual Impairments. *IEEE Transactions on Rehabilitation Engineering*, 7 (3), (1999), 372-384.

[3] Wall, S.A. and Brewster, S.A. Tac-tiles: Multimodal pie charts for visually impaired users. *Proc. Nordichi 2006*. ACM Press.(2006), 9-18.

[4] Choi, S.H. and Walker, B.N. Digitizer auditory graph: making graphs accessible to the visually impaired. *In Ext. Proc. CHI 2010*. ACM.(2010), 3445-3450.

[5] Riedenklau, E., Hermann, T., and Ritter, H. Tangible Active Objects and interactive sonification as a scatter plot alternative for the visually impaired. *In Proc. ICAD 2010*. ICAD.(2010), 1-7.

[6] Fishkin, K., A Taxonomy for and analysis of tangible interfaces. *Personal and Ubiquitous Computing*, 8 (2004), 347-358.

[7] Ljungblad, S., Hakansson, M., and Holmquist, L.E., Ubicomp challenges in collaborative scheduling: Pin & Play at the Gothenberg Film Festival. *Personal and Ubiquitous Computing*, 11 (7), (2007), 563-575.