Analysis of Haptics Evolution from Web Search Engines' Data

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Abstract— **This article proposes using search engine results data such as the number of results containing relevant terms, to measure the evolution of Haptics, the field devoted to the science and technology of the sense of touch. Haptics is a complex discipline which is at the intersection of the knowledge of several specialized fields like robotics, computer science, psychology, and mathematics. It can also appear as a new and emergent discipline due to the fact that many promising haptic interfaces, which allow innovative multimodal applications in many fields, have become mature only recently. The study presented in this article uses data collected at different periods of time (in December 1999, January 2004, January 2005, November 2006 and April 2007) on Web search engines from requests on three different terminologies: haptique, haptik and haptics, taken respectively from French, German, and English languages. The evolution of Haptics is seemingly reflected by to the online frequency of these specific terms over time. This evolution has been measured by considering the Internet community through search engines such as Google or Yahoo!.**

I. INTRODUCTION

Haptics is not a term well known to the public. Haptics at large refers to anything that has to do with the sense of touch. It is a term which was derived from the Greek verb *haptesthai* meaning *to touch*. It introduces the sense of touch and force into the human-computer interaction. Haptics is a complex discipline because it asks currently for the knowledge and/or the collaboration of several competencies like robotics, psychology, computer, or mathematics. It can also appear as a new discipline as many promising haptic interfaces became mature very recently. Thus, they allow innovative applications in many fields. Currently, research in this field is broadly categorized into human haptics, machine haptics, and computer haptics. Human haptics is mostly conducted by psychologists to study the mechanism of the touch modality, while machine haptics refers to the design of so called haptic devices to reproduce the sense of touch. Computer haptics covers all the aspects in haptics applications. Many applications in virtual reality call for the implementation of effective means for rendering to the human operator information on the softness and other mechanical properties of objects being touched [1]. The ability of humans to detect the softness of different objects by tactual exploration is intimately related to both kinaesthetic and cutaneous perception [2], [3], and

haptic displays should be designed in order to address such multi-modal perceptual channels. The emergence of a huge mature offer of haptic devices, such as those proposed by SensAble Technologies [4], [5] Immersion Technologies [6], Percro [7], or Force dimension [8] brings a variety of configurations for various applications and experiments. The basic idea of haptic devices is to provide users with force feedback information on the motion and/or the force that they generate.

Haptics is the physical contact between computer and user. This contact may be via the hand using a dagger, a pen, a mouse, a mobile phone, via the feet using a pedal, the full body, or even the tongue using a special joystick. There are two different types of sensing, *kinesthesia*, *tactile*. Kinesthesia is a sense mediated by end organs located in muscles, tendons, and joints. It is stimulated by body movements and it induces the force feedback, being the sense of force and motion. Tactile is related to the skin, and the feeling is mediated by receptors in the skin. It induces a tactile feedback and brings a large variety of configurations for various applications and experiments. It is the sense of touch. Good surveys on computer haptic rendering give further information on the complete haptic computation loop [9] and [10] which gives further information on the force calculations.

The use of the word haptics was introduced in the context of computer haptics from the beginning of the 90's. Similarly to computer graphics which generates and displays graphics content, computer haptics is concerned with the techniques and processes of generating and displaying haptic stimuli to the user. Computer haptics uses digital display technology as a medium for physically tangible interaction where objects can be simulated in an interactive manner. Computer haptics software concerned with generating and rendering touchable virtual objects is analogous to computer graphics. A commercial haptic interface, the PHANToM from SensAble Technologies (Cambridge, MA) [4], can be thought of as analogous to a computer display screen. The user either grasps a stylus or puts a finger in a thimble and uses them to touch, feel, and manipulate virtual objects within the device's workspace, which can be large enough to require the use of a user's entire arm. This new modality presents information to the user's hand and/or other parts of the body by exerting controlled forces through the haptic

interface. These forces are delivered to the user depending on the physical properties of the objects that can be perceived. The hardware components of this interface play an important role in displaying these forces through the response sensors to the user.

