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# THE HEIDELBERG TACTILE VISION SUBSTITUTION SYSTEM

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***Abstract***

*We have built and operated a tactile vision substitution system based on 48 piezoelectric actuators assembled in a movable tactile output unit. The unit can be positioned at any location on a two dimensional surface to explore the line structure of a virtual image. This virtual tactile display (VTD) receives data either from camera systems equipped with suitable image processing capabilities or from a computer. The device has been tested with 6 blind and 4 sighted subjects.*

## 1. Introduction

Since the pioneering work performed by Bach-y-Rita et al. [1] several different technologies have been explored to construct devices which are able to provide blind subjects with a substitution for vision making use of their tactile perception. Such devices are called *tactile vision substitution systems* (TVSS). In general three classes of stimuli, mechanotactile, electrotactile and thermotactile, have been exploited. A comprehensive overview including also applications of tactile displays for sighted people in the context of virtual reality can be found in [2]. A common problem for all tactile displays is the necessity to generate tactile patterns over a rather large geometrical surface. This turns out to be a challenge for mechanical design, electrical power dissipation and portability of such devices. The attempt described in this paper uses a concept called *virtual tactile display* (VTD). Here, a relatively small active area of 48 *tactile pixel elements* (taxels) is moved by the user across a large surface (164 mm × 159 mm). The tactile sensation is received with the fingertips. Only the small active area requires mechanical elements, supply of electrical power and computer control. The system is therefore simple and can be produced at low cost.

In the following we describe the technical design of the VTD, the different options of connecting data sources and first results obtained with the system comparing groups of sighted and blind subjects.

## 2. The Virtual Tactile Display (VTD)

A photograph of the VTD used in the Heidelberg TVSS is shown in figure 1. An aluminium base unit holds two parallel linear guiding rails with carriages moving on ball bearings (Type KUME 09 manufactured by INA Wälzlager, Herzogenaurach, Germany). A third identical rail is mounted perpendicular on the two parallel ones so that the carriage on the single rail can be moved with very little friction in x and y directions independently. The carriage on the single rail holds the tactile output unit which consists of 6 standard piezoelectric Braille display elements. The Braille elements (manufactured by METEC GmbH, Stuttgart, Germany) have 8 movable plastic actuators arranged in a 2 × 4 matrix. Each individual actuator is mounted on a pair of piezoelectric levers providing vertical movements of up to 0.7 mm. The piezocrystals require an operation voltage of 200 Volts which is generated locally in the desktop base unit by a DC/DC converter. The spacings between actuators are

3.21 mm and 2.45 mm in x and y-direction respectively. The tactile output field consists in total of 48 actuators distributed in an area of 43 mm × 16 mm which can be conveniently

**Figure 1 : Photograph of the VTD. The 3 rails and the tactile output unit are visible. The base unit is equipped with a laptop computer for control tasks. The photograph also shows a CMOS vision chip camera used together with the VTD to form a complete TVSS.**

covered with 3 fingertips . The absolute position of the tactile output unit is recorded with an optical sensor taken from a standard optical mouse (manufactured by Mouse Systems Corp., Fermont, USA). The tactile output unit can slide across an area of 164 mm × 159 mm providing access to 2600 virtual taxels (see definition above). The active surface of the tactile output unit corresponds to only 2% of the full accessible area. Table 1 summarises the main properties of the VTD.

| | |
|---|---|
| **Number of active taxels** | 6 × 8 |
| **Number of virtual taxels** | 2880 |
| **Active surface area** | 43 mm x 16 mm |
| **Virtual surface area** | 164 mm × 159 mm |
| **Distance between active taxels** | 3.21 mm (x) and 2.45 mm (y) |
| **Vertical taxel movement** | 0.7 mm |
| **Weight without computer** | 2.25 kg |

**Table 1: Mechanical properties of the *virtual tactile display* (VTD)**

## 3. Data Input and Output

The VTD receives image data to be displayed and sends position data of the tactile output unit. The position data are of twofold importance for the VTD. They provide the information to the laptop computer to calculate the correct pattern to be displayed in the active taxel field and they can be recorded on mass storage. The second feature is used for offline analysis of the detection strategies developed by subjects using the device. The image data are sent from a laptop computer via a standard 24 bit digital I/O PCMCIA card (Type DIO-24 manufactured by National Instruments). The card is also used to control additional external equipment like cameras. The position data recorded by the optical mouse system as well as the state of the three mouse buttons are sent to the serial port of the computer.

