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NÁVRH A ŘÍZENÍ PROTÉZY RUKY
DESIGN AND CONTROL OF A HAND PROSTHESIS

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Abstrakt
Práce předkládá metody a výsledky návrhu, výroby a výzkumu pětiprsté protézy ruky. Inspirace jdoucí z přírody a z toho vyvozený princip použitého mechanizmu je uveden. Základní koncept řídícího schéma založeného na procesingu a ohodnocení EMG je navrhnut a implementován. Části senzorického systému protézy jsou navrhnuty a zahrnuty do rídícího algoritmu a shématu. Velké množství inovací a návrhů pro budoucí práce a výzkum jsou prezentovány, stejně tak komplexní analýza a diskuse dosažených a možných budoucích výsledků.

Summary
The text shows idea flow, methods and results in design, manufacture and research of five–fingered prosthetic hand. The inspiration of the nature and mechanical principle elicited is presented. Fundamental control scheme based on processing and evaluation of EMG is designed and implemented. The segments of sensory system are designed and involved into the overall controll scheme idea. Large innovations and suggestions for future work and research are given with complex discussion through reached and hopefully future results.

Klíčová slova
protetika, EMG, ruka, vlnkova transformace, mechanicky princip

Keywords
prosthetic, EMG, hand, wavelet transform, mechanical principle

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Ing. Jakub Žajdlík

Contents

1 Introduction and Work Aims

Construction of a prosthesis and its control is a desire of man somewhere from the beginning of his existence. A lot of effort has been applied on it over the time but we are still far away from the design by the Nature however it does not mean that we should not to continue in exploring of this area.

This work is closely linked to [90] where mechanical design based on detailed study of human hand is presented as well as multi criteria analysis of actuators etc. In connection on that work these aims for the consequent research has been selected:

- **Verification of an Authentic Mechanical Principle** – The verification is done on the prototype which was manufactured for this purpose.
- **Design and Verification EMG Based Control Scheme** – The main problem of EMG (electromyogram – electromyographic signal) is its processing and evaluation. Its more less stochastic signal therefore some sophisticated methods like wavelet transform and artificial neural networks are used.
- **Design of Sensory System** – This is subtask of Control Scheme but finally it has been found as very large field of research and therefore it is considered as separate part.

The summary and overview of the current research worldwide can be found below same as reached results, innovations and conclusions which resulted from.

Mechanical Principles of Aids – Overview 2

The current state in a field of commercial prosthetic hands is such that probably only one producer has a device with an opposition of the thumb. [80] All others are just any kinds of pliers. [66] [58] [11]

If we have a look on mechanical constructions in research of the prostheses all of them has opposition of thumb but they are either reduced on number of degrees of freedom [84] [49] [85] or reduced on force performance by preloaded backward elastic elements [8] [93] [21] or has unideal adaptability of a grasp [88] [49] or both disadvantages mentioned above. [30] [29] Alternatively they are using "alternatives" of actuation like hydraulic systems [73] [69], pneumatic systems [7] or shape memory alloys [47] which bring quite a lot of complications and complexity. Some of a construction has insignificant number reduction of degrees of freedom they has good force parameters and kinematic behavior but they are very complex = expensive. [45] [77] [9]

Very good mechanical construction is possible to find in robotics hands like [36] or [51] but they are not usable in prosthetic because of high weight and actuators are not implemented in palm (unappropriate dimensions). However there are some reasons why to have a look toward this direction. [39] [70])

EMG – Acquisition and Processing – Overview 3

EMG alternatively MES (myoelectrosignal) in commercial field is used in very basic two channels control or rarely in time proportional controlling. [94] (little bit better than switch on/off)

There is a lot of papers where different processing and evaluation techniques of EMG are used. The most of researchers are interested in surface EMG (EMG measured on the skin – non invasive method) like [22] [62] [83] [50] [16] [3] [23] [64] [60] [52] [79] [75] but there are some papers talking about usability of intramuscular EMG [28] [53]. In [92], where control part is based on an EMG motion pattern classifier which combines variable learning rate (VLR) of neural network with parametric autoregressive (AR) model and wavelet transform seems to be very close to use as a commercial device.