Unlike computer graphics, the behavior of haptic interaction is bidirectional, due to energy and information flow in both directions from the user to the haptic interface and vice versa. It is of interest for many applications, such as Tele-operation and Virtual Reality. Tele-operation actions are understood not to be implemented directly by human hands. The implementing person can be far away from the action place, or she/he does not have a direct entrance and contact to it. This is the case with medical operations, whereby the practician wants to accomplish a medical operation or examination [11], [12]. Terms such as tele-operation, tele-presence, tele-robotics, and supervisory were managed interchangeably by the robotics community until the mid-nineties. From those terms, two were especially important to develop haptics systems: Tele-operation and Tele-presence. Tele-operation refers to the extension of a person sensing and manipulation capabilities to a remote location. Tele-presence can be described as the realistic way an operator feels while physically being at a remote site. In Virtual Reality, characteristics of the represented materials can be simulated and transferred to the user to get the feeling of being in contact with the material [13], [14]. It is here of importance that for the local manipulations a feedback takes place, so that one is informed about the local characteristics (temperature, surface texture, hardness, spatial arrangement), pressure strength and position of the tool at the same time. For different employments, suitable haptic elements must be used, to permit both execution and feedback to an action.

The haptic perception is also known as active touch perception. It is of primary importance for the planning, direction and execution of everyday actions. This is the most complex of human sensory systems [15], and it is gaining ever more importance for various scientific disciplines as well as practical industrial applications : neuroscience, psychology, medicine/physiology; companies involved in haptic research, e.g. robotics, electronic industry, automobile development, textile industry. Lots of keywords could be used to refer to this field : Haptic design, Haptic perception, Sense of touch, Touch sensations, Virtual haptic...

Therefore there exists an additional complexity in haptics as it is necessary to know distinct skills as robotics, psychology, computer science, or mathematics. This new science also appears as a new discipline. In this article, the goal is to measure this phenomenon through the number of results obtained on a Web search engine when searching a single term such as haptics.

A. Terminology

The terminology of the haptic word presented in this article is based on the English adjective `haptic` (Def. 1)

from which the English noun haptics comes. Its definition is as follows:

Definition 1 (haptic): [Greek haptikos, from haptesthai, to grasp, touch.] adj. of or relating to or proceeding from the sense of touch; "haptic data"; "a tactile reflex" [syn: tactile, tactual].

The `haptic` word does not exist in French as an academic terminology definition. It is a transposition of the English word. `Haptique` is a word directly taken from the French philosopher G. Deleuze [2], which himself quoted Riegl an Austrian art historian of the end of the XIX. For Riegl, the idea is that feeling comes also from the skin, and that it can not be satisfied only with eye (optical). In German, we will find haptics in the form `haptik` or `haptische Wahrnehmung`. We can learn from T.B. Sheridan that as a scientific term, haptics is traced to the German word haptik, as employed by M. Dessoir [16] meaning *the study of touch and tactile sensations, especially as a means of communication*[1].

As shown previously at the beginning of this section, the word haptics refers to the ability to experience the environment through active exploration, typically with our hands, as when palpating an object to gauge its shape and material properties. There is a relationship between the terms: haptics, touch, kinaesthetic and cutaneous perception. This is true in experimental psychology and physiology. In the same way, the community that performs research on haptic interfaces, haptic rendering algorithms and applications involving somesthetic information uses increasingly haptic and haptics to refer to all kinaesthetic and cutaneous perception capabilities. The choice of the term: haptics, in multiple languages, has been driven by analyzing the relevant terminology identifying this research. The analysis of this term provides insights to the understanding of the evolution of this field.

B. Methodology

This evolutionary study aims to demonstrate the evolution of the haptic discipline through Internet search engines significant communities. Thanks to new projections into haptic, it will be soon possible to reproduce feelings of touch close to reality with various modes of simulations, various peripherals in very large public applications such as cellular phones, personal computers, and also very specialized applications in particular in the medical field. The measurement of the explosion of this discipline is not so evident and can be done in different manner. The method used here is based on the observation of the search engines results. It shows that these last years were extremely dense in this field.

