TRANSMISSION OF TEMPERATURE SENSATIONS THROUGH UPPER-LIMB PROSTHESES

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***Abstract**. Commercial upper-limb prostheses do not allow users to receive any sensorial information, therefore the latter carry out mechanical activities insecurely and imprecisely, since there is a long distance between the upper-limb prosthesis and the natural member, from the functional point of view. That contributes to increase the upper-limb prostheses rejection level. The main objective in this work was to develop an artificial temperature interface system to be integrated to myoelectric prostheses. This artificial interface has sensors and actuators connecting: ambient, prostheses and its users. When the sensor detects some quantity temperature variation, it sends the information to the microcontroller, which processes the signal and sends another control signal to the actuator. The actuator stimulates the human receptors that will conduct the information to the nervous system. Five volunteers, myoelectric prostheses users, have tested the equipment. The artificial temperature interface (ATI) demonstrated to be efficient and allows the prostheses users to identify the different temperatures avoiding dangerous situations.*

***Keywords**: Prostheses, Gripper, Human Rehabilitation, Artificial Limb, Sensorial system.*

1. INTRODUCTION

The most used upper-limb prostheses do not allow users to receive any sensorial information, therefore the latter carry out mechanical activities insecurely and imprecisely, since there is a long distance between the upper-limb prostheses and the natural member, from the functional point of view. In the literature, most of the work on prosthetic hands has been developed based on the robotics works as Aguiar (2001) where grip control is exhaustively analyzed but not the sensorial information. Most people, who start using upper-limb prostheses, end up stopping using them. This contributes to increasing the prostheses rejection level (*Portaria* MS/SAS No.388, 1999), especially for bilateral amputees.

In this work, a prosthetic hand that aggregates sensorial functions (temperature) to the existing mechanical functions is demonstrated, transforming the prosthesis in a more complete and attractive system for users. The proposed approach may lead to an increase in the number of the prosthetics users and accelerate their progress in utilizing prosthesis resources.

The proposed artificial temperature interface is made up of two temperature sensors, which acts as human body receptors. It is believed that human heat receptors are stimulated by the alteration of the metabolic rates of the body, which are promoted by the modification of intracellular chemical reaction velocities (Guyton and Hall, 1996). Temperature receptors indicating warm sensation haven’t been histologically identified, only psychologically, but the existence of cold as well as warm receptors is considered (Guyton and Hall, 1996).

In the case of an artificial interface, when the sensor detects some quantity variation, it sends the information to the microcontroller, which processes the signal and sends another control signal to the actuator. The actuator stimulates the human receptors that will conduct the information to the nervous system.

Five volunteers, myoelectric prosthesis users, have tested the equipment. Two of them are forearm amputees, one is an arm amputee, one is a bilateral upper-limb amputee and one was born with a genetic malformation of the forearm, lacking part of it. All individuals have signed the *freely given and informed consent* to participate in the studies. Additionally the execution of this work was approved by the *Barão de Mauá* University Center Committee of Ethical Conduct in Human Research.

2. TEMPERATURE INTERFACE

A heat source can excite human body receptors indicating warm and cold temperatures perception. Although the perception of warm and cold can occur in other parts of the body, the hand and the forearm, for being in the more distal part, are most of the time the first channel of temperature perception. The non-detection of heat emitted by a source can cause accidents and even damage to the prosthesis during the execution of a task, which contributes to discouraging its use. With the impaired prosthesis it is probable that its use may be interrupted for a significant period of time, which may cause harm to the user.

Temperature levels are obtained by employing at least three different receptors: one that perceives if an object is warm, another that perceives if the object is cold and one that perceives pain, acting at the extremities of warm and cold perceptions (Vander, Sherman and Luciano, 1980). To emulate this ability, only one temperature sensor is used, a thermopile (figure 1) that works within the range of -20^{o}C to 85^{o}C. This sensor captures infrared radiation so that it can detect heat without establishing contact with a surface, for example.

Fig.1 - Thermopile.

As the thermopile detects the heat to which it has been exposed, the information is sent to a PIC microprocessor (series 16F, from Microchip), analyzed by a software especially developed for this purpose, treated and sent to the actuators. Electrical stimulation was the actuation form chosen to transmit the heat sensation to the user, because it is fast and allows variations that may inform different temperature ranges, as much, little or painful heat.

