Multi-Finger Haptic Interaction within the MIAMM Project

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Abstract

In this paper we provide a brief introduction to MIAMM – a multimodal system for exploration of music databases. Among the modalities supported, haptics plays a central role. In particular, multi-finger haptic interaction techniques for data shaping and exploration will be investigated. We explain our chosen methodology for designing these interaction techniques and compare our approach with previous work. To this end, we cover two aspects in more detail, a description of basic haptic building blocks to be used in a tool-box like fashion, and the notion of conceptual spaces, a means for describing the semantics of descriptors in the database in a pseudo-geometric form, well suited for both visualization and haptic interaction.

Keywords: Multi-finger haptic interaction, multi-modal, user interface.

1. Motivation

Haptic technology enables user interfaces to both create tactile sensations on the skin of the user as well as add the sensation of weight. In addition, active resistance can be provided to the movement of a user's hand.

Unlike more commonly used sensory channels such as audio and video, haptics has the unique property that input and output are tightly coupled. As a result, the same devices used to generate input to the machine can provide feedback to the user. This feature allows the user to immediately "feel" changes he makes to the data he manipulates. Through coordinated application of force feedback to multiple fingers on a user's hand, the sensation of manipulating and shaping complex user interface objects can be achieved. Such an interaction style can be compared to playing a musical instrument. The highly developed motoric skills of humans combined with the tight coupling between input and output allows musicians to play their instruments with virtuosity.

We believe that haptic technology will offer us the opportunity to design better user interfaces which feel more natural to the user, and that can be used in situations, where the eyes and ears of the user are focused on something else.

2. The MIAMM[1] project

The objective of the MIAMM project [10] is to develop new concepts and techniques in the field of multi-modal dialogs to allow fast and natural access to multimedia databases. In particular, the addition of multi-finger haptic interaction to other modalities will be of scientific interest. To that end, a prototype system will be designed and implemented that will serve as a test-bed for exploring these new types of man-machine interaction. For an application scenario guiding us in this effort, we chose music selection and exploration on a portable device with multi-modal interaction capabilities.

Such a device would be equipped with up to four keys positioned in a way that the fingers of one hand can each control one of those keys. The keys can both be pushed in and pulled out by the respective fingers along a certain distance and all fingers can operate in parallel. A key can actively exert forces to resist or aid the movement of the respective finger and provide vibrotactile signals to the fingertip. Figure 1 shows one possible incarnation of such a device.

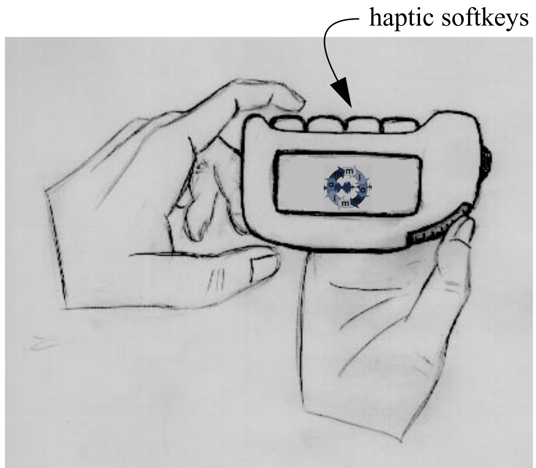

Figure 1. Artist's impression of MIAMM device.

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3. Overview

In the remainder of this paper we will focus on some central aspects of the conceptual work performed for the project. We explain our motivation for choosing a specific methodology, and explain how conceptual spaces help with the design of haptic interaction techniques and the corresponding visualization. Then we go into some detail about our classification of basic haptic building blocks used for single-key interaction. We conclude with a brief example of one of the multi-finger interaction experiments implemented for evaluation. But first, a short summary of the design issues relevant to haptic keys.

4. Haptic key interaction

When looking at force- and vibration-enabled keys, we can have several different perspectives: the keys as controls for the user versus the keys as haptic/vibrotactile displays for the system to feedback information; the keys as haptic elements versus the keys as vibrotactile elements; and the keys as separate keys versus the keys as a coordinated group of elements (like in a musical chord).