This work is voluntarily based on results measuring a number of pages found on specific search engines during a large period of time. Indeed, it has been possible to show the emergence of this discipline in a factual way by using tools that are independent of the scientific world and that are linked to a worldwide use of the Web. This

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[1]Oxford English Dictionary

work is useful to understand haptics in future research in multimedia technology and applications in the next years.

The authors chose a metric that comes from the Web, among other metrics such as the number of articles, the number of conferences related to this field. This metric is using search engine results data (number of results containing relevant terms) to measure the evolution of Haptics. It exists some informal precedents. For instance, Haptics-e: The Electronic Journal of Haptics Research has published the rating of haptics publication based on Compendex and Inspec engineering databases [17]. Compendex and Inspec engineering databases are part of the Engineering Village web-based information service.

Internet appears as a common tool for the diffusion of the work of references and of the scientific and technical activities. Internet is a privileged tool for the scientific diffusion, particularly in haptics which has a community all around the world.

This is made possible thanks to the specificity of this scientific field, which identifies itself rather easily with a single term not currently used in the current language. This single term thus makes it possible to trace haptics well, to isolate it well and to identify it in a correct manner. The identification of this scientific field by the use of this term is thus exceptional and avoids the use of a family of terms or keywords which would have been useful in most of other scientific disciplines.

The different timings, in which the searches have been conducted, is important in order to consider the evolution of the use of the terms. It is also important to measure these metrics during a long period : from 1999 to 2007 to compare results with the others coming from Google and Yahoo. It is the reason why the search engine Altavista is used in figures although it is a minor search engine. At this date 1999, it was the only one for which we collected these data with the exact kind of query that is to say : haptique, haptics and haptik. These data are coming from a preliminary study conducted by Altavista minor search engine. These first results were published in an article at the French Web site of CLVE : Communication and Life in Virtual Environnements. Altavista is currently a minor Web search engine. These data are relative up to 1999 and it is significant for this analysis to have data over a long period 1999 to 2007. Google or Yahoo results are more significant but covering a shorter period from 2004 to 2007.

In section II, we present the background by defining search engines. The collected data in terms of number of results when requesting for the three terms: `haptique`, `haptik`, and `haptics` are presented in section III. In section IV, we present our analysis of the collected data to show and quantify the evolution of the scientific field.

II. BACKGROUND

Search engines are huge databases of Web page files or documents that have been automatically assembled. There are two types of search engines. Individual search engines compile their own searchable databases on the Web whereas Metasearchers do not compile databases. Instead, they search the databases of multiple sets of individual engines simultaneously.

A search engine can be seen as a tool of research which references automatically the Web pages or documents being on the network using a program called spider or robot. The content of each page is analyzed and the pages are classified by order of relevance according to the keywords seized by the users of the search engine. Referencing can also be done manually via paying or free referencing.

The Nielsen//NetRatings MegaView Search reporting service [18] measures the search behavior of approximately 500,000 people worldwide. These Web surfers have real-time meters on their computers which monitor the sites they visit. This metered information is compiled to produce NetRatings results. The share of searches, at the date of July 2006, was about 49.2% for Google, as a leader of search engines, the second was Yahoo! with 23.8%.

Indeed, the results coming from several search engines such as Google [19], Yahoo! [20], and AltaVista [21], have a high service of quality and also a large coverage and use all over the world, see section II-A. Moreover, we use the results published in December 1999 on the Web site "Communication and Life in Virtual Environments" (CLVE). This publication allows us an interesting study on the evolution of the haptic term while comparing rigorously with the same queries and on the same search engines from the year 1999 to the year 2007.

