Where are we with Haptic Visualization?

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Abstract

There is a growing interest into non-visual forms of data communication, not only driven by the need for accessible representations but also because researchers are realizing the potential of understanding information better or differently through other modalities. Thus, haptic visualization is an immature but exciting area; it represents the abstract realization of information through the use of tactile or force-feedback devices. Through such a realization the user can gain quantitative, qualitative or nominal understanding of some underlying data. This paper presents the growth and development of haptic visualization, shows current trends, and acts as a snapshot of history. In fact, we remember the past based on temporal landmarks: we remember what we were doing when we heard the news of 9/11. Thus it is interesting and useful to look at the subject in the context of key events and seminal work. Moreover, it helps us to not re-invent the wheel: something that is far too common with interdisciplinary work. Thus, we take a holistic approach to the literature and place the research in context of important historic events and seminal work, which shows the reader where we have been, and points towards the future.

1. Introduction

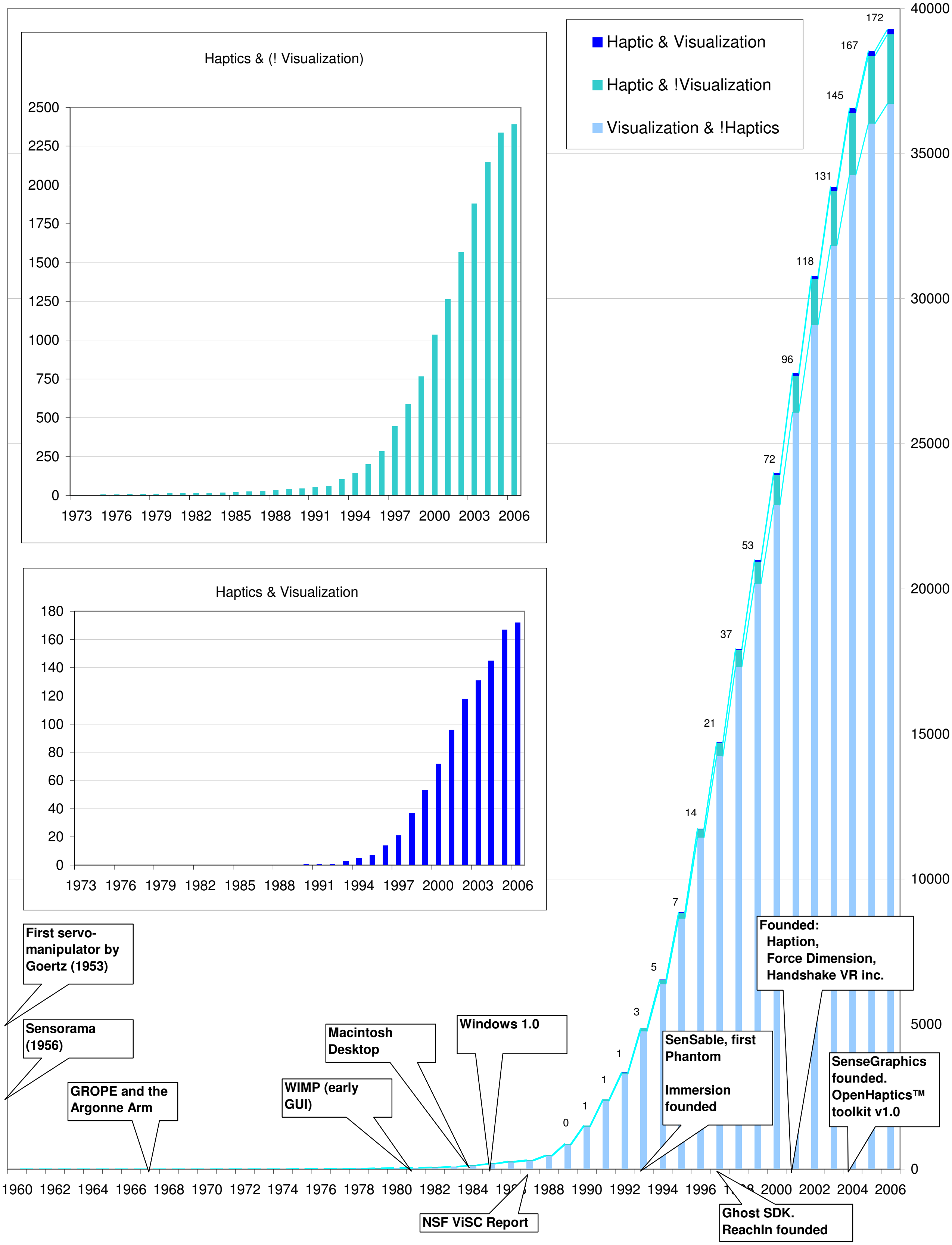
There is burgeoning interest into non-visual forms of visualization: utilizing touch and tactile devices, sound (sonification) and even smell (olfaction) to represent information [14]. Haptics is an important modality, which can be used to display information. This 'haptic display' may be usefully considered by three parts: first an electro-mechanical device that is capable of exerting forces to the user, second, a mathematical model that the user is trying to perceive, and finally 'haptic rendering', which computes the forces required to realize the model [42]. If the haptic display represents a room, then the model would allow the user to *feel* that a desk is solid, that a rubber-band is elastic, and that the wooden desktop is rough: It is the model that the user is understanding. Likewise, with haptic visualization, the user is aiming to understand the underlying model, perceiving that, for instance, the amount of rain fall has increased in comparison to last year, or that the average earnings in one town increased by 3.7% while it decreased by 2% in another town. In the instance of haptic visualization, the underlying model is an abstract concept that both holds the data and the mapping of that data into a tangible form. In visualization, the former is known as the *data table*, and the information is mapped into tangible information through *retinal variables*.

