Investigating Tactile Sensation in the Hand Using a Robot-Based Tactile Assessment Tool

Elisabeth Wilhelm(✉), Michael Mace, Atsushi Takagi, Ildar Farkhatdinov, Sarah Guy, and Etienne Burdet

Department of Bioengineering, Imperial College London, London SW7 2AZ, UK
e.wilhelm@imperial.ac.uk

Abstract. This paper describes a new robot-based tool for assessing tactile deficits in the hand of neurologically impaired individuals. Automating tactile assessment could: (1) increase the reliability of the measurement, (2) facilitate assessment in patients with limited mobility, and (3) decrease the time needed to assess tactile deficits. Using a portable robot, all probes needed for clinical or scientific assessment can be presented to the fingertip at a predefined scanning speed (dynamic mode), or pressed against the skin for a precisely defined amount of time with controlled contact force (static mode). In addition to the data collected from the sensors that are used to control the motion of the robot, four force sensors located underneath the sample holder for probes presented in dynamic mode allow precise estimation of the contact force. The usability of the device is demonstrated in a preliminary study investigating the roughness and edge detection thresholds in five healthy subjects.

Keywords: Tactile sensing · Assessment · Tactile deficits · Haptic interface

1 Introduction

Motor disorders are often closely related to a loss of touch sensation. If the tactile sensation is impaired, the brain gets limited information about the hands position, the contact force with the environment, the deformation caused by this force, and the objects temperature. To compensate for this loss, the brain has to rely on vision, even though vision is slow and not suitable for contact tasks [5].

Due to the importance of tactile sensing in everyday life, tactile assessment is usually an integral part of the neurological examination. However, this is often limited to pressing cotton tips or tools in order to cause a pinprick sensation against different parts of the skin. In most cases the forces to be applied during this procedure are controlled manually by the examiner, thus have limited inter- and intra-examiner reliability [8].

In order to overcome reliability problems of tactile assessments several protocols including the revised Nottingham sensory assessment [13], the Rivermead

© Springer International Publishing Switzerland 2016
F. Bello et al. (Eds.): EuroHaptics 2016, Part II, LNCS 9775, pp. 17–24, 2016.
DOI: 10.1007/978-3-319-42324-1_2

assessment of somatosensory performance [14], and the quantitative sensory testing [11] have been introduced. These protocols increase the reliability by using standardized tools and intense training of the clinicians [4].

Automation could increase the assessment reliability and also provide the therapist with more information about the contact between the subject and the sample with data recorded during a trial, and can help reduce the assessment duration. However, to our knowledge only one fully automated assessment tool has been developed so far [6]. This sophisticated device is limited to the assessment of proprioception, pressure and vibration thresholds.

In order to investigate whether automation of the tactile assessment can increase its reliability and provide information not available with conventional assessment tools, we developed a novel assessment tool based on the portable version of the *Hi5* robotic interface [9]. This enables us to carry out assessment of static tactile sensation as well as of the sensation when exploring a surface even for patients with limited mobility. The robot allows us to control the scanning speed while recording the contact forces. To demonstrate the usability of the device we investigated the roughness threshold and the edge detection threshold of five healthy subjects. In the future we will also add a static assessment mode in which the robot controls the force with which the stimuli are pressed against the skin.

2 Design of the Robotic Assessment Tool

The experimental setup uses the portable *Hi5* haptic interface shown in Fig. 1. The portable *Hi5* was designed based on the original *Hi5* human-human haptic interaction and fMRI compatible interfaces [3,9]. A Maxon DC motor (RE65 353301 with encoder 1024 CPR) is attached to a rigid milled aluminium frame, which drives an output shaft with the help of pre-loaded cable transmission. Moving parts such as pulleys and bearings with adjustable preload for reducing backlash are cased in the 3D printed housing. The interface can be easily affixed to a desk top for interacting with a user through the handle or any other end-effector while the arm lies on a dedicated support as shown in Fig. 1B. In this study the original wrist handle of the interface was replaced with the custom designed end-effector enclosing a set of sensors and actuators required for the experiments. The main motor of the system is controlled at 500 Hz with Maxon ESCON 50/5 motor controller (powered by 48 V supply) and NI DAQ PCI 6221 (National Instruments) card connected to a desktop PC.