A comprehensive overview of methods how to control multifunctional prosthetic hands by processing the electromyographic signal with detailed description of signal conditioning and preprocessing, feature extraction, dimensionality reduction, pattern recognition and offline and online learning can be found in [91]. This is really large field of research and the knowledge of advance artificial intelligence is needed. [26]

4 Sensory Systems – Overview

Kind of sensory system is even used in commercial prosthesis like [80] or [66]. In this case it is probably force and partially slip sensor based on piezoelectric principle to add into prosthesis controlling some autonomy to help keeping of an object in the hand.

The detection of slip is considered as a main value to determine if object is stable in hand or not. As basic one can be used acoustic (microphone) or optic sensor. [46] Which are quite sensitive on environment noise. Better alternative is piezoelectric sensor that is usually integrated together with temperature and force sensor at finger tip. [14] [15] [12] The force sensor is more significant for robotic arms but in most cases are implemented in prosthetic hands too. Usually are based on capacitance or strain gauge with possibility to measure torque. [13] [51] [36] To detect only touch and partially slip there is possible to use tactile arrays (displays) some time called artificial skin. [43] [9] [6] [5] There are some systems that use FSR (Force Sensor Resistor) in combination with accelerometer. [71]

There is not possible exactly say which sensor is best but as a very good solution and implementation can be found in [14] where in finger tip is integrated temperature, force and slip sensor or in [9] where are used a flexible layer with contact sensors to cover the hand, triaxial force sensors integrated in the fingertips and a compliant skin with embedded 3D force microsensors to measure force distribution at the fingertips.

5 Inspiration by the Nature and Mechanical Principle Elicited

This chapter shows all ideas comes from inspiration by the nature. [97], [67]

The layout of muscles and related tendons on physical forearm is on Figure 5.1. (informal picture only) If we consider Muscle Flexor Digitorum Profundus as a one actuator (in our case DC motor) we need another device such as a divider of force to divide power toward individual fingers. The nature solve this problem by partial innervation of muscle toward a particular tendon. So by one muscle is possible to control more tendons. Therefore assembly of levers were designed to divide the force from one DC motor to the five fingers. (Figure 5.2)

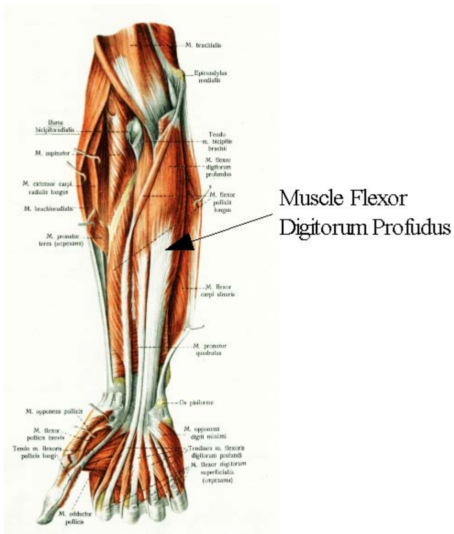

Figure 5.1: Muscles of Forearm (right side, front view; third layer) [97]

If we continue in an investigation of human hand toward tips of fingers we can find that each joint is actuated by own tendon (Figure 5.3 – informal picture only) leaded from different layer of muscles and more over some joints are supported by other muscles (Figure 5.4 – informal picture only).