Since the 1987 report on Scientific Visualization [20] there has been a growth of 'visual' methods to help users perceive information. The word visualization has become to commonly mean 'a visual form or graphic representation of data'. We often hear people describing that they have generated a visualization of their data. Hence, the more purist definition of visualization, that incorporates the notion of 'forming a mental picture', gets ignored. We believe visualization to be a more encompassing word that describes a process; the process of transforming something (data) that is 'unseen' or un-perceivable in its current form into something (whether a graphic or sound or haptic sensation) that is 'seen' and perceivable.

Through haptic visualization the user aims to understand both qualitative and quantitative information, to gain new knowledge and understand the richness of the data source. Haptic visualization is different to merely creating haptic interfaces or as a modality to bring more realism to a virtual world; much the same way, as visualization is different to graphical-user-interfaces (GUI). It is true that graphical constructs are used in both visualization and GUI design – but the entities in a GUI tend to map to one unique function, for example by clicking on an icon it loads one program.

Over the last twenty years significant work has been published on all aspects of haptic visualization; we have certainly seen the development and commercialization of haptic devices, and important research has been achieved. Thus, this paper takes an overview of this research and places it into the context of key and significant events in history.

Figure 1. Growth of papers in Visualization, Haptics and Haptic Visualization



2 Key moments in history

Figure 1 shows some key moments in history related to haptic visualization. It is easy to see that haptic applications really took off with the development of force feedback devices. These early systems were initially developed as manipulators for teleoperation in the nuclear industry [35] to access remote and dangerous locations.

In 1967 Fred Brooks and his team developed the first haptic visualization; the project GROPE [4]. Their molecular docking application used the Argonne Remote Manipulator (ARM) to provide forces such that the user could *feel* the bonds between the molecules and interact with them. Through this exploration the user could explore and gain knowledge about that underlying molecular model. In fact GROPE is probably the earliest use of the term 'haptic visualization'. The visualization field itself really started flourishing after the NSF report into Visualization in Scientific Computing in 1987 [20].