A software package has been developed to control data input/output and to perform image processing calculations on the laptop computer. Image data can be provided by an external camera, via a TCP/IP link by another computer (e.g. Internet) or by bitmap images stored on the local computer. The bitmap images can also be assembled to form a video movie in order to simulate motion of objects. The software package includes a set of standard image processing filters in order to match the image information to the capabilities of the VTD and of the human user. The maximum update rate of images transferred to the VTD is approximately 60 Hz. This number is reduced when external devices (cameras) are connected or extensive image processing is performed on the laptop computer.

The VTD is part of the complete Heidelberg TVSS which includes CMOS cameras for real world image recording [3 - 7] as well as analog image pre-processing circuits in VLSI implemention [8]. The VLSI chips for image acquisition and control are dedicated developments in the framework of the TVSS development.  Figure 2 shows a block diagram of the complete system [9].

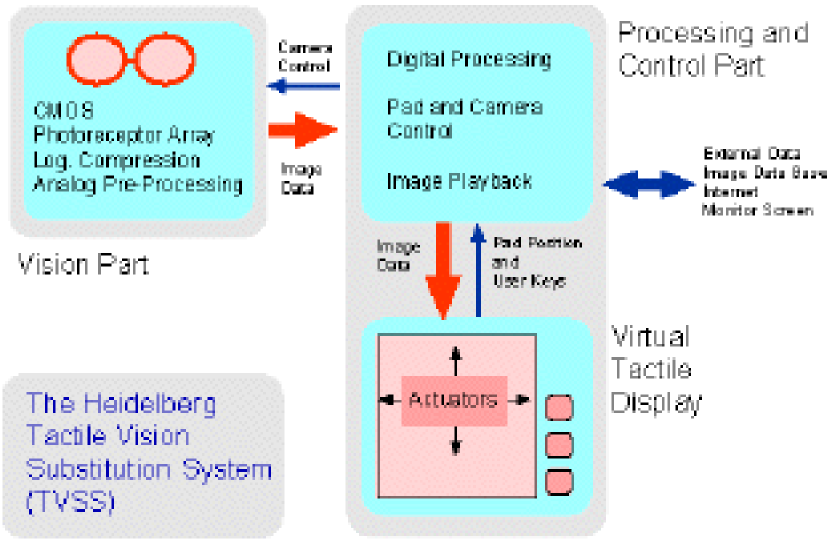


**Figure 2 : Block diagram of the complete Heidelberg TVSS. The VTD is connected to a processing and control part (laptop computer) and a vision part comprising dedicated VLSI chips for image acquisition and pre-processing.**

## 4. Results

First tests of the VTD have been carried out with a group of 6 blind and 4 sighted subjects. All subjects have been informed about the nature of the device and the test procedure and haven given their free consent to participate in the study.

The sighted subjects were in the age range between 21 and 30 with an average of 28 years. Two of them were females and two were males. The sighted subjects were blindfolded during the tests. The blind subjects were all males and in the age range between 16 and 25 with an average of 18 years. Five of the blind subjects had no remnant visual capabilities. One of them was able to recognise large intensity variations. Two of the blind subject lost their vision during the first 5 years of their lives. The other four blind subjects were congenitally blind.

