Perceptual biases in Tactile flow

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Abstract

In this paper we report on results of a psychophysical experiment in which the optic illusion of Ouchi is reproduced in the tactile domain. In the vision field, when eyes scan over a texture grid, consisting in two rectangular checkerboard patterns oriented in orthogonal directions, the inset pattern appears to move relatively to the surrounding grid. A simplified 3D version of this pattern was realized and a group of subjects were asked to touch it while it was vibrating. Outcomes of this experiment are discussed in terms of tactile flow and the related aperture problem.

1. Introduction

In our previous work [1], we formulated the hypothesis that there might exist a tactile counterpart to optic flow [5], called tactile flow, responsible for gathering information about relative motion, shape and softness. In particular, it has been showed the possibility to reproduce in tactile form some well known optic illusions based on the aperture problem of the optic flow, mainly focusing on the popular illusion called "barber pole" [4].

Psychophysical experiments investigating how humans integrate incoherent tactile flow stimuli have been implemented [2] showing how behaviors in tactile perception bear a strong resemblance between the brain processing of optic and tactile flow.

In this work we investigate on tactile illusion caused by the lack of integration of biased local components of flow. A bias in the local tactile flow components (obtained by a suitable, Ouchi-like texture pattern on the object) can generate an incoherent distribution of flow on a single fingertip, causing illusory segmentation of the texture perception.

A simplified 3D model of the Ouchi's pattern was realized by means a technique of micro-printing in a nylon structure. This pattern was placed on the end-effector of the Delta Haptic Device (DHD) which was suitably controlled via PC. The pad was moved beneath a metallic plane endowed with a small opening through which subjects could put their forefinger and touch the moving pad. The motion imposed on the pad was a vibration in random direction of 4Hz with 2mm of amplitude. This frequency was chosen in order to maximize the response of Meissner corpuscles, partially elicit the Merkel receptors and quelling the remaining mechanoreceptors. A group of 20 subjects volunteered to touch the pad and report on what they perceive. Results are discussed, interpreted and compared with those of the more known optic illusion.

2. Psychophysical Experiment– Methods

In our experiment, the pad should vibrate according to certain specifications. In particular, the oscillation frequency should be comprised within a predetermined range and the amplitude of vibration should be quite small. In order to attain these requirements with sufficient reliability, we used Delta Haptic Device (DHD) by Force Dimension (fig. 1). The idea of using this commercial device is justified by the observation that some kinaesthetic parameters, such as position and velocity, can be dynamically estimated during the tactile manipulation while other parameters, such as forces along desired axes, can be timely fixed without compromising realism (the parameters' values are always coherent) and performance. However, the aim of our experiment was only to induce a vibration without imposing forces. The frequency and amplitude of vibrations were a posteriori verified by reading the output of the position sensor integrated in the device.

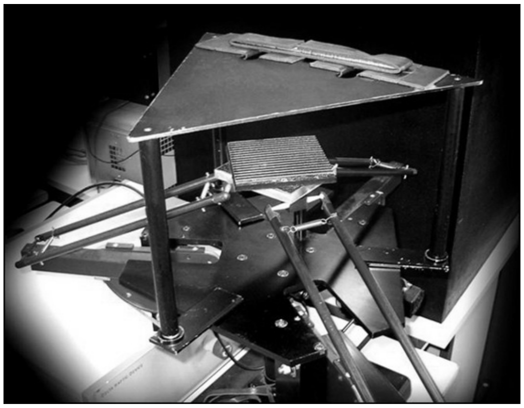

Fig. 1 – The Delta Haptic Device by ForceDimension used for the experiment.

The haptic environment has been implemented by using a personal computer and by developing a tool in Visual C++ in order to decide and give the motion strategy.
The software has been designed taking into account typical characteristics of a haptic environment, including real time and feedback control, by means a proper interface (GUI).
The tool consists of a simple Dialog based on Graphical User Interface (GUI).
The core of the tool is a Haptic thread which runs at approximately 1000 Hz (in other terms one step each millisecond) and allows fixing or measuring the position on the workspace of the DHD end-effector, evaluating and/or set relative or absolute positions.
By pushing a virtual button on the GUI it was possible to start and stop the experimental session.
In this case a low-level control has been implemented by using two predefined library's function dhdGetPosition(xd,yd,zd) and dhdSetForce(fx,fy,fz). Furthermore, a real time class has been included in order to synchronize the movement and realize the required haptic timing.