It means that we should use for each joint (DIP – distal interphalangeal, PIP – proximal interphalangeal) one and for some joints (MCP – metacarpophalangeal) more actuators. Question is if human hand is able to bend each finger in each joint separately and if it is needed in every day life. On the base of this consideration we can build up simplified mechanism showed on Figure 5.5. Which have been used at prototype. (Figure 5.6)

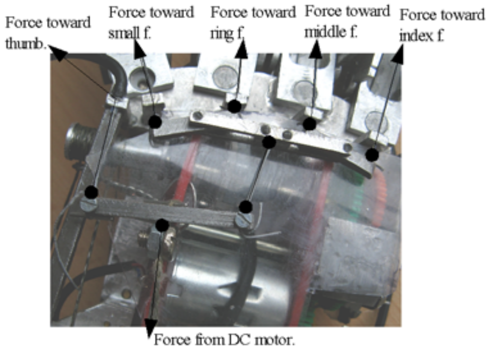

Figure 5.2: Assembly of Levers

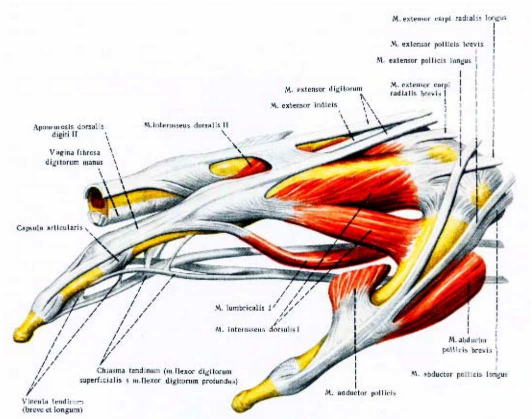

Figure 5.3: Layout of Muscles and Tendons in a Finger [97]

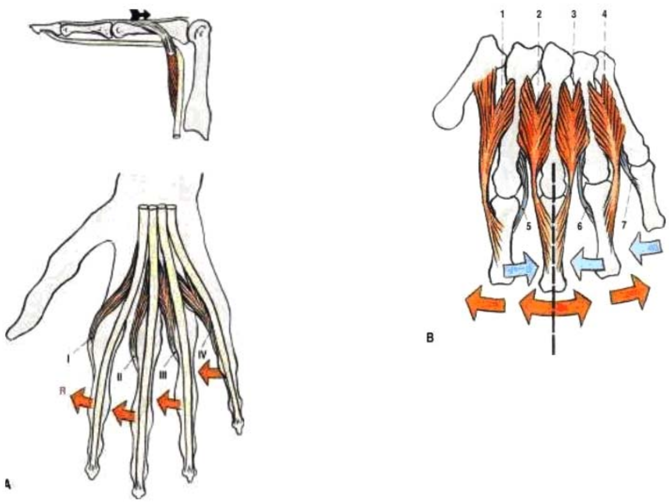

Figure 5.4: Schematic of Muscle Functions and Layout (m. lumbricales (A) and m. inlerossei (B);A musculi lumbricales; right hand; view from front top – schematic of coverage m. lumbricalis against metakarpofalange joint and against interfalange joints by tension behind dorsal aponcurose of finger; side view I-IV m. lumbricalis I-IV;B musculi interossei; left hand; dorsum side view 1 - 4 mm interossei dorsales 5 - 7 mm interossei palmares) [97]