4.1 Control versus Feedback

Obviously, the manifest usage of the keys is for the user to control some parameter of the system (the 'device'). However, the system itself can use the keys to actively exert forces on the finger and also to display vibrotactile patterns to the finger. Thus, the keys can be used by the system to display any kind of information about the system's state. An example can illustrate this principle. Suppose the user has just used the keys to formulate or issue a search in a database and after some time is warned by the system that the search result has become available, e.g., through a vibratory signal. Feedback like this – actively given information by the system about the current system's state – should be distinguished from haptic and vibrotactile sensations passively relating to the way a particular type of key is pushed down or pulled at. Examples of this latter case are computer-controlled implementations of a zero-point indication (somewhat similar to the subtle equal-power click found on the rotary dial controlling the "balance" on many audio amplifiers), or the clicks felt when pressing down keys on a keyboard. Therefore, system feedback is feedback that depends on the system's state, not on the instantaneous position of a key. Haptic or vibrotactile signals that do depend on the instantaneous position of a specific key are there to facilitate the control functionality of that key and are therefore part of that control functionality. Note that, in order to move the keys, the user has to exert a force, which is why we might as well use the term 'haptic input' when referring to the control function of the keys.

4.2 Haptic versus Vibrotactile

Haptic signals consist of forces exerted on the finger aimed at influencing the finger's movement along the key's degree-of-freedom. The user may have various sensations resulting from these signals: the key might seem to resist movement, might seem to start moving itself, might feel spring loaded, etc. Vibrotactile signals consist of a sequence of localized vibrations, typically applied to the ventral or frontal side of the finger tips. The vibrations are usually within the 50-400Hz range, typically 250Hz in many applications. For the purpose of the MIAMM project we will assume that there is always only one vibrotactile element attached to each key. However, the sensitivity of the finger tips is such that a concept in which multiple independent vibrotactile actuators stimulate each finger is fully conceivable.

4.3 Single versus Multiple Keys

When using more than one key at the same time, new opportunities arise. A specific coordinated activation of multiple keys can then be defined to have a separate meaning. For instance, a set of three keys, each with its own functionality attached, might be given a new combined functionality, like: when all three keys are pulled at the same time, that concerted action is to be understood as a general 'escape'-command. There are many more ways in which multiple keys can be combined. We will therefore need to consider both the single key and the multiple key perspectives.

5. Methodology

Within the MIAMM project we deploy a multi-disciplinary approach to solving the issues associated with the given task by investigating all relevant aspects from four different angles (see Figure 2).

On the one side, the results from the task analysis effort specifically performed for the project provide us with a top-down view of the kind of tasks and operations users will perform while searching for music. On the other side, we are working on implementing an extensive collection of basic haptic and tactile interaction primitives as well as basic multi-finger grasping primitives. The domain model for MIAMM is designed to describe the music stored in our data base, and makes explicit the attributes and relations between music titles that we later rely on for searching.

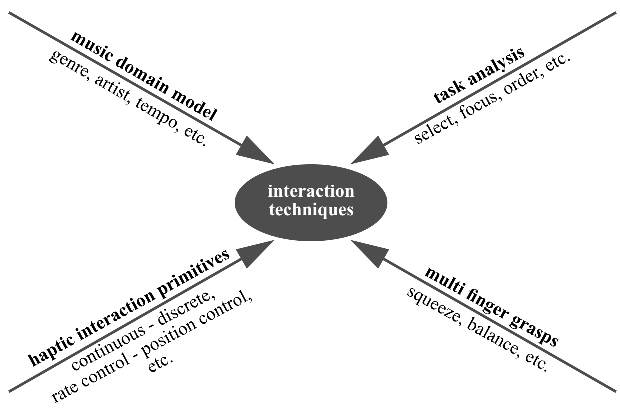

Figure 2: Design dimensions for haptic interaction techniques.

We are exploring the complete design space for haptic interaction techniques by finding promising combinations of elements along each dimension of that space: the attributes and relations from the music domain model, the basic user actions gained from the task analysis, an exhaustive set of basic haptic interaction primitives, and a collection of coordinated multi-finger grasps.The resulting fragments of user interaction are being implemented as prototypes and evaluated through a series of usability tests and formal experiments.

