FROM THE FIELD

Restoring Sensory Feedback Enables Real-Time Control of Prosthetic Hand

By Eugenio Guglielmelli

Figure 1. Using restored tactile feedback to select appropriate force to grasp an object.

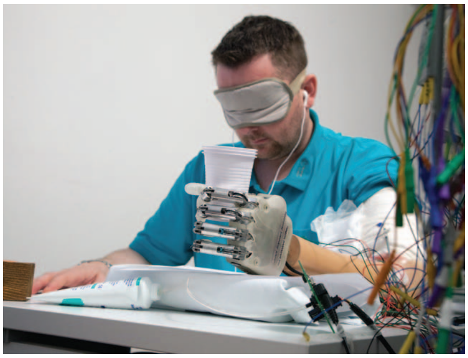

Figure 2. A successful grasping task of a deformable object.

On 5 February 2013, the results of the second major experimental step of the LifeHand project were unveiled in conjunction with the publication of a related research article in the international journal *Science Translational Medicine* [1]. The work is coauthored by a group of Italian and other European research centers: 1) Scuola Superiore Sant'Anna, 2) Catholic University of Rome, 3) Campus Bio-Medico University of Rome, 4) IRCSS San Raffaele La Pisana, 5) EPFL—Switzerland, 6) University of Freiburg—Germany, and 7) Aalborg University—Denmark.

The experimentation also highlighted the importance of reactivating tactile feedback to enable the patient to use the robotic prosthesis with dexterity.

LifeHand2 is the natural evolution of the research that led to the 2008 success of LifeHand1. The patient was an Italian–Brazilian national, Pierpaolo Petruzziello, who had undergone the exact same amputation (left arm immediately below the elbow) as Dennis Aabo Sørensen, the subject of this second experimentation. Also, in that case, the patient's median and ulnar nerves were implanted with four intraneural electrodes, connected to the biomechatronic prosthesis CyberHand, which is two generations older than the OpenHand used by Dennis. The size, ability to move fingers, and weight (just over 0.60 kg) are equivalent to that of a human hand. The tactile sensor readings, because of a special conversion and decoding algorithm and a custom neurostimulation unit, were used to send back an electric charge proportional to the amount of pressure used in touching objects or other external elements.

LifeHand1's objective was to enable the patient to carry out three basic hand movements (fist, claw, and thumb to index finger) via direct communication between the prosthesis and the brain, passing directly and exclusively through the nervous system, as opposed to unnatural communication. The motor commands dispatched from the brain to the periphery may also be collected by myoelectric electrodes fixed onto positions on the body surface corresponding to specific muscular tissues, such as the pectoral or arm muscles. In turn, the myoelectric electrodes send back the movement signal to the prosthesis. While the communication is effective, it is nevertheless unnatural. In 2008, a major effort was devoted to the decoding and classification of efferent neural control signals, thus enabling direct motor control of the robotic prosthesis by the brain. LifeHand1's objective was reached [2], even if the neural control of the prosthesis was handled without the artificial hand being implanted on the patient's stump and without any sensory feedback being sent by the prosthesis to the brain. Five years after from the first experimentation, with LifeHand2, researchers have been striving to also create a tactile response that, from the sensors of the prosthesis, would reach the patient's brain. The brain, because of the sensory information, should succeed in recognizing the shape and consistency of objects, gauging, as a result, the amount of strength to be applied with every holding movement. In the case of

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Figure 3. Using restored sensory feedback for recognizing a rigid object shape.

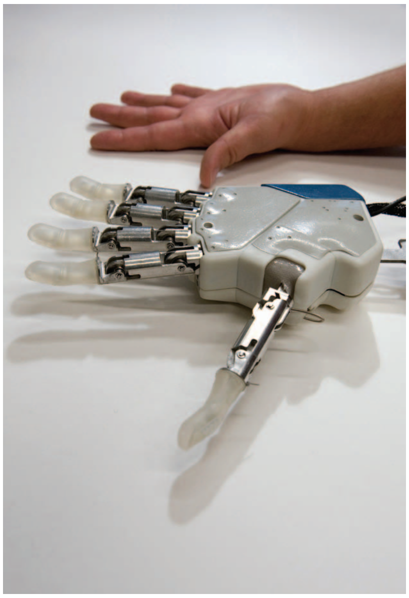

Figure 4. A comparative view of the shape and dimension of the robotic hand used for the LifeHand2 experiments with respect to the human hand.