When used as a tactile assessment tool, the interface is equipped with the custom-made assessment handle (see Fig. 2A) while the armrest is extended and raised to cover the moving parts of the robotic device. The whole designed assessment system is portable, weighs less than 10 kg, and easy to set up on a desk. It can be controlled from a laptop and be easily re-configured for different types of tactile assessments. For instance, the dynamic mode simulates the active exploration of a surface while the static mode can be used to present a stimulus with a controlled force level.

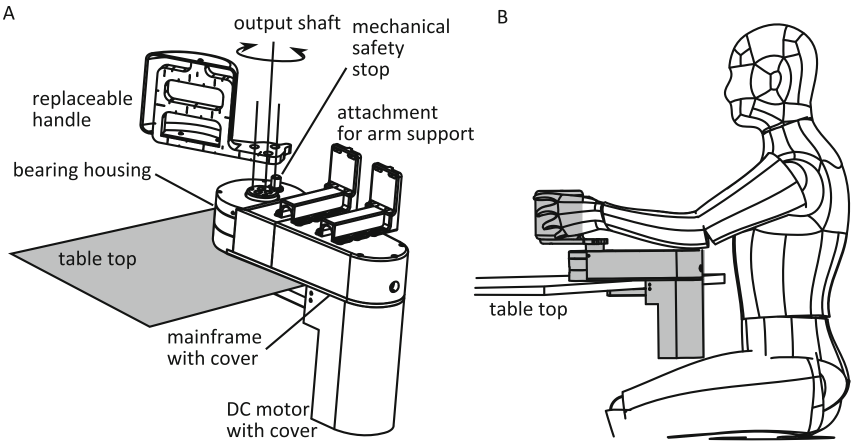

Fig. 1. Portable Hi5 haptic interface for human motor control studies. A: design overview; the interface can be used with various handles and end-effectors. B: User interacting with Hi5 attached to a table-top.

2.1 Dynamic Measurements

A dynamic measurement is meant to simulate the haptic exploration of an object or a surface with the finger by inducing a relative movement between the surface and the fingertips. This information can be used to identify the geometry of an object and to gather information about the surface texture [12]. A direct comparison between dynamic and static two point discrimination reveals that the accuracy of the spatial resolution of tactile sensation in the dynamic task is higher than the one obtained in the static measurement [10]. Furthermore, the inter-examiner reliability of dynamic measurements has been reported to be higher than the one obtained during a static two-point discrimination task [2].

In dynamic mode, the subject rests his arm on the armrest and the finger to be tested can easily drop down on the surface of the horizontal sample holder (Fig. 2B). Inside this sample holder four force sensors (micro load cell type 3132_0, Phidget, Canada) record the force applied by the subject during the assessment (Fig. 2C). A metal plate ensures that all force sensors are in contact with the sample holder and take part in the recording. Samples and reference are glued to this metal plate using double-sided adhesive tape. During each trial the device carries out one forward and one backward movement passing the samples underneath the subject's finger while position control ensures that the scanning velocity is maintained even if a subject presses hard against the surface.

2.2 Static Measurements

In static measurements the stimulus is presented by pressing a probe to the skin, with stimuli including light touch, deep touch, two-point discrimination