A. Web Search Engines

Dirk Lewandowski et al. [22] said that the numerous research papers dealing with the quality of Web search engines can be divided into two groups. The first one deals with the quality of search engines' results. The second one deals with the quality of the search engines' databases. Google or other search engines do not give simply the result of binary combinative crossing between pages answering the request and others not answering or less matching, they do more. They constitute a sight on the world and watch activities. They give global information and redistribute it via user-selections according to a local prism which is the request. They are machines of vision which operate with our apprehension of the world. To our knowledge, there is no study on the volume of results retrieved from a query on pre-selected single words in order to illustrate the evolution of an emergent scientific discipline.

B. Classification

The quantities shown in Table 1 are expressed in percentages of share of market. This classification of the search engines is established according to the generated traffic. The numbers mentioned in this table belong to the company Onestat [23] . This last classification (November 2003), once more, devotes +0.9 to Google [19] which

TABLE I.
WORLD BAROMETER OF THE SEARCH ENGINES. COURTESY OF ONESTAT[23].

	November 03	May 03	January 03	October 02	August 02	June 02	April 02
Google	56.1	55.2	54.7	55.1	53.2	51.1	46.5
Yahoo!	21.5	21.7	22.1	20.6	20.4	19.9	20.6
Msn	9.4	9.6	9.5	9.4	9.1	8.4	7.8
Aol	3.7	3.8	3.7	3.5	2.9	2.2	1.6
Lycos	2.3	2.6	2.8	3.0	3.7	4.3	4.6
AltaVista	1.9	2.2	2.5	2.4	2.8	3.8	6.4
Jeeves	1.6	1.5	1.5	X	X	X	X
Ixquick	X	X	X	1.7	2.2	2.3	2.4

accentuates its supremacy on its competitors. Behind the leader, Yahoo! [20], MSN [24] and AOL [25] preserve their places of honor while with -0.3, Lycos [26] and AltaVista [21] continue to lose importance on the market.

The use of search engines, in particular Google, is nowadays generalized. The relevance of the increase of the number of documents or Web pages found compared to the increase of scientific, cultural or industrial activity around the haptic subject is then becoming relevant and interesting to be observed during a period of time. These results allow an objective and quantifiable measurement of interest growing that is carried for this discipline. For this study, we chose Google and Yahoo! which are respectively first and second of the onestat barometer, and AltaVista which, although is nowadays only classified 6th, for the reasons presented in section [?].

The progression is probably less spectacular than these figures indicate, because of the continuously increasing number of web-pages and webcontent. However, the years after 2000 were already largely supported on the Web and although numbers are linked to the growth of internet, we still think that the progression found is valid.

III. COLLECTED DATA

In this section, we show our data collected from the three different search engines at different periods of time. The used queries were identical at each time and for each search engine [21], [20], [19] as presented in section II-A, and the queries were very simple containing only one word, taken from the following terms: haptique, for the French terminology, haptik, for the German terminology, and haptics for the English terminology.

We dispose of two sets of data collected differently. The first set has been collected from an article on the haptique French terminology published by the "Communication and Life in Virtual Environment" Web site in December 1999, and only based on the Altavista search engine [21]. The second set of data has been processed by us at different periods of time: January 2004, January 2005, November 2006, and finally April 2007. The following table (Table 2) presents the data we have collected.

IV. ANALYSIS OF THE RESULTS

In this section we present our analysis of the collected data. In section IV-A, we first look at the evolution of

the haptic terms with the data collected exclusively on the altavista Web site. In section IV-B, we compare the results of the data collected amongst the different selected search engines over the last 4 years.

A. Comparison on collected data on Altavista from 1999 to 2007

At the beginning of the year 1999, the haptic activity was a field of specialists in robotics, in psychology and in other fields, but it still remained fairly confidential. The use of the German terminology Haptik or the French terminology Haptique, anglicism of the haptic term, was not spread in the scientific circles and at that time, the mechanical term "retour d'effort" (force feedback) was very largely used in the French community. However, 61 answers were obtained in January 1999 when entering Haptique in the Altavista search engine [21]. With haptics, the English terminology, the number increased to 1454. The term Haptik generated 64 results. In addition, the Web query in 1999 showed the existence of the "Electronic Journal of Haptics Research" [27].