2.1 Tactile Ouchi Illusion: experimental session

20 subjects (12 females, 8 males) volunteered to participate to the experiment. Their ages ranged from 25 to 31 years, with an average of 28.1, with a university degree and normal health conditions. All participants were naïve of the purposes of the experiment.

The goal of this experiment was to replicate and study the Ouchi optic illusion in the tactile domain. The Ouchi's visual pattern reported on the left side of fig. 2 has the propriety that small relative motions between the pattern and the eyes cause illusory perception of a partition of the inset from the background region. The effect can be achieved either with small retinal motions or a slight jiggling of the paper and is rather robust over large changes in pattern, frequencies and boundary shapes. A possible explanation is that the illusion is caused by a segmentation of the optic flow field due to a biased estimation of local optic flow components [3].

Actually, the estimation of image velocity is generally biased, and for particular spatial gradient distribution similar to the Ouchi pattern the bias is particularly pronounced, giving rise to large differences in the velocity estimates between the inner and the outer zone of pattern.

Transposing the experiment in tactile form, we realized a simplified version of the Ouchi pattern fig. 2 (on the right side) with size comparable to fingertips' dimensions. Pad was realized by means of 3D printing on a structure of nylon. It presents a series of 1mm high, 1mm wide parallel ridges separated by 2mm grooves, and the contours are smoothed with a curvature radius of 0.2mm. Ridges in the inset are orthogonally inclined with respect to the ridges in background. Lubricant was used on both fingertip and pad.

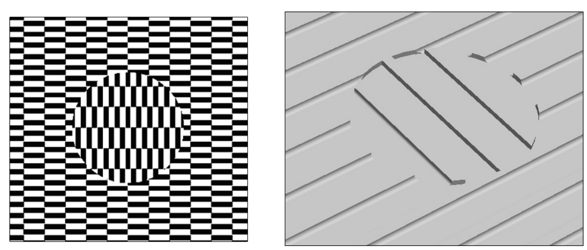

Fig. 2 - The Ouchi Pattern (left) and its simplified version (right) used in the experiment.

This pad was placed on the end-effector of the DHD combined to a fixed mechanical structure in which one opening of about the size of a human forefinger was used to allow subjects to put their right forefinger.

The device and the pad were hidden to subjects' view by a curtain.

The DHD was programmed to vibrate with frequency of 4Hz and 2mm of amplitude in random direction; the DHD's push-button allowed us to remove the vibration at the end of the experiment.

All subjects (all right handed) used their right hand forefinger to touch the pad. Each subject kept still the finger while the pad is vibrating as long as he likes. After experimenting he was asked to freely describe the tactile perception without any suggestions.

2.1.1 Results

45% of subjects reported feeling an illusory perception. Among these, a subgroup of subjects (66,6%) perceived a segmented texture, in which the inner circle was felt raised against the surrounding area, and the remaining volunteers (33,3%) received the complementary perception. However, in both situations a different depth between the inner circle and the surrounding area was perceived. These results well agreed with the visual Ouchi's illusion and could be explained in terms of segmentation of the tactile flow consequent to a different local bias. The oscillation of 4 Hz involves mainly the Meissner corpuscles, more sensitive to vibrations, but partially elicits also the Merkel disks. In this way the two categories of mechanoreceptors, i.e. Merkel and Meissner corpuscles, judged to play an important role in the tactile flow are both addressed.

The low percentage of subjects reporting illusion has been probably caused by the poor tactile resolution and contrast compared to the resolution of the optic system, therefore only the most sensitive subjects (largely female subjects in our tests) perceived an illusion.

In literature a number of works can be found about optic version of the Ouchi illusion, aimed to understand how different parameters of the patter may influence illusion perception.

Khang and Essock [6] performed experiments with a number of variation of the original pattern to evaluate the impact of various parameters, such as orientation and size of the pattern elements, luminance and blurring. They found that a sinusoidal waveform instead of the rectangular one or a blurred version of the pattern strongly reduce the magnitude of the illusory relative motion and of the segmentation effect.

In fig. 3 and fig. 4 can be observed two version of the Ouchi pattern with an increasing blur effect, which presents a decreasing magnitude of illusion.