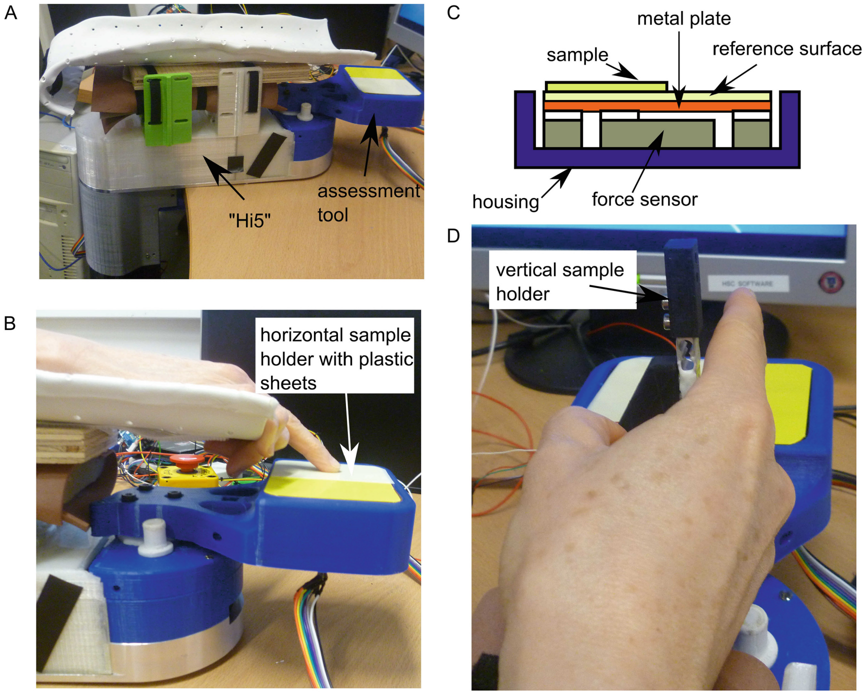

Fig. 2. Portable Hi5 haptic interface equipped with the custom-made assessment tool. A: Photograph of the whole experimental set-up; the handle has been replaced with the assessment tool and the armrest has been raised to ensure that the subjects can comfortably position their hand on the device. B: Photograph showing the device used during assessment in dynamic mode. The robot presents the two plastic sheets which are mounted on the horizontal sample holder to the subject's fingertip. C: Schematic showing the inside of the horizontal sample holder of the assessment tool. The device houses four force sensors. A metal plate ensures that the weight is transferred to all force sensors. On top of this metal plate the reference surface which is either the reference sandpaper or a plastic sheet are mounted. During the trial the sample (e.g. a sandpaper or plastic sheet) is attached to the reference surface. D: In static mode the vertical sample holder is mounted on the assessment tool. This sample holder is equipped with a force sensor and can be used to press a sample against the hand with a controlled force level.

and vibration. In clinical practice the examiner controls the pressure. Passive mechanisms that have been introduced to facilitate this control of the force work only if the contact angle is exactly 90° and the probe does not slip on the skin; otherwise the forces and contact surfaces are not the ones that were intended. In contrast, an automated control can regulate and record the contact forces within the trial. For this purpose we designed the vertical sample holder (see Fig. 2D) which can be attached to the assessment tool. It is equipped with a force sensor (micro load cell type 3132_0, Phidgest, Canada). During a trial this sensor records the contact forces that occur at the sample holder and feeds them into a control algorithm which than adjusts the torque of the motor of the robot.

3 User Interface

The experimental setup includes two computer screens, one for the subject and one for the examiner. The subjects screen is used to describe them the task, prompt them with specific questions during the trial and is used to record their answers, thus ensuring uniformity of the questions across the subjects and minimising a possible influence of the examiner. The second monitor is used to guide the examiner through the assessment, and presents her or him with the samples to be used within the next trial. The samples are determined by a test structure, based on psychophysics, implemented in the program in order to minimize the amount of samples that need to be used. To ensure that the examiner does not mix up the samples to be used a dialogue box requires the examiner to identify the samples that are mounted on the device. Furthermore the examiner is asked to confirm that there are no obstacles and that the patient is located in the right position before the control algorithm will allow the robot to move, thus the trial can proceed safely. During each trial the examiner can observe the contact force that is executed by the subject so that s/he can intervene if the contact force exceeds a safe range that is known not to cause any damage on the skin.

4 Preliminary Experiments

We tested the usability of the new tool and the robot-assisted assessment for determining the *roughness discrimination thresholds* as defined in [7] and the ability to detect a difference in the height between two surfaces which we defined as *edge detection threshold*. Five healthy male subjects aged 26 to 33 years old were recruited among the students and staff of the Bioengineering Department of Imperial College London for the experimental validation. The study was approved by the institutional ethical committee and all subjects gave written informed consent prior to participating in the trial.

4.1 Method

The **roughness discrimination task** was conducted based on the experimental design reported by Libouton et al. [7]. In order to reduce the duration of the assessment the number of sandpapers was limited to four rough sandpapers (P80, P120, P180, and P240 with a grid size of 195 μm, 127 μm, 78 μm, and 58 μm, respectively) and three smooth sandpapers (P400, P600, and P1000, with a grid size of 35 μm, 25.8 μm, and 18 μm, respectively) to be compared with a reference sandpaper (P320, grit size 46 μm), and two interlaced staircases were used to replace the double staircase algorithm. During each trial the subjects were seated in front of the table their arm comfortably resting on Hi5s armrest. The subjects were introduced to the task by a standardized text which was depicted on the subject screen. A cardboard box was used to cover their hand from their view throughout the whole experiment. The whole surface of the horizontal sample holder was covered with the reference sandpaper. Before the beginning of the trial, subjects were asked to lift their finger so that the sandpaper to be compared with the reference could be mounted on one side of the sample holder. During the trial the robot moved the assessment tool from the zero position marked by the mechanical stop on the left side to an angle of 80° and returned to the zero position at the same speed. One back and forward movement took 13.7 ± 2.6 s which equals the time the sandpapers were presented to the subject during the trial. After this the subject was asked which of the two surfaces was rougher. In addition to the answer left or right there was also the option to give the answer "don't know" if a subject was not sure or the sample became lose during the trial.