At the beginning of the year 2004, the results progressed considerably compared to 1999. Thus, when entering Haptique as a request in the Altavista search engine, $1,009$ answers were obtained in January 2004. With Haptics, the number increased to $10,964$. Haptik gave $3,387$ answers (see the Table 2). Some example of results demonstrate the existence in 2004 of "The Haptics Community Web site" [28], the "Symposium on Haptic Interfaces" [29], the "International Society for Haptics" [30], and the "Electronic Journal of Haptics Research" [27] still in use. Beginning of year 2005, results increased continuously for the three terminologies; for the term haptics, the tendency is exponential reaching $51,200$ results.

In the three years 2004, 2005 and 2006, the haptic field progressed significantly, and figures give us a quantitative indication of this progression. The graph showing the evolution 1 for each term: haptique, haptik, and haptics, illustrates a very strong progression of the use of the term haptics, which remains always considerably higher the French or German terminologies. The German term although than having a score similar to its French counterpart, shows a stronger progression in its use growing at a rate of 67.82 new results each month during the

Search Engine	Altavista (AV)					Google (G)				Yahoo (Y)			
Year	99	04	05	06	07	04	05	06	07	04	05	06	07
Haptique	61	1009	1790	12100	11300	2020	10100	5400	56700	1380	1810	12100	11300
Haptik	64	3387	15800	109000	97200	7970	32900	251000	29000	5540	15800	109000	97000
Haptics	1454	10964	51200	342000	362000	27900	90500	778000	765000	18800	50300	342000	363000
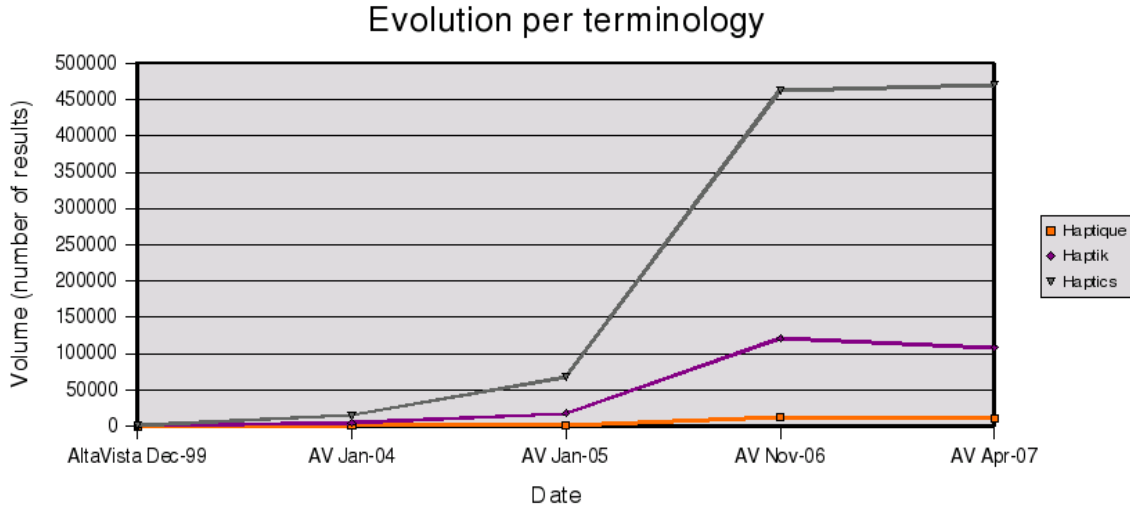
Figure 1. Evolution graph for each following term: haptique, haptik, and haptics.

period of 1999 to 2004. The French term thus remains in last position, with a score which is 16.54 times more important over a 49-month period, growing with 19.35 new results each month. This progression is calculated using Definition 2 described below as E_{avg}. The results are shown in Table III and on Figure 1.