We performed a trivial optic test to understand the importance of the optic focus and contrast on illusion perception.

Indeed, in the optic version of illusion, short-sighted subjects taking out their glasses reported a decrease of the effect (tests independently performed on different subjects).

Moreover, we would like to stress that, while almost in all experiments performed in literature subjects reported to perceive a relative motion between inset and background regions, only a percentage of them reported an apparent depth discontinuity [8].

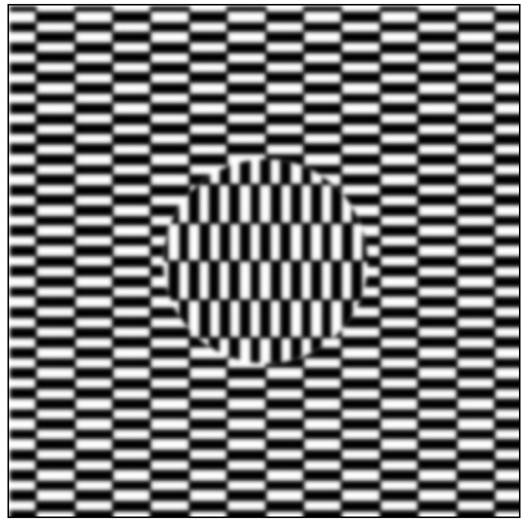

Fig. 3 – A blurred version of the Ouchi pattern.

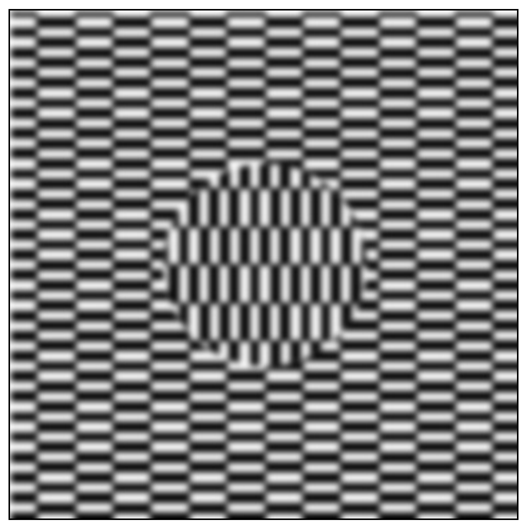

Fig. 4 – A more blurred version of the Ouchi pattern.

3. Discussion and Conclusion

The visual Ouchi illusion is due to the Japanese artist Hajime Ouchi who invented a pattern with inset and background regions containing different and non-uniform gradient distributions. The single tile used to make up the pattern is four times longer than it is wide, and this implies a gradient distribution in a small region with four times as many normal flow measurements in one direction as the other. This

difference in gradient distributions leads to a biased perception in different directions of the optic flow when it is estimated from local measurements. A set of psychophysical studies aiming at investigating the perception of moving pads, having different sinusoidal gratings of different orientations and frequencies, have also found consistent biases in human judgments of pattern velocity. In particular the perceived pattern motion direction was biased towards the direction perpendicular to the orientation of the grating with higher frequencies [7]. A similar experiment was performed in the tactile domain. A simplified 3D pattern inspired to the Ouchi grating was realized of nylon. It is worthwhile noting the difficulty of implementing a pad with a detailed texture having the size of a forefinger. The lack of high spatial resolution, indeed, impinged on the performance of the experiment. In order to replicate the illusion in tactile terms, the only solution was to make the pad vibrating at a suitable frequency. Subjects could touch with their right forefinger the pad keeping the finger still. In this way the tactile exploration occurred in passive manner. Moreover, since the aim of the experiment was to mainly elicit the mechanoreceptor deemed to play a relevant role in the tactile flow mechanism, we have chosen a vibration frequency of the pad of 4 Hz.
This frequency, actually, falls within the bandwidth of Meissner corpuscles (which best respond in the range of 3-40 Hz), being responsible for sensing vibrations, but it is also the upper frequency cut-off of the Merkel receptors which, in addition to a pretty good response to dynamical stimuli, has a better spatial resolution.
Taking into account the hurdles to perform the experiment, results are very encouraging and represent a further assessment of the existence of tactile flow.

4. Acknowledgement

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