6. Conceptual spaces

As the MIAMM multimodal dialog also incorporates spoken language interaction, it features a rich knowledge base about the domain of our application: music content. Such a domain model consists of meta-data in the form of attribute-value pairs in conjunction with a semantic model that represents the actual meaning and interrelations among the descriptors. For instance, a traditional representation for the "genre" term would be a hierarchical taxonomy of main genre, sub-genres, etc. as present in online music-stores. The meaning and structure of less formal descriptors, such as for rhythm, sound or affective values, like "rocking", "yelling", "energetic", "romantic", are much harder to grasp. The space such concepts are occupying often eludes a rigorous formalization.

However, for direct haptic interaction in the underlying conceptual spaces, the system has to render them, literally, "graspable". Therefore, it is necessary to establish a link between concepts and physical or geometrical notions. A corresponding approach to concept formation in cognitive science, which indeed bridges the gap between semantics and geometry, is known as "conceptual spaces" [3].

Their principles of construction are a) to identify a number of "quality dimensions" which span the concept's space in combination with b) a topological or metrical notion of "closeness" or "distance". They should express phenomenal rather than physical dimensions, so as to reflect as far as possible human perception and intuition, based on "similarity" judgements.

Consider for instance the concept of "time of the day", which one would naturally associate with a circular topology of either 2×12 or 24 hours, rather than a bound interval [0–24]. Alternatively, consider color space, for which Cartesian RGB-triples are a possible structure. Humans, however, would judge similar colors rather by lightness, hue, and saturation, which suggests that HSL-triples on a color spindle (see figure 3) would be the more appropriate conceptual space for colors to live in.

The spindle model provides important cues for visualization and "haptization", as well as for interaction, filtering, or exploration of a color space. This example has been chosen deliberately, since in human (color-) psychology [4], there exist rich connotations between colors and emotions, sounds, or timbres, such as "bright" sound, feeling "blue", or feeling melancholic.

For the sake of discussion, let us suppose there exists a mapping between attribute values for music and for color that maintains the similarity metric for color, which can be used as a conceptual space for these attributes. Such a coupling is of benefit for the design of both aspects, the haptic and the conceptual one.

First, the geometric conceptualization is particularly useful for efficient haptic interactions, such as for data-shaping or filtering. Second, it is possible to evaluate how intuitive the conceptualizations chosen by the designers are through evaluation of the haptic and visual interface by users.

In terms of the chosen scenario, querying for similar content can be realized as a search for music of similar "coloration". Given the query results as a set, the size of it, a notion of mass, shape, and characteristic elements are then determined by means of the underlying conceptual space. These notions can subsequently be used for graphical as well as for haptic feedback. Moreover, haptic interactions can now be tightly coupled with the quality dimensions of this space.

For instance, squeezing a "color spindle" as a metaphor for shaping the sound space can be coupled with a corresponding filtering of result sets and rendered with real-time graphics (compare with the example given in the next section). Exploring or shifting focus can be guided or steered along quality dimensions of the underlying attributes, similar to the way dynamic vector fields are used in [2]. The user could sense a resistance that indicates how many (similar) items are located between the current and a more "rocking" selection, or he could explore the space towards a more "romantic" selection for an evening serenade, which the system would know to be located in the opposite direction.

From an architectural point of view, the modelling in terms of conceptual spaces allows for an abstract but expressive interface description between the haptics-graphics sub-system on the one side, and the dialog and domain model on the other side. Practically speaking, such a conceptual space can identify and define a number of

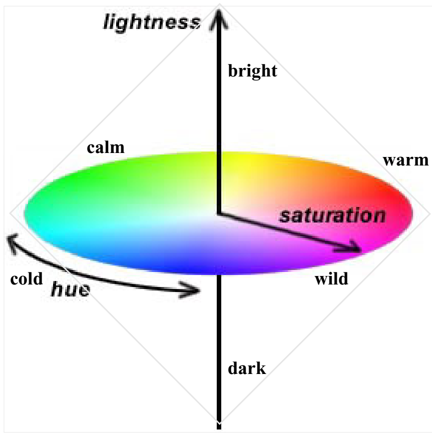

Figure 3. The HSL color spindle as an example for a conceptual space representing some simple affective values.