While hardware and computer interfaces were rapidly improving, with the release of Windows and the Macintosh desktop, researchers were starting to develop haptic displays. Although initially expensive, the PHANTOM^{TM} [19] was warmly received. The development of the PHANTOM device and GHOST software and their widespread availability triggered the real growth of haptic techniques. Libraries and APIs such as GHOST SDK^{TM}, OPENHAPTICS^{TM}, Reachin^{TM} API and more recently H3D API have flourished and allow any basic programmer to easily design applications without requiring any hardware knowledge. Since the development of the first haptic library (GHOST) in 1997, techniques using haptics have multiplied and the area of haptic visualization grown.

3 Influential & related areas

A researcher, after browsing the literature through any of the bibliography search engines (CiteSeer, CS collection of bibliographies, INSPEC etc) in search for relevant 'haptic visualization' papers, will be quick to notice that many different subject areas impact upon haptic visualization. These independent disciplines influence haptic visualization and provide the foundation and backbone for much of the research. Haptic research is influenced by the studies done in psychology, ergonomics, engineering, and virtual reality, while visualization is influenced by computer graphics, image processing, computer vision, computer-aided design, signal processing, user interface studies [20]. In this section we take a brief look at key papers[1], and key ideas, that directly impinge upon haptic visualization.

[1]One way to locate 'key papers' is through co-citation indexes. We have used the CiteSeer search engine to gain information on co-citations, and the CS Collection of bibliographies to generate the quantities in Figure 1

Haptic rendering is obviously a key area for haptic visualization. For instance, in their seminal paper: Ruspini at al. [32] state "...For this synergy of haptics and graphics to flourish .. haptic systems must be capable of modeling environments with the same richness, complexity and interactivity that can be found in existing graphic systems". In fact in that paper they detail an excellent haptic rendering system that provides tactile display of graphical information.

Haptic rendering includes many concepts; in particular, collision detection is a fundamental concept that underpins many haptic applications, and needs to be done accurately and fast. Klosowski et al. write "applications such as haptic force-feedback can require over 1000 collisions per second" [10]. A useful survey on collision detection is by Lin and Gottschalk [13], although published eight years ago, it provides a good overview of the main collision detection algorithms. Another key concept in haptic rendering is the concept of the "god-object" [42], which generates a proxy model of the object and helps overcome problems with small objects, thin objects, and multiple objects.

Many of these haptic renderings are generated within a virtual environment. This brings challenges of navigation and menu operation. Although, specifically detailing that this manipulation is for the "lack of haptic feedback" the paper "Moving Objects in Space"[22] is a well cited paper of various virtual manipulation and selection paradigms based on proprioception (the sense a user has of his/her own body). In the field of VR, virtual surgery brings a number of difficulties: it requires both the abilities to "interact in real-time with the virtual organs through a force-feedback device and to perform a real-time visualization of the deformations" [16]. Virtual reality influences haptic visualization because many haptic visualization solutions are integrated in a virtual reality environment.

Finally, perception is an important influential area on haptic visualization. Perception studies, of how users feel and understand haptic information, are extremely important, and although not much research has been done in this area, there are some interesting and important results; including, Oakley et al.'s "putting the feel in 'look and feel' "[23] and the perception of gradient [27].

4 Haptic visualization

As discussed in the introduction, haptic visualization is all about understanding the underlying mathematical model. Because there are different types of data, different models are required to realize that information. The classification we use is based on work by Lohse et al [15] and orders the haptic representations by the structure of their form.