From November 2006 to April 2007, the positive progression stopped. The evolution of the results per month even appear negative, for instance, -694.12 for the German terminology. This observation of the progression is very interesting and could indicate that after the last years which have been very intensive, the field is entering a new period of consolidation and maturity.

Definition 2 (Average evolution per month): We define the average evolution per month as:

$$E_{avg} = \frac{n_{d_1} - n_{d_0}}{duration[d_0 \ d_1]} \qquad (1)$$

where n_{d_1} is the result number at the date d_1, n_{d_0} is the result number at the date d_0 with $d_0 < d_1$, and $duration[d_0 \ d_1]$ is the duration of the period between the date d_0 and d_1, in number of months.

The graph shown in Figure 2, illustrates the average evolution per month (as calculated with the equation in definition 2) in term of numbers of new results each month. The growth of the results given via AltaVista for quering the terms haptique, haptik, and haptics is exponential, over the time period covering December 1999, January 2004, January 2005, and January 2006, reaching $18,000$ new results in average evolution per month at the year 2006. These observations reflect the very strong

progression of this field and the many applications in the cultural, artistic as well as medical or scientist fields. During the last period of our observations, from November 2006 to April 2007, we can observe that the English term continues to be used and spread, whereas the French one and especially the German one are regressing with, for instance, a negative result of -1685.71 in average for each month of this period. We remark that there is a kind of slowness in the progression of the volume of results. It could be the beginning of a new age of this scientific field, with more consolidation of all the knowledge and productions, and also a convergence of the terminologies. The behavior of the data referred here might not relate only to the online evolution of haptics but, for example, to a decreased Web indexing by Altavista. As Altavista's market importance and possibly its Web index coverage, have declined over time. The increase/decrease in the online frequency of haptics-related terms is due to :

- the growth of the research community,
- the growth of the research community online presence,
- the growth of the Web,
- the growth of search engine indexes.

B. Data collection comparison on Google, Yahoo and AltaVista

In Figure 4, we present the results obtained with the terms: haptique, haptic, and haptics, on the three search engines: Google, Yahoo and AltaVista, which were selected as explained in section II-A. On one hand, it shows

TABLE III.
COMPUTATION OF THE EVOLUTION PER MONTH OF THE GROWTH OF RESULTS OF QUERYING HAPTIQUE, HAPTIK, AND HAPTICS ON THE
ALTAVISTA SEARCH ENGINE.