LifeHand2, the prosthesis was fitted onto the arm of the amputated patient, thereby creating a more natural physical condition than in 2008, even though the device is still experimental.

The communication hardware between the nerve fibers and computer were the intraneural electrodes placed in the patient's nerves, based on the technology known as *transverse intrafascicular multichannel electrodes* and designed, made, and tested to be placed transversally to the nerve fascicles (with a minimum diameter of 220 µm, equivalent to about three human hairs). The transversal implant onto the nerves is aimed at establishing the largest possible amount of contact points between the communication channels of the electrodes and the nervous fibers to amplify the possibility of communicating with the central nervous system. The 16 electrical contacts (or active sites) that are incorporated in the electrodes are made from platinum and iridium oxide on a sublayer of polyimide, guaranteeing their isolation and flexibility. During experimentation, the electrodes (80 µm in diameter each) proved to have an extremely high level of selective activation of the nerve fiber distributed across the length of the nerve. This helped to generate sensations in the patient's nervous system using much lower intensity level impulses than with the LifeHand1 2008 experimentation.

An analysis of experimental data of LifeHand2 provided researchers with scientific feedback that confirmed the possibility of restoring, to a patient whose upper limb had been amputated, tactile sensations and the ability to handle objects in a near-natural way. Specifically, as displayed in Figures 1–4, the patient was quickly able to learn how to use an anthropomorphic robotic prosthetic hand to

- combine the sensory areas to robustly manipulate the overall palm force
- distinguish the different consistencies of hard, medium, and soft objects (with more than 78.7% accuracy)
- recognize the basic shape and size of objects, such as the cylinder of a bottle, the sphere of a baseball, and the oval of a mandarin (88% accuracy)
- understand the location of an object in relation to the hand, therefore sending to the prosthesis the most appropriate command to shape the best grasp (97% accuracy)
- self-rectify when applying the wrong amount of pressure on an object during the movement itself, due to the communication flow between the prosthesis and the brain, in a reaction time of less than 100 ms
- manage, in real time, the different levels of exerted force for the two different nerve sensory areas (index finger, thumb, and small finger) while holding an object in the palm of the hand (with 93% accuracy).

The experimentation also highlighted the importance of reactivating tactile feedback to enable the patient to use the robotic prosthesis with dexterity. On the one hand, when the artificial circuit taking sensory information from the prosthesis to the brain was deactivated, the patient's dexterity markedly diminished despite his being able to see. On the other hand, holding exercises with active sensory feedback were undertaken blindfolded and in acoustic isolation.

Starting from the demonstration of the possibility of restoring fine motor control capabilities in amputees by exploiting learning processes based on sensory feedback, it is expected that LifeHand2 can trigger many new research developments in the field of robotic prostheses and robot-based rehabilitation and assistive solutions. To read more on the LifeHand2 experimental studies, visit www.unicampus.it/lifehand/lifehand-2-the-project and www.project-time.eu.

References

[1] S. Raspopovic, M. Capogrosso, F. M. Petrini, M. Bonizzato, J. Rigosa, G. D. Pino, J. Carpaneto, M. Controzzi, T. Boretius, E. Fernandez, G. Granata, C. M. Oddo, L. Citi, A. L. Ciancio, C. Cipriani, M. C. Carrozza, W. Jensen, E. Guglielmelli, T. Stieglitz, P. M. Rossini, and S. Micera, "Restoring natural sensory feedback in real-time bidirectional hand prostheses," *Sci. Trans. Med.*, vol. 6, no. 222, p. 222ra19, 2014.

[2] P. M. Rossini, S. Micera, A. Benvenuto, J. Carpaneto, G. Cavallo, L. Citi, C. Cipriani, L. Denaro, V. Denaro, G. Di Pino, F. Ferreri, E. Guglielmelli, K.-P. Hoffmann, S. Raspopovic, J. Rigosa, L. Rossini, M. Tombini, and P. Dario, "Double nerve intraneural interface implant on a human amputee for robotic hand control," *Clin. Neurophysiol.*, vol. 121, no. 5, pp. 777–783, 2010.