Charts/Graphs display mathematical or statistical information, and include line graphs, scatter plots, histograms and bar charts. Force-feedback line graph visualization has been well researched. Line graphs realize the information in a continuous and progressive manner, which matches in well with the pen-like interface of the PHANTOM. Work includes modeling the line as a cylinder or raised ridge [7, 40], applying attraction forces to help the user stay on the line [7], discovering that valleys rather than ridges enabled better perception [41] and designing methods to explore around the line [28]. Perceiving quantifiable information is important; one way is to include gridlines. Fritz and Barner [7] stated that gridlines were necessary, whereas Yu et al. [40] underlined they were rather ineffective and confusing, because they relied on the user's short term memory. Speech and spatial sounds have also been used to realize such quantities [25]. Perceiving multiple lines, especially intersecting lines, is another challenge; solutions include: friction [40] and sound [39]. In addition, researchers have looked at bar charts, modelling the bars as valleys for the PHANTOM or enclosures with the Logitech WingMan^{TM} mouse [38], and pie charts [39].

Maps communicate spatial meaning, geographic or physical space, i.e. maps have an explicit and clear association from a point on the map to a specific point in reality, e.g. an x-ray image maps the soft and hard tissue of that knee. Various researchers have investigated haptic visualizations that could be named maps. For instance, Jeong and Gluck [8] conducted several studies to evaluate the effectiveness of multimodality on choropleth maps: displaying the amount of cats and dogs per capita in each state. Using the Logitech iFeel^{TM} mouse they studied four models: color with color, color with auditory, color with haptic, and haptic with auditory. The results revealed that audio alone provided the shortest completion time and that the best recall rates were achieved with the multimodal displays, especially when audio was combined with haptics. Other researchers have focused on 3D maps such as building layouts. For example, König et al. [11] summarized building outlines. Springsguth and Weber [33] developed virtual maps accessible to the visually impaired combining engraved streets and 3D objects such as buildings. Lahav and Modiuser [12] presented a 3D multisensory virtual indoor environment that users navigated with the Microsoft force feedback Joystick. In scientific visualization, Avila and Sobierajski [1] used the PHANTOM to convey volumetric information. Finally, one important cue in the understanding of maps is the perception of orientation and especially proprioception, e.g. navigation of real environments has been aided by the haptic vest [6] while haptic cues of virtual worlds has also been studied [24].

Networks describe relational information, including trees and hierarchies e.g. a connects to b then c. Networks have not been well researched, however, music is one example of relational information. Chu [5] designed the TouchSound software which used vibrations to locate features in the music, while Beamish et al. [2] realized a haptic turntable which output various effects of the music.

Symbols & glyphs are images that are instantly recognizable and have associated meanings, e.g. road traffic signs or icons on a windows operating system. Work in this area includes the seminal work on *tactons* [3] and *haptic icons* [18] and recently Luk et al. [17] built a haptic vocabulary based on task-scenarios. Glyphs contain multiple parts, have many ligaments and can provide quantifiable and qualitative information. Guidelines for the use of *haptic glyphs* (or Hlyphs) have also been proposed [30].

Diagrams illustrate some process, phenomenon, or concept. In visual terms they include schematic diagrams and illustrations. In fact, not much work has been done in haptic diagrams, the most relevant is by Kahol et al. [9] who used tactile pulses to realize block diagrams; long pulses indicated text with x,y coordinates being mapped to the duration of a tactile pulse.

Drawings & Pictures represent images, often of real-world scenarios. Static tactile methods, using (say) swell paper, have been widely adopted as a simple but effective way to realize information. Way and Barner present two seminal papers on automatic visual to tactile translation [36, 37], while Rassmus-Gröhn et al. [26] developed a haptic-audio drawing program, where lines could be drawn with positive and negative relief using the PHANTOM.

5 Discussion

It is clear, from merely the content of this paper, that haptic visualization is a young but developing area, and that the topic relies upon and is influenced by many fields. Thus, 'where are we with haptic visualization'? We have certainly started down the road, and have generated some important findings. However in absolute quantities, compared to the overall haptic growth and the growth of the visualization field (see Figure 1), the evolution of haptic visualization is poor. But in percentage terms haptic visualization is growing faster than haptics. Moreover, it seems that applications follow technology. Indeed, lots of effort have been expended developing new haptic technologies, looking at haptic rendering, haptic augmentation (teleoperation, virtual reality) and at developing new haptic devices, and so there are fewer papers on haptic applications. As a matter of fact, in the 2006 Eurohaptics conference we count 34 papers in the devices topic, 30 in haptic rendering and only 10 papers in the haptic visualization topic.