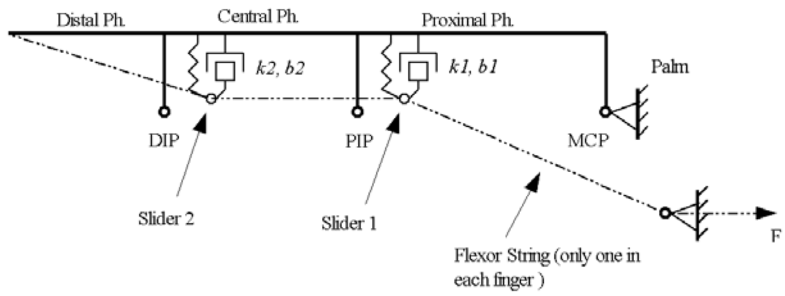

Figure 5.5: Principle of Finger Mechanism

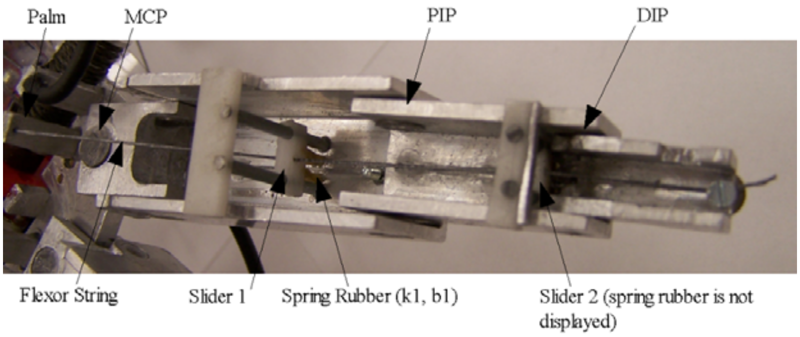

Figure 5.6: Principle of Finger Mechanism – Prototype

Mechanism works this way: A force F is applied by a string which leads through two sliders (Slider 1, Slider 2). Connection between slider and phalange is realised by springs (k1, k2, b1, b2 – power rubber). Therefore the first motion generated when the string is pulled is in the MCP joint. Other joints can be activated only if the slider is under the appropriate joint. The PIP moves only if Slider 2 is under its (PIP) joint and the DIP joint moves only if Slider 1 is going under DIP joint.

Duction of fingers is realised by leading a string 1.5 mm beside MCP vertical axe. See Figure 5.7. System of strings leading around the MCP axes is designed to keep operation of prosthesis thus that when hand closes the adduction of four fingers is performed and when the prosthesis opens the fingers do the abduction. Middle finger is without duction and it is intent to be used for precious pinch grasp.

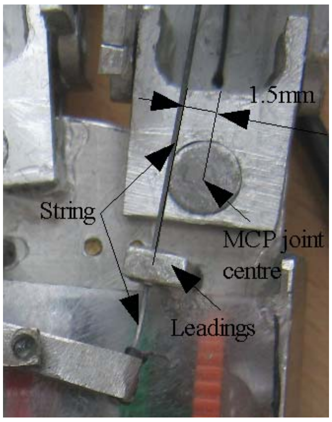

Figure 5.7: Realization of Duction

3D model, Simulations and Optimization of a Grasp 6

The 3D model on the base of ideas mentioned above have been created. With this model some basic analysis (kinematic, dynamical, structural) were done under very simplified marginal conditions. In [90] you can find detailed description of all parameters. Figure 6.1 shows, just for an illustration, the behavior of the mechanism. There is a resultant of the velocity on tips of fingers in a global coordinate system, located in the wrist (Figure 6.2), during movement from fully opened hand to fully closed. Very fast changes in velocity (position, acceleration too) are brought up which are caused by mechanism principle matter and very ideal conditions of simulation. (no friction, gravity, dumping, effects of rubber glove, environment, ...) so this results give just rough but useful information of mechanism behavior.