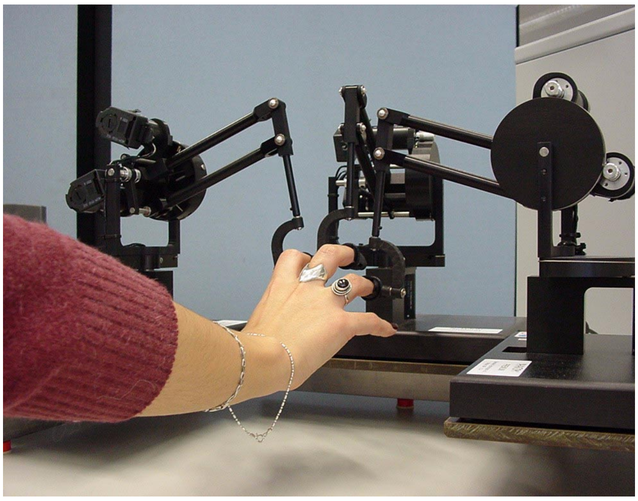

Figure 4. Picture of the multi-PHANToM setup.

"meaningful" dimensions, and their geometrical structure. Domain objects serve as input to the visualization and "haptization" units with pseudo-geometrical information added, which allows for efficient semantic-aware interactions. The output of a haptic interaction, e.g. a selection, can consist of a region in the conceptual space, rather than a mere set of items. Such haptic interactions in a closed-loop fashion for selecting, filtering, and data-shaping in an expressive, content-aware database is the focus of our current research efforts.

7. Experimental system

For our experiments we are using a setup with multiple PHANToMs from SensAble Technologies [11] controlled by a single PC. The software is based on the *GHOST* SDK provided by the manufacturer.

As shown by the picture in figure 4, one particular configuration consists of three PHANToMs arranged in a half circle that allows a user to put his index finger, middle finger, and ring finger into the end gimbals of each of the devices. By restricting the degrees of freedom of each PHANToM to a straight line in space perpendicular to the surface of the desk, we can simulate the behavior of haptically enhanced buttons as sketched in figure 1. Different prototypes of haptically enhanced devices can be easily simulated with such a test-bed by replacing the constraints on the PHANToM's movement as mentioned above.

We have developed, and are still developing basic interaction primitives for both single-key haptic interaction and coordinated multi-key interaction.

7.1 Basic haptic building blocks

These low-level interaction primitives are the basic building blocks that can be combined to implement high-level functional (user) requirements.

In this paper we concentrate on one example of these basic building blocks. The design of the basic building blocks for single control keys (haptic input) is based on four classification dimensions with two levels each. Other classification dimensions and levels are conceivable, but we consider this to be the smallest set of dimensions and levels needed to describe the vast majority of all control types. We have thus derived a set of 16 basic mappings of key input to controlled parameter (table not shown here). These mappings only become apparent to the user when she can observe the value of the controlled parameter. Without such observations, the user is principally oblivious to the effects of her control actions. The classification dimensions used are:

- **scale type**: continuous vs. discrete. A continuous scale implies that the elements on it are ordered in a continuous way. A discrete scale implies that the elements are categorized and possibly ordered. The latter means that there exists a logical order among the elements, e.g., the ten years within a decade. Elements without a logical order are for example artists, styles, etc.
- **scale range**: from 0 to x versus from –y to x. Some variables will only have positive values, i.e., a scale from 0 to x (e.g., volume); while other variables have a scale from –y via 0 to x. The important difference between both scales is the marked position of the 0 (or neutral point).
- **control order**: position vs. rate control, i.e., the order of the transfer function between input and result. With position control, there is a fixed relation between the position of the key and the level of the variable under control. Position control (e.g., a classical turn dial for volume control) is only useful when the range of the variable under control is limited and can be completely spread along the range of movement of the key. In rate control (e.g., as in volume control with one button for volume down and one for volume up), one controls not the position of the variable under control, but the speed of movement along its scale.
- **special function**: absent vs. present. This dimension is added to implement special functions on one or both ends of the control range.

Haptic and vibrotactile signals can be applied directly during the control action to support the user in her understanding of what the key's current status is and what the mapping between key input and controlled parameter is. This can significantly improve the control performance. There are several aspects of the keys that can be supported. Some relate to the above mentioned mappings and therefore to the classification dimensions for single control keys outlined above; others relate to the status of the key in the context of the interaction. Some examples of these basic building blocks for force and vibration enabling of single key controls are given in Table 1.