Edge detection or the ability to identify the outer bounds of an object is known to be an important component of tactile exploration [1]. In order to assess this quality of the sense of touch we designed a new protocol with a test structure similar to the one used during the investigation of the tactile roughness detection threshold. Instead of sandpapers we used plastic sheets with a defined height of 0.508 mm; 0.381 mm; 0.254 mm; 0.19 mm; 0.127 mm; 0.1016 mm; 0.0762 mm; 0.0508 mm, respectively (shim stock, RS, UK). As depicted in Fig. 2, the horizontal sample holder was covered with a plastic sheet in order to ensure that the surface properties of the sample holder and the sample were the same. Before the trial the plastic sheet with the height to be tested was mounted on top of the sheet that covers the sample holder using double sided tape. After the robot presented the sample to the subject in the same way as during the roughness detection task the subjects were prompted with the question which part of the surface was higher than the other. In case they were unsure they had the option to vote "don't know". The order in which the samples were presented was chosen by the control algorithm implementing an interlaced staircase structure to determine the next sample depending on the answer given by the subject.

4.2 Results: Edge Detection and Roughness Discrimination

The thresholds which were recorded in the five subjects are depicted in Table 1. Each threshold represents the smallest difference in grit size between the sample and the reference paper, for which the subject was still able to correctly identify the location of the rougher surface in more than 75 % of the trials. The mean 75 % just noticeable difference for rougher sandpapers and smoother sandpapers were $24 \pm 9.8\,\mu$m and $7.1 \pm 4.3\,\mu$m respectively. These values are similar to the ones obtained by Libouton et al. [7] who reported tactile roughness discrimination thresholds to be $44 \pm 32.5\,\mu$m and $15 \pm 8.5\,\mu$m for rough and smooth sandpapers, respectively. However, in contrast to their findings that detecting smoothness was easier for most subjects, our subjects found it more difficult to differentiate between the smooth surfaces, and two subjects were even unable to give the correct answer in 75 % of the trials with the smoothest sandpaper (P1000).

Table 1. Roughness and edge detection thresholds

Task subject:	1	2	3	4	5
Rough sandpapers (μm)	32	32	12	32	12
Smooth sandpapers (μm)	x	20.2	20.2	11	x
Edge detection (mm)	0.0762	0.0508	0.0508	0.0508	0.0508

These two cases are marked with "x" in Table 1. However, both of these subjects do extensive climbing training, which may affect their fingers roughness and tactile sensation.

Regarding the forces that were applied, we were not able to detect any difference within the same subject scanning surfaces of different roughness, which again is consistent with the findings of Libouton et al. [7]. On average our subjects applied a contact force, which equals the sum of the forces recorded by all four force sensors, of 0.5092±0.2585 N when they performed this task.

In a second test, we assessed the ability of the subjects to detect an edge on a plastic surface. In this test all but one subject were able to detect which surface was higher even if the thinnest plastic shim sheet was mounted on the plate. In total that leads to a 75 % just noticeable difference of 0.0022±0.0004" or 0.056±0.01 mm. The average contact force that was applied during this task was 0.5468±0.4280 N, which is slightly higher then the one used in the roughness discrimination task. No correlation between the results in the two different tests could be identified.

5 Conclusion and Outlook

In this paper, we described a new robot-based assessment tool for investigating tactile sensation. The device can be used to provide tactile stimulation for dynamic and static measurements in a controlled manner. During each trial the robotic device records data, such as scanning speed, contact force and position of the finger, which can be used to investigate the quality of the tactile stimulation and therefore assist the therapist during the neurological evaluation. We demonstrated the usability of the device in a study during which the roughness thresholds and the threshold for edge detection was assessed in five healthy subjects. The results were consistent with those of Libouton et al. [7] who investigated tactile roughness detection thresholds using active touch.

