Mechatronics 21 (2011) 604–613

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

A mechatronic platform for human touch studies

Calogero Maria Oddo [a], Lucia Beccai [b], Nicola Vitiello [a,*], Helena Backlund Wasling [c], Johan Wessberg [c], Maria Chiara Carrozza [a]

[a] The BioRobotics Institute, Scuola Superiore Sant'Anna, viale Rinaldo Piaggio 34, I-56025 Pontedera, Pisa, Italy
[b] Center for Micro-BioRobotics@SSSA, Istituto Italiano di Tecnologia (IIT), viale Rinaldo Piaggio 34, I-56025 Pontedera, Pisa, Italy
[c] Department of Physiology, University of Gothenburg, Medicinaregatan 11, SE-40530 Goteborg, Sweden

ARTICLE INFO

Article history:
Received 10 April 2010
Accepted 27 February 2011
Available online 23 March 2011

Keywords:
Mechatronic tactile stimulator
Electrophysiological measurements
Fingertip mechanoreceptors
Microneurography
Tactile stimuli encoding
Biorobotics

ABSTRACT

The development of a mechatronic tactile stimulation platform for touch studies is presented. The platform was developed for stimulation of the fingertip using textured surfaces, providing repeatable tangential sliding motion of stimuli with controlled indentation force. Particular requirements were addressed to make the platform suitable for neurophysiological studies in humans with particular reference to electrophysiological measurements, but allowing a variety of other studies too, such as psychophysical, tribological and artificial touch ones. The design of the mechatronic tactile stimulator is detailed, as well as the performance in tracking reference trajectories. Using microneurography, we recorded from human tactile afferents and validated the platform compatibility with the exacting demands of electrophysiological methods, comprising the absence of spurious vibrations and the lack of relevant electromagnetic interference.

1. Introduction

To study neuronal mechanisms of the sense of touch in the human hand, active or passive protocols are used. In active touch the subjects are asked to explore tactile stimuli [1], while in passive studies tactile stimuli are presented to the fingertip, which is kept still [2]. The exploration or presentation of stimuli should be replicated several times in the same conditions to infer models based on statistical analysis of acquired data [3]. To achieve standardization and repeatability, the passive touch approach requires a robotic stimulator that enables detailed analyses of receptor response or Central Nervous System (CNS) processing through controlled variation of stimulation parameters, of stimulus materials, spatial coarseness and tribological properties, to make comparisons between sessions or participants, or to average over a large number of replications. As regards the neurophysiologic experimental paradigms, in the periphery the activity of single afferents in the skin can be recorded using the microneurography technique [4]; CNS activity can be probed using electroencephalography (EEG) to reconstruct cortical sources [5], while sensory thresholds and percepts can be assessed using psychophysical methods [6].

This study presents the development of a 2 DoFs mechatronic system that could indent and slide textured stimuli to the fingerpad with feedback-controlled normal contact force and parametric sliding trajectories while recording the normal and tangential forces at finger-stimulus interface. The robotic system has been devised with an open design approach since it is simple to command via a graphical user interface, is upgradable thanks to the FPGA control electronics, and can be used to perform neurophysiological studies in humans with techniques such as microneurography and EEG [7] even in combination with psychophysical experimental paradigms. Also, it is suitable for tribological and artificial touch studies as well and it allows to implement a wide variety of protocols for active [8] and passive studies [9].

There are a number of particular requirements in the design of such a robotic device. First, to allow repeatable experiments with standardized conditions, accuracy and precision in the control of stimulation parameters, such as the contact force and the sliding velocity profile, is required. Second, the device must guarantee a range of forces and movement velocities covering those that would be used by humans in the exploration of textures, while both normal and tangential forces need to be recorded as they are fundamental for human touch investigation. Studies on discriminative touch [10,11] suggested: for the indentation force a range of at least 100 mN–5 N, with a control accuracy of about 5% of the reference force and sensing resolution within a few mN; 100 mm of stroke along the sliding direction and velocities up to 150 mm/s with μm position sensing resolution and steady state control accu-

* Corresponding author. Tel.: +39 050 883 472; fax: +39 050 883 101/497.
E-mail addresses: oddoc@sssup.it (C.M. Oddo), lucia.beccai@iit.it (L. Beccai), n.vitiello@sssup.it (N. Vitiello), helena.backlund@physiol.gu.se (H.B. Wasling), wessberg@physiol.gu.se (J. Wessberg), chiara.carrozza@sssup.it (M.C. Carrozza).

0957-4158/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mechatronics.2011.02.012

racy. The third challenging requirement, given that some classes of tactile receptors are highly sensitive to vibration up to 400 Hz or more [12], is in developing a stimulator that could get into contact with the human finger free from any spurious vibration that could interfere with the encoding of tactile stimuli. Fourth, electrophysiological methods such as microneurography and EEG involve recording of signals in the μV range, and electromagnetic interference from the robotic system has to be minimized. Fifth, these experiments can require the participant to sit in a natural position and to remain relaxed for hours. Hence, the subject's comfort puts stringent demands on the mounting of the device and on the control laws of each DoF so that it can be adapted in 3D space to the position of the subject's arm, hand and finger [13].

Finally, the programming operation by the experimenter to implement the targeted protocols has to be simple and flexible, and upgradeability of the platform should be possible.