Four surface electrodes were used as actuators (figure 2). One pair to "indicate" low temperature ranges and another pair for high temperature ranges. Although the same task could theoretically be done with three sensors, during the tests the use of two pairs has shown to be more effective, since their positions on the skin could be better defined, preventing interferences and enhancing their performance.

Proper electrode positioning must be rigorously observed to prevent significant discomfort or avoid placing it on motor points and points that can generate interference in the sensors of the myoelectric prosthesis signals.

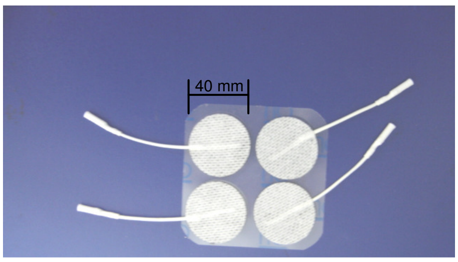


Fig.2 – Surface electrodes CF3200

Room temperature, used as reference, is measured by using a different temperature sensor model LM35. Thus, with the two temperature sensors plus the microcontroller and the actuators, the user has been able to identify if a heat source was warm or cold and estimate its temperature.

The logic of the software developed and installed in the microprocessor was based on the relation of temperature sensors. When the room temperature value, provided by LM35, is determined, the software defined its working range. This range allows, through the thermopile, determine if a specific external heat source is cold or warm.

The temperature information is transmitted to the prostheses user nervous system by different frequency of electric pulses (per second - measured in Hertz, Hz) discharged on the user through the electrodes. To illustrate how the system works, suppose room temperature read by LM35 is 22^{o}C, the working range is selected. In this range from 20,1^{o}C to 25^{o}C, users cannot suffer any stimulation (0 Hz), because, for them, that room temperature is the reference.

Temperatures perception above 25°C are considered warm and temperatures perception below 20,1°C are considered cold. The selected electrodes are used to transmit the temperature perception to the prosthesis users. Temperature perception is given by the electrical signal frequency that is proportional to the thermopile temperature information.

Extreme temperatures will cause some discomfort, warning for danger. Physiologically it would be the beginning of the pain sensation (Costanzo, 2004). All these parameters can be individually adjusted at the system startup, according to each user's perception threshold.

3. MYOELECTRIC PROSTHESES USER'S TEST

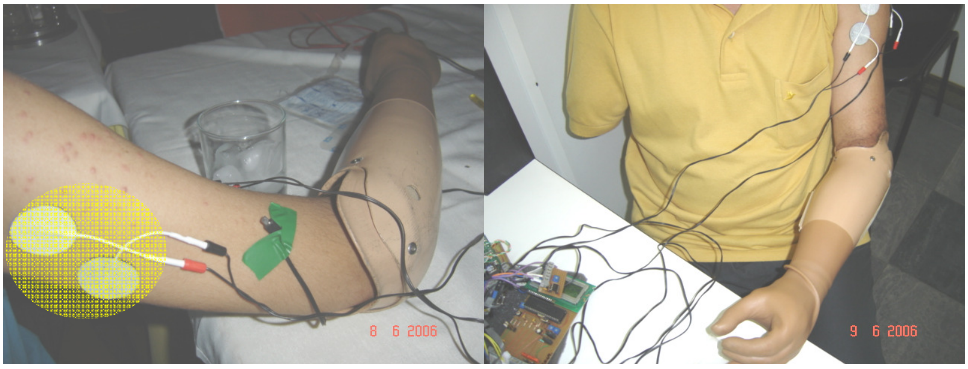
3.1. Preparing Prostheses and its Users

The electrodes were placed on the volunteers arm or forearm. Three or four surface electrodes used with electrical stimulation were employed. Initially three electrodes were used to study how they would function and a fourth one was coupled if the results were not satisfactory.

After connected the prosthesis with the *artificial temperature interface* (ATI), the user did a fast recognition (about ten seconds) of its functionality and signal perception. A correspondence between the received stimulus and its meaning was established, which could later be directly understood due to the brain's plasticity as the corresponding measurement (Bach-Y-Rita and Kercel, 2003). Thus, it can be expected that with daily use, after some period of time, the user can perceive the electrical stimulus in that region as a temperature and not as an electrical stimulus.

3.2. Tests descriptions

The thermopile was excited with several heat sources, including low temperature ones, as shown in Figure 3a, where a glass of ice was used to change the temperature perception. In both pictures (a and b), the electrodes are shown. Better results were obtained when the electrodes were disposed in two pairs. When three electrodes were used, the distinction between temperatures became less clear. Moreover, the discomfort and the possibility of interference were higher in this case because of the electrodes proximity. Therefore, it was decided to use four electrodes with all users.



