Non-invasive electromyography-based sensing for proportional prosthesis control

by

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ABSTRACT

The best design of a multi-function tool is the human hand. Normal limb functionality is taken for granted until the day it is lost. Maslow's theory of human motivation suggests self-actualisation and control of one's own situation being most needed.

The psychological implications of any disability are described in Maslow's theory of human motivation, based on human hierarchy of needs. "Self-actualisation" is placed on top of all needs. By having the ability to function normal and independent and the feeling of being in control of one's own life or actions, usually associated with being successful in life. An amputation has a major impact on a person's self-esteem and affects their life style. People tend to have the urge to replace what they had, at least with a counterpart with equal performance. Should patients have a limb amputated, the question is, what functionality remains in the surrounding muscles and nerves?

Biomechatronics is introduced at the North West University (NWU), with the aim to research a complete proportional powered prosthetic hand. The versatility of the human hand suggests that it is a complex part of the body, and the future goal of the development of proportional prosthesis control is divided into several studies. This particular study focuses on the human-machine interface (HMI) or the sensing component for prosthesis control. The HMI has to be able to provide Matlab®/Simulink® with the sensed data as Matlab®/Simulink® will be used for future research.

The HMI makes use of surface electromyography (sEMG). sEMG could be the most elegant design approach, as no medical surgery procedures are required to have a device implanted. By considering the rate at which technology improves, it would also be unwise to insert an implant that becomes out-dated in a short time. The sEMG electrodes consist of a set of five electrodes in a wristband fitted to a patient's forearm. This interfaces the patient with the sEMG platform. The electrodes sense antagonist muscle activity through the patient's skin, and is regarded as a non-invasive HMI.

The sEMG sensing platform is an interface board that acts as a serial emulator (COM port) that connects the sEMG sensors to the Matlab®/Simulink® environment via USB. The platform's circuitry converts the dual-channel analogue input sEMG signals into digital format. A calibration algorithm calibrates the sensors with the push of a button, using automatic gain control (AGC). A pulse duration modulation (PDM) servo is used to test the effect of visual feedback on the accuracy of performing a gesture according to an animation.

The proportional control algorithm is implemented in Simulink® and has the capability of decoding dual-channel antagonist muscles' sEMG signal into position and force information. The algorithm and platform is evaluated by making use of a gesture animation that asks the user to mimic the gesture. The power of visual feedback on the accuracy of human gestures should not be underestimated, and is demonstrated in this study.

The results obtained from this study verify the functionality of the sEMG platform and demonstrates the possibility of proportional control through sEMG.

OPSOMMING

Die hand word beskou as die mees bruikbare meganiese stelsel. Normaal funksionerende ledemate word as vanselfsprekend gevind tot die dag aanbreek wanneer 'n amputasie onvermeideilik is.

Maslow is bekend vir sy teorie wat handel oor menslike gedrag en motivering. Hy maak die stelling dat die vermoë van 'n persoon om in beheer van 'n situatsie as een van die belangrikste prioriteite vir 'n mens aangesien die persoon nie meer self basiese funksies kan verrig nie.

'n Gewrigsamputasie verander 'n persoon se selfbeeld en self-motivering aansienlik, aangesien 'n persoon nie meer basiese funksies self kan verrig nie. Hierdie mense se behoefte is om die verlore hand te vervang wat hulle gehad het, met ‘n plaasvervanger wat soortgelyk funksioneer. Die vraag is, met ‘n gewrigsamputasie, watter funksies bly in hul omliggende spiere en senuwees agter, om te gebruik vir prostese beheer?

Die veelsydigheid van die menslike hand impliseer dat dit 'n komplekse taak is om ‘n plaasverganger te onwikkel. Die vooruitsig vir handprosteses dui daarop dat werk gedoen behoort te word op proporsionele beheer gebaseerde prosteses. Biomegatronika is onlangs bekend gestel by die Noord-Wes University (NWU), met die doel om ‘n volledige elektroniese aangedrewe prostese te ontwikkel.

Die navorsingplan verdeel die proporsionele beheer aangedrewe prostese navorsing die in verskeie sub-projekte. Hierdie loodsprojek fokus op die mens-masjien koppelvlak (MMK) en dien as platform vir die toets van nuwe beheeralgoritmes en seinverwerkingstegnieke. Matlab®/Simulink® is geïdentifiseer as sagteware platform vir die reeks studies wat volg. The koppelvlak moet in staat wees om inligting beskikbaar te stel aan Matlab®/Simulink® aangesien Matlab®/Simulink® gebruik gaan word vir navorsing wat volg.