In the future we will add static measurements such as two-point discrimination, and pressure threshold and investigate the usability of the device in a clinical study.

Acknowledgments. This work was supported by a fellowship within the Postdoc-Program of the German Academic Exchange Service (DAAD), as well as by EU-FP7 PEOPLE-ITN-317488-CONTEST, ICT-601003 BALANCE, ICT-2013-10 SYMBITRON, and EU-H2020 ICT-644727 COGIMON.

References

1. Chorley, C., Melhuish, C., Pipe, T., Rossiter, J.: Tactile edge detection. In: 2010 IEEE Sensors, pp. 2593–2598. IEEE (2010)
2. Dellon, A.L., Mackinnon, S.E., Crosby, P.M.: Reliability of two-point discrimination measurements. J. Hand Surg. **12**(5), 693–696 (1987)
3. Farkhatdinov, I., Garnier, A., Burdet, E.: Development and evaluation of a portable mr compatible haptic interface for human motor control. In: 2015 IEEE World Haptics Conference (WHC), pp. 196–201. IEEE (2015)
4. Geber, C., Klein, T., Azad, S., Birklein, F., Gierthmühlen, J., Huge, V., Lauchart, M., Nitzsche, D., Stengel, M., Valet, M., et al.: Test-retest and interobserver reliability of quantitative sensory testing according to the protocol of the german research network on neuropathic pain (dfns): a multi-centre study. PAIN® **152**(3), 548–556 (2011)
5. Johansson, R.S., Flanagan, J.R.: Coding and use of tactile signals from the fingertips in object manipulation tasks. Nat. Rev. Neurosci. **10**(5), 345–359 (2009)
6. Lambercy, O., Robles, A.J., Kim, Y., Gassert, R.: Design of a robotic device for assessment and rehabilitation of hand sensory function. In: 2011 IEEE International Conference on Rehabilitation Robotics (ICORR), pp. 1–6. IEEE (2011)
7. Libouton, X., Barbier, O., Plaghki, L., Thonnard, J.L.: Tactile roughness discrimination threshold is unrelated to tactile spatial acuity. Behav. Brain Res. **208**(2), 473–478 (2010)
8. Lincoln, N.B., Crow, J., Jackson, J., Waters, G., Adams, S., Hodgson, P.: The unreliability of sensory assessments. Clin. Rehabil. **5**(4), 273–282 (1991)
9. Melendez-Calderon, A., Bagutti, L., Pedrono, B., Burdet, E.: Hi5: a versatile dual-wrist device to study human-human interaction and bimanual control. In: 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 2578–2583. IEEE (2011)
10. van Nes, S.I., Faber, C.G., Hamers, R.M., Harschnitz, O., Bakkers, M., Hermans, M.C., Meijer, R.J., van Doorn, P.A., Merkies, I.S., Group, P.S., et al.: Revising two-point discrimination assessment in normal aging and in patients with polyneuropathies. J. Neurol. Neurosurg. Psychiatry **79**(7), 832–834 (2008)
11. Rolke, R., Baron, R., Maier, C., Tölle, T., Treede, R.D., Beyer, A., Binder, A., Birbaumer, N., Birklein, F., Bötefür, I., et al.: Quantitative sensory testing in the german research network on neuropathic pain (dfns): standardized protocol and reference values. PAIN **123**(3), 231–243 (2006)
12. Rosen, B., Lundborg, G.: A new tactile gnosis instrument in sensibility testing. J. Hand Ther. **11**(4), 251–257 (1998)
13. Stolk-Hornsveld, F., Crow, J., Hendriks, E., Van Der Baan, R., Harmeling-Van Der Wel, B.: The erasmus mc modifications to the (revised) nottingham sensory assessment: a reliable somatosensory assessment measure for patients with intracranial disorders. Clinical rehabilitation **20**(2), 160–172 (2006)
14. Winward, C.E., Halligan, P.W., Wade, D.T.: The rivermead assessment of somatosensory performance (rasp): standardization and reliability data. Clin. Rehabil. **16**(5), 523–533 (2002)

http://www.springer.com/978-3-319-42323-4

Haptics: Perception, Devices, Control, and Applications
10th International Conference, EuroHaptics 2016,
London, UK, July 4-7, 2016, Proceedings, Part II
Bello, F.; Kajimoto, H.; Visell, Y. (Eds.)
2016, XXIII, 514 p. 275 illus., Softcover
ISBN: 978-3-319-42323-4