Period	1999 to 2004 (49 months)	2004 to 2005 (12 months)	2005 to 2006 (22 months)	2006 to 2007 (7 months)
Haptique	19.35	65.08	468.64	-114.29
Haptik	67.82	1034.42	4236.36	-1685.71
Haptics	194.08	3353	13218.18	2857.14
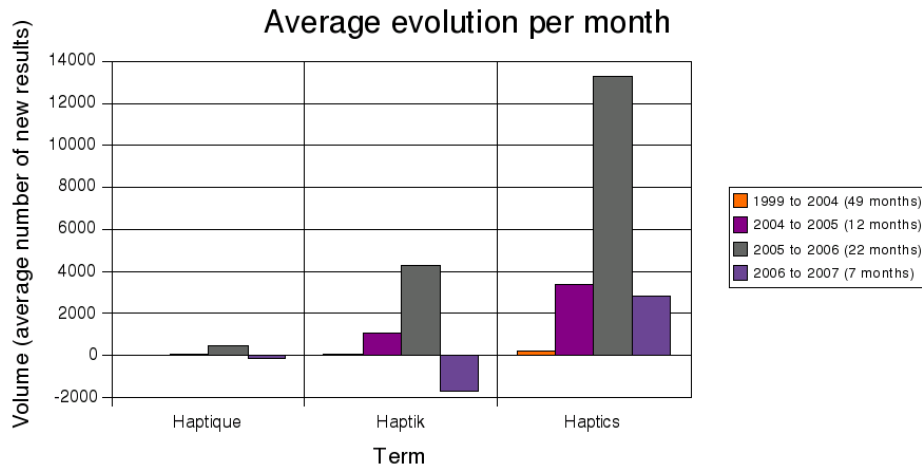
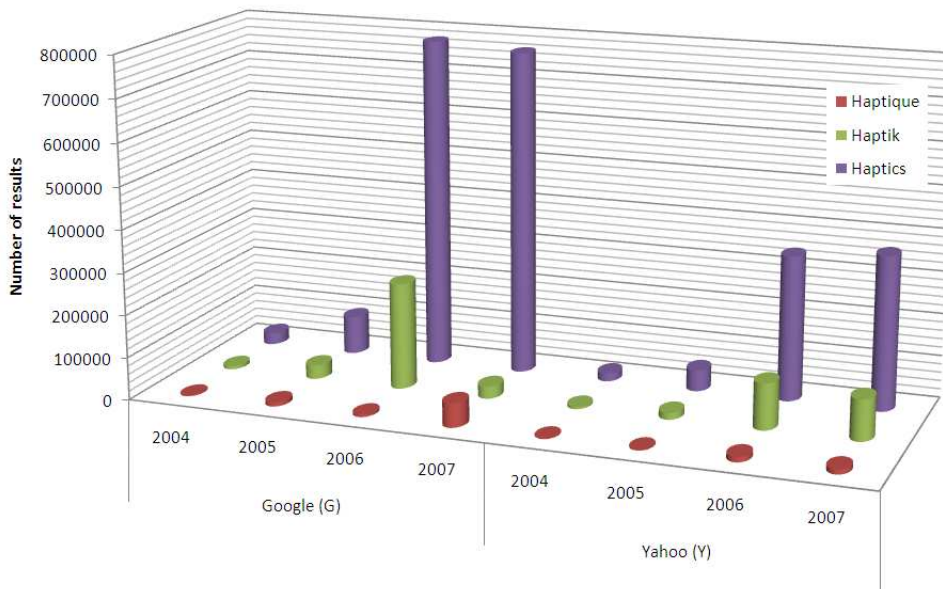Figure 2. Average evolution per month for Altavista search engine.

Figure 3. Comparison of the results with Google and Yahoo search engines at different periods of time.

that the terminological proportion is preserved for each search engine. On the other hand, it appears very clearly that the Google search engine references on average two times more pages relative to the subject of haptics in the three languages than AltaVista does. AltaVista provides 23% of the results, Yahoo 31% and Google 46% proving to be a leader of the search engines with a total of 37, 890 results for the three terminologies taken together. Clearly, the haptics terminology is preeminent. Indeed,

as illustrated in Figure 4, the comparison of the different search engines in 2004, 2005, and 2006 on haptics shows clearly a great progression in 2006 reaching a number of 778, 000 pages found compared to January 2005 and January 2004. In 2007 the deceleration is noticeable with a number of results reaching 765, 000.

V. CONCLUSIONS

We conclude by mentioning Thomas B. Sheridan [1] analysis and comments on the place of haptics in natu-
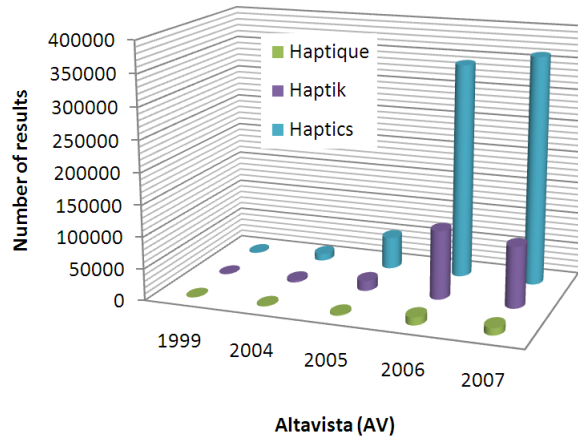
Figure 4. Comparison of the results with AltaVista search engine at different periods of time.