(a) (b)

Fig 3 - Sensing system tests with two users. Highlighted are the temperature actuators.

In this training stage, the users could recognize the system and understand the feedback signals from actuator. After a training period no longer than 29 minutes, including 3-minute stops for resting at every 5 minutes of training, test evaluation stage for temperature recognition was started.

The first part of this test stage, which lasted 20 minutes, was similar to the training phase, but the users did not have access to the information about the temperature source. Therefore, the users have to distinguish and estimate the temperature only by using the actuator information.

In the second part of the tests stage, which also lasted 20 minutes, the users were let free to approximate the prostheses to any heat source and comment their perception and sensation.

4. RESULTS

During the tests all five users could identify the differences between cold and warm temperatures. Four of them could distinguish five different temperature ranges, one was able to distinguish four ranges and no users were able to discriminate the six temperature ranges from the ten given possibilities. Only two users considered the first electrical stimulus as unpleasant, and one kept on considering it unpleasant during the entire test. The data are shown in Table 1.

Table 1 – Behaviors of prosthesis users during temperature perception tests.

Answers of prosthesis users during temperature tests						
	Able to distinguish between cold and warm.	Able to identify 4 temperature ranges.	Able to identify 5 temperature ranges.	Able to identify 6 temperature ranges.	Consider the stimulus unpleasant in the initial phase of tests.	Consider the stimulus unpleasant even after the initial phase of tests.
Number of users	5	5	4	0	2	1

5. DISCUSSIONS AND CONCLUSIONS

The sensorial system was conceived to work as the interface between the environment and the user. To accomplish this goal, strategies based on human physiology were developed, allowing information about temperature and even pain to be transmitted to the user through the least possible number of sensors and actuators. The system was developed in a way that it is adaptable to most of commercially available myoelectric prostheses, therefore more accessible to users.

The apparatus used for training allows users to verify the temperature of the object. Then it is possible to establish the equivalence between stimulus perception and real fact. This makes training interesting and motivating, leading users to practice more and, consequently, to progress.

At the tests execution's break phase it was possible to observe that users wish to play freely checking the temperature sensors and heat sources relation.

The approval of the system made possible the verification of its effectiveness during the tests, whether in the laboratory or with users. This effectiveness can be enhanced by using a greater number of sensors and actuators, which must simplify and improve the temperature discrimination that could be sensed by the prosthesis. A relevant functional gain may be considered to have been added to the myoelectric prosthesis, making it more similar to the human hand.

For lower-limb prosthesis, users feel safe and present better control and integration with it. It is frequently considered to be a real part of the user's body. The same has not yet been observed with upper-limb prosthesis. With the approval of the proposed sensorial system, both technically and by the users, an interesting opportunity shall be created to improve the quality of these products and make them resemble the natural limb.

With these positive results, the study will be continued by adapting the sensorial system to myoelectric prosthesis and verifying its performance in daily tasks. All system will be embedded in the prosthesis with the exception of the electrodes and its wires.

6. ACKNOWLEDGEMENTS

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4. REFERENCES

Aguiar, PM. Controle simultâneo de força e posição em garras antropomórficas. 2001. 72 f. Dissertação (Mestrado em Engenharia Mecânica) – Escola de Engenharia de São Carlos, 2001, Universidade de São Paulo, São Carlos.

Portaria do Ministério da Saúde, Secretária de Assistência à Saúde No. 388. Disponível em: <http://portal.saude.gov.br/portal/sas/sapd/visualizar_texto.cfm?idtxt=21583>. Acesso em: 17.nov.2010.

Vander, A.J.; Sherman, J.H.; Luciano, D.S. Human physiology: the mechanisms of body function.1980, 3. ed. São Paulo: McGraw Hill.

Bach-Y-Rita P, Kercel SW. Sensory substitution and the human-machine interface. Trends in Cognitive Sciences,2003, v.7, n.12, p. 541-546, Dec.

Guyton AC, Hall JE. Tratado de fisiologia médica. 9ª ed., 1996, Rio de Janeiro: Guanabara Koogan.

Costanzo LS. Fisiologia. 2ª ed., 2004, Rio de Janeiro: Guanabara Koogan. 392p.

5. RESPONSIBILITY NOTICE

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