It is true that current haptic technology, although fulfilling basic user requirements, still present several limitations and challenges such as: the lack of combined tactile and force feedback devices, the one point interaction as in the case of the PHANTOM, the size of the workspace, resolution, etc. Thus, there is still a need to investigate and foster haptic technologies. But, not withstanding the current limitations of the devices, we should start to move our attention and efforts to developing applications, especially haptic visualization.

However, before developing effective techniques, the first step is to acquire knowledge of the area. This, can prove to be difficult, especially for new researchers and students starting off research. There are some good books, resources, and relevant reviews (e.g.[35] and [34]). But, what is needed are more specific books, comprehensive reviews and insightful tutorials; covering topics such as haptic rendering algorithms or haptic devices, haptic visualization techniques and API's, and detailing limitations, challenges and solutions to using different haptic devices and generating different haptic applications.

Often review articles and books come out of conferences and workshops, and it is good to see the introduction of various workshops and conferences such as Haptic Audio Visual Environments and their Applications (HAVE) since 2002, Haptic Human-Computer Interaction in 2000 and the Haptic and Audio Interaction Design in 2006 and two International symposiums on Non-visual & Multimodal Visualization (M2Vis) in 2004 and 2005. There is still a need for specialist workshops on non-visual visualization, especially haptic visualization. Although more publications and workshops dedicated to haptic visualization are necessary, one should bear in mind that these should bring together researchers from a broad range of disciplines.

Through reading the papers it is clear that most developers have focused on conveying the form of the graphic, rather than purveying the meaning of the information [29]. In visualization *retinal variables* are used to convey the meaning of the information. But, researchers have tended to generate their application as a direct translation from the visual to the haptic domain. Although it is useful to 'learn from the visual' it may not be the best way to realize that information. Various researchers have started to address this issue. E.g. McGookin et al. [21] presented some guidelines, and suggested that multiple views of haptic graphs with each view presenting specific information would be beneficial, while Roberts et al. [31] proposed an 'Exploded View' view model. But, as developers we should think how our information could be effectively mapped into haptics, rather than focusing on the form.

Finally, some areas of haptic visualization are clearly more researched than others. For instance, there has been little work done in the areas of networks and schematic diagrams.

6 Conclusion

So where are we with haptic visualization? When one mentions haptics, one thinks about rendering and devices and not so much about haptic visualization. Is it that important then to explore that area? Unsurprisingly, the answer is yes. Indeed, developing effective (graphical) visualizations has already proven to be an extremely important and useful tool for society, and there are clear benefits to developing haptic visualization applications.

As it has been highlighted using the figure 1, haptic visualization is a young field; yet full of exciting challenges. It is clear that the haptic research area really came of age with the wide availability of tools such as the PHANTOM and the useful GHOST library, and although much research is focused on haptic rendering algorithms and haptic devices, attention is slowly moving to developing more applications, especially in visualization.

There is still much work to be done, and the challenges need to be solved in collaboration with researchers from multiple disciplines. Interdisciplinary research is often quoted as being hard to research and hard to fund. The research is challenging because it requires the researcher to understand important concepts across multiple fields, as well as search for relevant material from non-related databases. The work is hard to fund, because it may come under different funding agents with different agenda, the reviewers of one discipline may say something is novel, while other reviewers say it is commonplace.

Finally, there is certainly a lot of knowledge that can be transfered and applied from one discipline to haptic visualization and indeed we should learn from the (graphics) visualization work for effective presentation methods. But, the knowledge should not be naively applied, in fact it should be used to inspire and inform haptic visualization developments, and the developer should focus on techniques that specifically represent the underlying data.

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