Table 1. Example of basic haptic building blocks.

BBB code	Key Aspect	Support Function	Support Signal
B3FVE-01	Discrete steps	Border between adjacent elements is felt	Small force-bump or short vibration
B3FVE-02	Marked neutral Point	Unique point along scale can be located haptically	Several options, including a very small localized force pit
B3FVE-03	Endpoint notification	Physical end of range of key is felt	Impenetrable wall, simulated by highly repulsive forces beyond a certain point
B3FVE-04	Rate Control	Automatic recentering to rate=0 when key is released	Spring-loaded key, simulated by an elastic force that pulls the key to its neutral point
B3FVE-05	Special function	Indicate activation of the special function after having moved the key sufficiently in one direction	Several options, including a short, high-frequency pulsed vibratory signal
B3FVE-06	Marked default value	Reference point along scale can be located haptically	Several options, including a very small localized force pit
B3FVE-07	Finger hold	Provides a comfortable resting position for an inactive finger	A localized force pit of a certain extent, instantiated at the place where the finger is when the key becomes inactive

7.2 Multi-finger interaction

As an example of a multi-finger interaction we are currently investigating, consider the following scenario. A user places a query to a music data base and receives a large number of titles displayed on the screen as a result. The titles might be arranged as "stars" within galaxies (compare with Rennison [7]) in 3D space. The galaxies are grouped according to certain criteria such as genre, date of recording, and others pre-selected by the user. Instead of navigating within that space by flying through the space (as would be the preferred method in virtual reality applications) the user can shift his focus from one area in space to another by pressing down on one of the haptic buttons. If, for example, he depresses the button associated with "Jazz" harder than the one associated with "Rock", Jazz music titles fade away from the user relative to those categorized as Rock.

In this example, multi-finger interaction is used to shape a data set which can be compared to filtering. Other techniques are closer related to navigation in large data sets. The combination of such multi-finger interaction primitives with the single-key basic building blocks described earlier, provides us with the tools for our tool-box approach of prototyping new haptic interaction techniques.

8. Related work

The vast majority of haptic user interface applications can be categorized into two areas: One centers on using a general purpose, high degree-of-freedom (DOF) haptic device, like the PHANToM [11], for applications such as virtual reality, surgical simulation, and interaction with 3D graphics models. The other area of work in haptics is mostly related to the video game market where lower resolution force feedback effects are generated for dedicated, consumer grade devices, such as haptic mice, joysticks, and game controllers.

In all these applications, haptics is used to augment the interaction with virtual worlds with the explicit goal of making this interaction as realistic as possible. Rarely is haptics used to create new forms of man-machine interactions that go beyond immersive, virtual reality applications.

In [6] a handheld haptics media controller is described that allows the user to interact with streaming media such as video or music. The underlying concepts for the design of that device are explained in detail in [9]. In short, physicality is restored to digital media through a mediating dynamic system rather then by manipulating the media itself.

Our approach shares with these examples the combination of low DOF haptic interaction techniques with the use of mediating physical models to manipulate a highly complex search space. However, our research focus is directed towards applying haptic interaction to multiple fingers simultaneously.

Multi-finger, haptic interaction has been investigated mainly in the context of data gloves for virtual reality (VR) applications. A good example for such a device can be found in [1]. Such gloves allow for dexterous interactions with virtual objects by applying force feedback to multiple fingers of a user's hand. This capability has been exploited to enrich the sensation of grasping virtual objects in VR applications. In [8] an architecture for a multimodal user interface is presented in which such a glove is also used to read hand gestures. However, these gestures do not lead to any closed-loop feedback from the system.

In contrast to providing gesture input only, or the simulation of grasping real-world like virtual objects, our vision for multi-finger haptic interaction is about exploration of complex databases through the interaction with a virtual world that uses physical models which are not necessarily faithful copies of the real world, but allow for intuitive interactions with the semantic structure of the underlying content.

In [12] a multi-point haptic interface setup is described which is similar to the one discussed in this paper. Their paper addresses the perceptual and psycho-physical issues related to multiple contact point haptic devices. Our research is focused on finding new interaction paradigms made possible through the application of multi-finger haptics.