ral and technological evolution. The haptic capability is primitive on the evolutionary time scale. Early creatures had force sensitive skin or discrete structures such as hairs or antennae. For example, a hapteron is an "organ of attachment by which certain aquatic plants or algae fasten themselves to rocks". In some cases it takes the form of a suction cup. Exteroceptor organs for vision and hearing generally came much later in evolution. Curiously, exactly the reverse occurred in human development of sensing technology. Edison is credited with inventing the telephone and gramophone (record player) in the late 1800s. Radio Corporation of America (RCA) scientists and others are credited with invention of television in the 1930s. Haptics, though of scientific interest to sensory psychologists and physiologists, did not have an equivalent technological implementation until very recently. In contrast, it may be said that currently artificial haptic sensing and display are nowhere close to the sophistication of artificial auditory and visual sensing and display.

With a quantitative method based on search engines' data in terms of number of retrieved results, we have shown that haptics's activities are increasing and that the place of haptics is changing. This study shows that this scientific discipline which could appear in 1999 like a confidential discipline, knows a remarkable evolution. It is to be noticed, however, that search engines have improved a lot, which undeniably influences our results. The activities around or in relation with this discipline follow a strong increase at the level of research, robotics or applications, and everyday usage in particular in the medical fields. Under every "Haptique" or "haptik" or "haptics" terminologies, these words that were qualified as rarely used in 1999, tend to be now used by an increasingly broader community. The tables of results contained in this study will be able in their turn to constitute recorded data available for future comparative studies on this discipline full with resources and innovations.

A. *Future work*

Further work could be done to complete the study and analysis of the haptic evolution. Haptic displays are emerging as effective interaction aids for improving the realism of virtual worlds. Being able to touch, feel, and manipulate objects in virtual environments has a large number of exciting applications. The underlying technology, both in terms of electromechanical hardware and computer software, is becoming mature and has opened up novel and interesting research areas. In their paper, Srinivasan and Basdogan [31] clarify the terminology of human and machine haptics and provide a brief overview of the progress recently achieved in these fields, based on their investigations as well as other studies. They describe the major advances in a new discipline, Computer Haptics (analogous to computer graphics), that is concerned with the techniques and processes associated with generating and displaying haptic stimuli to the human user. A next stage could consist in building a taxonomy of the English term haptics based on the taxonomies induced by the statistical models of the search engines. In the manner that our analysis made it possible to show the fast emergence of this field of research via the study of the results of the principal search engines that should be looked in more detail to the fields or categories which are attached to this complex field of research. This work will help in understanding how integrate haptics into multi-modal and distributed virtual environments, and in speculating on the challenges for the future. This work will highlight how rapidly the haptics field grows.

Our article presents a worthy idea with preliminary data, but the proposed methodology has limitations. The future work will consist in extracting a taxonomy of haptics based on those used in search engines, in order to develop a categorization of haptics. Our future work will be also to analyze its evolution with alternatives for future research, such as using databases of scholarly articles instead of search engine data. A classification in terms of categories could be defined in order to present the different features of this discipline. The Open Directory Project (ODP), also known as Dmoz [32], is a multilingual open content directory of World Wide Web links owned by Netscape that is constructed and maintained by a community of volunteer editors. For instance, Dmoz gives

5 categories or clusters:

- Computers: Virtual Reality: Haptics
- Computers: Robotics: Research
- Science: Software: Simulation
- Computers: Virtual Reality: Companies
- Computers: Computer Science: Computer Graphics

In the same manner, in the search engine Mooter [33], the first level in the hierarchy of clusters found, gives seven clusters named as following: haptics, touch, Internet, research, haptic, conferences, tactile. The Kartoo [34] search engine gives other clusters: intelligent, science, SensAble, virtual, research, or device. The aim will be to construct a taxonomy of haptics based on these engine taxonomies to extract a global taxonomy.

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