Die gebruik van oppervlak Elektromyografie (sEMG) tegnologie word gebruik as die mens-masjien koppelvlak (MMK). sEMG word beskou as die mees elegante manier om spierbeweging mee te karrakteriseer, aangesien geen mediese operasies of prosedures benodig word om die tegniek te gebruik nie. Teen die tempo waarteen tegnologie verbeter, sou dit ook onverstandig wees om 'n sensor in ‘n pasiënt in te plant, wat tegnologies gou kan uitfaseer. Die sEMG elektrodes bestaan uit ‘n stel van vyf elektrodes vervat in ‘n armband, en koppel die pasiënt se voorarm aan die sEMG platform. Die elektrodes tel antagonistiese spieraktiwiteit deur die pasiënt se vel op, en word dus beskou as 'n nie-indringende MMK.

Die sEMG platform dien as 'n nagemaakte seriale koppelvlak (COM-poort). Die koppeling tussen die sEMG sensors en Matlab®/Simulink® word deur middel van die rekenaar se USB poort gemaak. Die platform bevat al die stroombane om dubbel-kanaal analoog sEMG insette om te skakel na digitale formaat. 'n Kalibrasie algoritme kalibreer die sensors met die druk van 'n knoppie. Hierdie algoritme maak gebruik van digitaal-verstelbare weestande om die seinsterkte te verstel.

Die dekoderings algoritme het die vermoë om, van dubbel-kanaal, antagonistiese spier sEMG insette, die posisie en die krag wat die pasiënt wil uitvoer met sy/haar hand te dekodeer. Hierdie inligting demonstreer die moontlikheid vir die proporsionele beheer van ‘n prostese.

DECLARATION

I, Henno Esterhuyse, hereby declare that the thesis entitled "Non-invasive electromyography-based sensing for proportional prosthesis control' is my own original work and has not already been submitted to another university or institution for examination.

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Signed on 30th day of April 2012

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And this is the confidence that we have towards Him, that if we ask anything according to His will, He hears us. – 1John 5:14

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LIST OF ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
ADC	Analog to Digital Converter
AGC	Automatic Gain Control
ANN	Artificial Neural Network
ANS	Autonomic Nervous System
BCI	Brain-Computer Interface
BMI	Brain-Machine Interface
CAD	Computer Aided Design
CCVS	Current Controlled Voltage Source
CER	Crossover Error Rate
CMRR	Common Mode Rejection Ratio
CNS	Central Nervous System
DC	Direct Current
DE	Differential Equation
DET	Detection Error Trade-off
DOF	Degree Of Freedom
DSP	Digital Signal Processing
DVD	Digital Versatile/Video Disc
ECoG	Electrocorticography
EEG	Electroencephalography
EER	Equal Error Rate
EMG	Electromyography
EMI	Electromagnetic Interference
ERS	Event-Related Synchronization
ERD	Event-Related Desynchronization
FAR	False Accept Rate
FER	Failure to Enroll Rate
FMR	False Match Rate
FMRI	Functional Magnetic Resonance Imaging
FNMR	False Non-Match Rate
FRR	False Rejection Rate
FER	Failure to Enroll Rate
GUI	Graphical User Interface
iEMG	Intramuscular Electromyography
I/O	Input and Output
HMI	Human-Machine Interface
KSPS	Kilo Samples per Second
LED	Light Emitting Diode
MEG	Magnetoencephalography
NWU	North West University
MUAPT	Motor Unit Action Potential Trains
NIRS	Near-infrared reflectance spectroscopy
NIS	Neural Interface System
PC	Personal Computer
PDM	Pulse Duration Modulation
PCB	Printed Circuit Board
PNS	Peripheral Nervous System
ROC	Relative Operating Characteristic
sEMG	Surface Electromyography
SIL	Single In-Line connector
SNR	Signal to Noise Ratio

SNS	Somatic Nervous System
SPI	Spinal Cord Injury
TMR	Targeted Muscle Reinnervation
USB	Universal Serial Bus

LIST OF SYMBOLS

Ag	Silver
AgCl	Silver-Chloride
g	Gram (mass)
Hz	Hertz (Frequency)
I	Through-variable current (electrical) or force (mechanical) measure in Ampere
Ω	Ohm (Resistance)
V	Across-variable potential difference measured in Voltage (electrical) or tension (mechanical) in Newton