EXTENDED ABSTRACT of the Doctoral thesis:

Interactive and effective representation of digital content through touch using local tactile feedback

The increasing availability of on-line resources and the widespread practice of storing data over the internet arise the problem of their accessibility for visually impaired people.
The conveyed information is multifarious and uses different ways of representation, i.e. text, images, graphs.
Text is generally rendered on refreshable Braille cells or text-to-speech engines, while limited solutions exist for graphical information.
Graphics are, in general, visually represented in a 2D topography in which the position in the 2D space refers to a meaning. In a typical vision-based environment, such as a PC screen or a website, the distinction among data is ensured by overlapping the content or by assigning content to a specific location in the 2D space.
Color labels, the use of shadows and the choice of a particular perspective help to compact multiple meanings: they are semantic features attached to a two-dimensional representation.
Visually impaired people do not have access to such representations. Yet, they know how to interact with 3D spaces, such as a dressed table where the dishes, the fork, the knife and a glass have specific locations and precise functions to be remembered.

This is not possible with digital information.
A translation from the visual domain to the available modalities is therefore necessary to study if this access is somewhat possible.
However, the translation of information from vision to another sensory modality, for example touch, is necessarily impaired due to the superiority of vision over touch during the acquisition process.
Yet, compromises exist as visual information can be simplified, sketched. A picture can become a map. An object can become a geometrical shape. Under some circumstances, and with a reasonable loss of generality, touch *can* substitute vision. In particular, when touch substitutes vision, data can be differentiated by modulating vibration attributes (e.g. frequency, amplitude and duration), force feedback (e.g. changes in acceleration) or adding a further dimension to the tactile feedback (e.g. from two to three dimensions).
In this thesis the last mode has been chosen, because it mimics our natural way of following object profiles with fingers.
Specifically, regardless if a hand lying on an object is moving or not, our tactile and proprioceptive systems are both stimulated and tell us something about which object we are manipulating, what can be its shape and size.
We attempted to work with three dimensions because our goal is to display features of *geometrical* content, to which arbitrary semantics can be attached.
Our motivation stems from the fact that much of everyday tasks performed by blind people make use, for example, of proprioceptive information represented by haptic and acoustic feedback in the peripersonal space, that is the space surrounding our bodies and where objects can be reached and manipulated.
However, nowadays few effective methods exist which exploit this habit when accessing digital data; using touch to sense digital data in more than one dimension is something almost unknown to visually impaired persons.
Some evidence reports that the brain of blind persons can process tactile digital information in similar ways to sighted persons. The potential of blind persons in understanding digital three dimensional content seems largely underestimated.

The goal of this PhD thesis is to test how to exploit tactile stimulation to render digital information non visually, so that cognitive maps associated with this information can be efficiently elicited from visually impaired persons.
In particular, the focus is to deliver geometrical information in a learning scenario.
The contribution of this research is to demonstrate that it is possible to deliver a tactile three dimensional content with a simple stimulation mode which renders local geometrical features in three degrees of freedom, while global features are delegated to the person's active exploration.

In the physical world, sighted people perceive hundreds of visual objects at a glance, but automatically ignore items that are not important, not interesting or operationally irrelevant.

With touch, this is very difficult to achieve.
In fact, a person who is blind may need to establish selective perception filters to limit cognitive overload caused by over-detailed tactile environments.
Some tactile maps installed in train stations, for example, are reputed useless by the blind community, as there is too much information only suitable for vision, certainly not for touch.
There are essential operational features of objects, but there is also a frequent abundance of decorative properties that have no operational value and can be ignored.
When delivering digital content through touch, such content is not physical, but virtual.
To build a percept of a real object, with appropriate stimulation means, is not obvious.
What is 'appropriate' is a central topic addressed in this thesis. We consider the case of virtual geometrical content: **is it possible to find an appropriate stimulation mode that helps to effectively build mental models from virtual geometrical primitives?** Then, **how do visually impaired persons react to such stimulation mode, as compared to sighted persons?**

Moreover, a completely blind interaction with virtual environment in a learning scenario is something little investigated because visually impaired subjects are often passive agents of exercises with fixed environment constraints.
For this reason, as ultimate research question of this thesis, **can visually impaired people manipulate dynamic virtual content through touch?**
This process is much more challenging than only exploring and learning a virtual content, but at the same time it leads to a more conscious and dynamic creation of the spatial understanding of an environment during tactile exploration.
As a result, visually impaired participants were able to actively handle the components of a virtual environment.

From the point of view of basic research in haptics this thesis demonstrates that both persons with and without visual impairment were able to understand spatial layouts of *global* tactile scalar fields by approximating them with *local elevation* and *local inclination* only, while missing information can be delegated to spontaneous proprioceptive strategies.
This stimulation can be used in applications where vocal cues are insufficient to provide spatial information, such as web surfing.
Vocal cues, in fact, are successful descriptive tools but they often appear to be annoying and lack spatial representation, which is crucial in the process of data recall.

Moreover, this research can be used to improve the state of the art in rehabilitation engineering.
More often the evaluations of rehabilitation protocols and aids, in the research context, are limited to the performances associated to the accomplishment of a task.
However, the ability to fulfill a certain task remains incomplete and almost unpredictable if not associated to measures able to disclose the motivations and the modalities leading to a certain performance.
The subjective demand associated to a task can provide a complementary measure to further evaluate the impact of that tool on a visually impaired person.
Recent works suggest that performance can be predicted by a combination of behavioural and subjective variables.
The choice of a particular strategy and participants' perception of cognitive load, in fact, reflected the objective difficulty of the tasks.
For this reason, in all the experiments described in this thesis, different classes of data were collected: together with performance evaluations, behavioral and subjective aspects were taken into account.
Therefore behavior and subjective information helped to understand which are the underpinnings of a certain result and consequently to plan targeted strategies that could possibly improve the performances.