All these requirements and specifications have hitherto not been addressed by a single device in the scientific literature. LaMotte and colleagues presented an advanced stimulator [14], which was too bulky to be easily oriented in 3D space and which relied on the early digital electronics available at the time; the scotch yolk stimulator [15] used a complex mechanism resulting in a lack of flexibility of the experimental protocol; the rotating drum stimulators [16,17] regulated the indentation force in open loop, and thus could not reject external disturbances. Finally, with respect to studies on encoding of texture and its related dimensions (e.g. roughness), most platforms were developed for experiments in monkeys [18] rather than humans, then presenting less demanding requirements since higher level of invasiveness is tolerated in animal model studies.

Here, we outline the development of a platform that fulfils all these requirements for tactile stimulation in human studies, and that was replicated in five exemplars with customizations for electrophysiological, psychophysical, and artificial touch studies and for tribological experiments on different tactile surfaces as well. A typical passive touch sequence, with stimulus indentation and sliding is presented and quantitative indexes are calculated for assessing over repeated runs the performances of the controllers of the 2 DoFs. Using microneurography, we recorded from human tactile afferents under passive touch stimulation and showed that the platform is compatible with the exacting demands of electrophysiological methods, specifically the absence of spurious vibrations and lack of electromagnetic interference.

2. Materials

2.1. Mechanism and actuation

The core system had two orthogonal DoFs (Fig. 1) to indent and slide the tactile stimulus tangentially to the fingerpad. A voice-coil actuator (NCC05-18-060-2X, H2W Tech.) applied the indentation force with a 12.7 mm stroke. A linear guide (LTP 60.180.0804-02, SKF Multitec) driven by a DC motor (RE35, Maxon Motors) applied the sliding motion through a 4 mm pitch ball bearing screw, allowing a maximum velocity of 300 mm/s and a stroke of 110 mm. The propagation of the small vibrations produced by the screw was filtered by applying four vibration isolation mounts (520053, Radiaflex) at the corners of the interface between the voice-coil actuator and the linear guide. Each of the used vibration isolation mounts had an axial stiffness (indentation direction) of 133.3 N/mm and a radial stiffness (sliding direction) of 16.7 N/mm. Considering the parallel of the four elements, the resulting axial stiffness was 533.3 N/mm and the radial stiffness was 66.7 N/mm. This means that, by applying a 500 mN indentation force (i.e. a typical value in the targeted experimental protocols) a maximum deformation of 1 μm will occur. Moreover, in the developed platform the axial deformation is not subjected to very limiting constraints since, as detailed in the following, the indentation axis is under force control. Oppositely, the resulting stiffness along the sliding direction needs attention since such axis is under position control. In this case, a tangential force component of 500 mN (i.e. a typical experimental value) will cause a deformation of 7.5 μm along the sliding direction (resulting from equilibrium of forces) and an acceptable (lower than 0.02°, resulting from equilibrium of torques) misalignment between the sliding direction and the tactile stimulus on top the voice-coil actuator, complying with the design constraints. Linear Current Amplifier Modules (LCAM, Quanser), guaranteeing very low electromagnetic interference, were chosen for driving the actuators. Switching power devices were avoided since the typical (10–50 kHz) range for PWM carrier frequency is higher than half the microneurography sampling rate, but just outside the cutoff

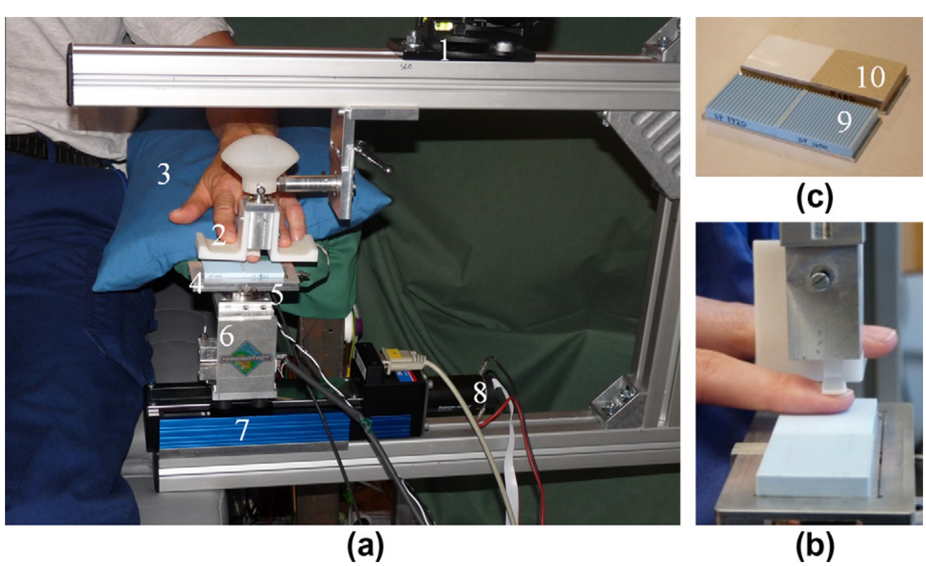

Fig. 1. (a) Experimental set-up during microneurography: frame hold by spherical joint (1), hand-finger support system (2), vacuum cast for arm support (3), carrier for stimuli (4), load cell (5), voice-coil actuator assembly for indentation of stimuli (6), linear guide for tangential sliding of stimuli (7), DC motor with encoder (8). (b) Fingerpad-stimulus interface with finger fixation system and free fingers support. (c) Examples of the used stimuli glued to a changeable aluminum plate: a couple of ridged stimuli (9), smooth plastic and rough sandpaper (10).