Another application of haptics can be found in the paper from Donal and Henle [2]. They describe using a PHANToM to interactively adjust complex animations of anthropomorphic figures. A parametric family of animations is encoded in such a way that a time-varying, high order vector field (HOVF) can be constructed. The user experiences this vector field as physical forces that guide him along certain trajectories such that he can avoid "bad" regions of the animation control space. This technique can be thought of providing means for manipulating a high degree-of-freedom system from a low degree-of-freedom control space.

In contrast to controlling the animation of avatars, the interaction techniques investigated in MIAMM are centered on exploration and similarity search in large music data bases. The low degree-of-freedom control space is comprised of the dimensions along which the user intends to explore the data base. The complete database constitutes the high dimensional system. As explained in more detail in the section about conceptual spaces, there is no "natural" path to follow in music exploration, as is the case with animations of anthropomorphic figures, which is typically based on data gained through motion capture.

9. Conclusion and future work

In this paper we report on the current status of the project MIAMM, which has now passed the conceptual phase leading to first prototype implementations. We focus on aspects of multi-finger haptic interaction for shaping data sets as part of the browsing and exploration of large music databases. To this end, we have developed a framework of basic, single-key haptic interaction primitives that can be combined to build more complex haptic interaction techniques. In addition, we propose the notion of conceptual spaces as a means to amend query results from a data base in such a way that both the visualization and the haptic interaction component can operate on such a set in a pseudo-geometric fashion.

Through extended evaluation both of the haptic interaction techniques and the fully integrated multimodal system we intend to gain insights into how haptics can best be applied to the task of search and exploration in large databases.

We expect this work to be the starting point of a development towards the design of a haptic/tactile toolkit comparable to those well established in the domain of graphical user interfaces.

References

[1] Bouzit, M., Popescu, G. Burdea, G. and Boian R. "The Rutgers Master II-ND force Feedback Glove". in Proc. of the IEEE VR2002 10th Symp. on Haptic Interfaces for Virtual Environment and Teleoperator Systems, Orlando, FL, 2002.

[2] Donal, B.and Henle, F. "Using Haptic Vector Fields for Animation Motion Control". In Proc. IEEE Int. Conf. on Robotics and Automation (ICRA), San Francisco, April 2000.

[3] Gärdenfors, Peter. "Conceptual Spaces: The Geometry of Thought", The MIT Press, 2000, ISBN 0-262-07199-1.

[4] Guilford J.P. "The affective value of color as a function of hue, tint, and chroma" In Journal of Experimental Psychology, June (1934).

[5] Mackinlay, J. D., Card, S. K., et al. "Semantic Analysis of the Design Space of Input Devices" In *Human-Computer Interaction* 5: 145-190 (1990).

[6] MacLean, K. E., Shaver, M. J., and Pai, D. K. "Handheld Haptics: A USB Media Controller with Force Sensing," in Proc. of the IEEE VR2002 10th Symp. on Haptic Interfaces for Virtual Environment and Teleoperator Systems, Orlando, FL, 2002.

[7] Rennison, Earl. "Galaxy of News: An Approach to Visualizing and Understanding Expansive News Landscapes" in Proceedings of the ACM Symposium on User Interface Software and Technology (UIST '94), Marina del Rey, CA. November 2-4, 1994.

[8] Shaikh, A., Juth, S., Medl, A. Marsic, I., Kulikowski C., and Flanagan, J.L."An Architecture for Fusion of Multimodal Information". In Proceedings of the Workshop on Perceptual User Interfaces, Banff, Alberta, Canada, October 1997.

[9] Snibbe, S.S., MacLean, K.E., Shaw, R., Roderick, J.B., Verplank, W., Scheeff, M. "Haptic Metaphors for Digital Media," in Proc. of ACM Symp. on User Interface Software & Technology (UIST '01), Orlando, FL, 2001.

[10] The MIAMM project web site: www.miamm.org

[11] The SensAble Technologies Inc. web site: www.sensable.com.

[12] Wall, S.A. and Harwin S.H. "Design of a Multiple Point Haptic Interface". In Proceedings of EuroHaptics 2001, Birmingham, July 2001.