After an introduction to the VTD technology and operational principles the subjects were given the task to recognise 21 simple geometrical images stored in the data base of the computer. The images represented simple geometrical patterns like squares, triangles, circles and crosses with different sizes and orientations. No time limitation was given for the recognition of the images. All users were able to recognise all images correctly. The individual movement üatterns of the tactile output unit was recorded and captured on mass storage for later offline analysis. Details of the test procedure as well as all test images are described in [10]. A first analysis of the offline data has demonstrated the functionality of the VTD and beyond this revealed some remarkable differences in performance and strategy of blind and sighted VTD users. The recording of space-time coordinates allows to quantitatively evaluate the users performance. The most obvious parameters in this aspect are recognition time and average moving velocity. Table 2 summarises the performance numbers for the two groups of blind and sighted subjects.

| | **Average for blind subjects** | **r.m.s. for blind subject** | **Average for sighted subjects** | **r.m.s. for sighted subjects** |
|---|---|---|---|---|
| **Recognition time (s)** | 10.0 | 5.8 | 26.1 | 14.4 |
| **Average moving velocity (taxel/s)** | 29.3 | 17.6 | 17.5 | 6.22 |

**Table 2 : Performance in image recognition measured with the VTD for blind and sighted subjects..**

Roughly speaking, the blind subjects were able to recognise the images more than twice as fast as the sighted subjects. Their moving speed is almost a factor 2 higher than that of

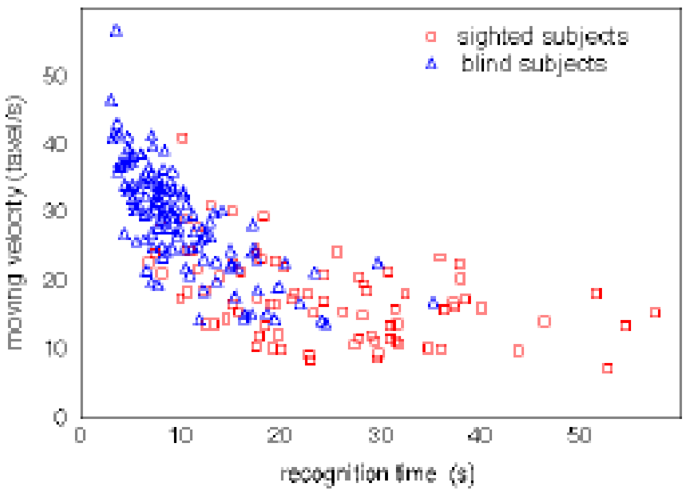


**Figure 3 : Velocity versus time diagram for blind (triangles) and sighted (squares) subjects.**

sighted subjects. This fact can also be seen in the correlation plot between recognition time and moving velocity shown in figure 3.  The individual data points line up on a hyperbola in the time versus velocity diagram. This demonstrates the fact that both groups use the same effective scan path but with half the recognition time for blind subjects. In the language of information theory this means that the bandwidth for using the VTD is twice as high for blind subjects compared to sighted subjects.

First studies have also been performed to better understand the recognition strategies when using the VTD. A single example is shown in figure 4 were the scan paths for a triangle are plotted for a blind and a sighted subject.

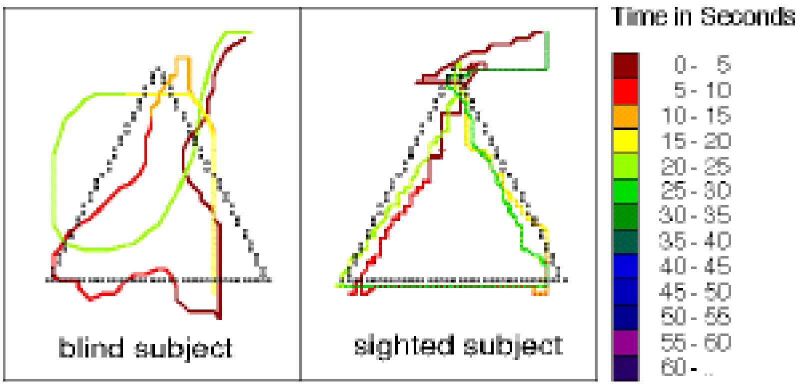


**Figure 4 : Pattern recognition strategy with the VTD comparing a blind and a sighted subject.**

It is evident that the sighted subject follows the line pattern very carefully whereas the blind subject tends to make movements which are weakly correlated with the pattern to be recognised. The data recorded in this study have the potential to understand this feature in more detail by not only looking at the average performance but by analysing individual recognition strategies differentially in space and time. It is hoped that these studies will provide new insights into the pattern recognition capabilities of the blind, which in turn can be used to further improve the VTD concept or other tactile displays.

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