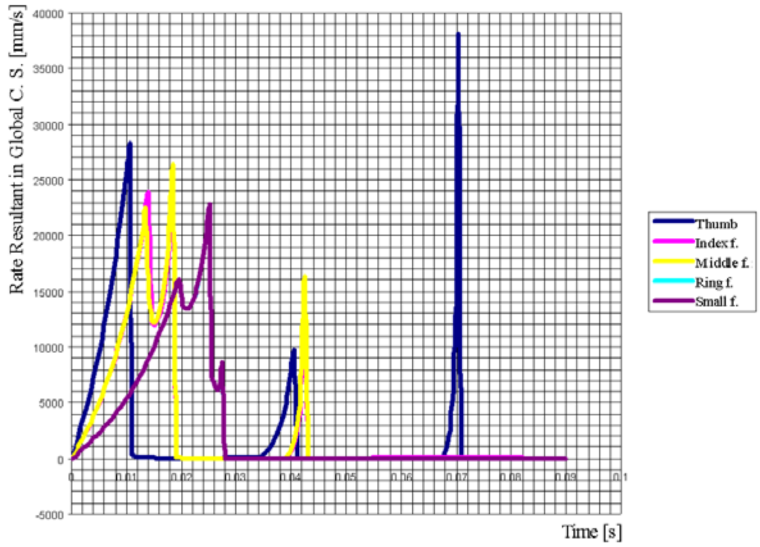

Figure 6.1: Velocity Resultants for Each Tip Point of Fingers

The kinematic simulation showed that proposed angle of opposition of the thumb against four fingers and applied forces to each finger were not appropriate to keep ball (100mm diameter) stable in the hand. Therefore optimization (system Pro/Mechanica - Motion) was used to obtain force value for each finger and sufficient start angle of opposition of thumb for this type of grasp – grasp of 100mm diameter ball which is considered as a basic one.

As a goal of optimization was to find a minimal or zero value of resultant virtual joint between ball and palm located in Point 1 (Figure 6.2) in plain XZ and angle of opposition of thumb. (Figure 6.3) What correspond with consideration to keep ball stable in given layout of fingers. Before optimization ball was escaping from the grasp on more opened side – between thumb and small finger.

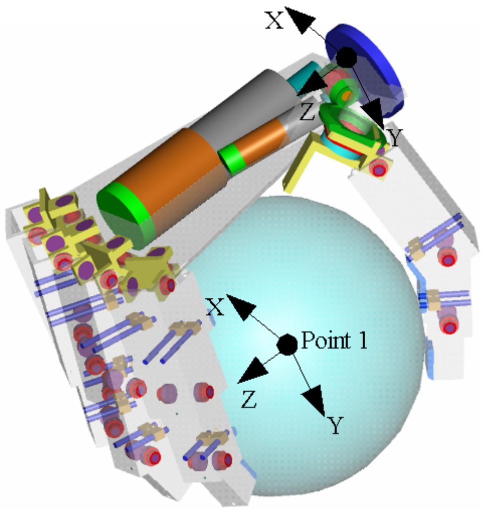

Figure 6.2: Model Composition for Optimization

Parameters of last attempt to optimize this grasp with goal described above are in Table 6.1.

Parameter	Min.Value	Initial Value	Max. Value	Units
Thumb Force	-350	-290.1	-230	N
Index F. Force	-150	-100.9	-50	N
Middle F. Force	-150	-100.2	-50	N
Ring F. Force	-150	-99.51	-50	N
Small F. Force	-150	-98.95	-50	N
Thumb Angle	1.5	1.932	2.5	rad

Table 6.1: Initial and Allowed Ranges of Parameters

Optimization Convergence Tolerance: 0.1 %.

Maximum Number of Optimization Iterations: 30.

The initial values of parameters were find during some ancestral optimizations attempts.

After three iterations and 53 calls goal/limit function these results are given. (Table 6.2)

The value of goal was accepted as a satisfactory value what has been validate by successful consequential motion simulation. Dimensions of levers (Figure 5.2) – force layout – were determined on the base of this optimization.

For complete information about 3D model: all fingers are dimensionally same and Figure 6.4 shows overall dimensions.

Parameter	Optimized Value	Ratio
Thumb Force	-290N	42.2%
Index F. Force	-100N	14.6%
Middle F. Force	-99.7N	14.5%
Ring F. Force	-99N	14.4%
Small F. Force	-98.5N	14.3%
Thumb Angle	1.9rad	-
Goal of opt.	0.183N	-
Sum of Applied Force	687.2N	100%

Table 6.2: Results of Final Optimization

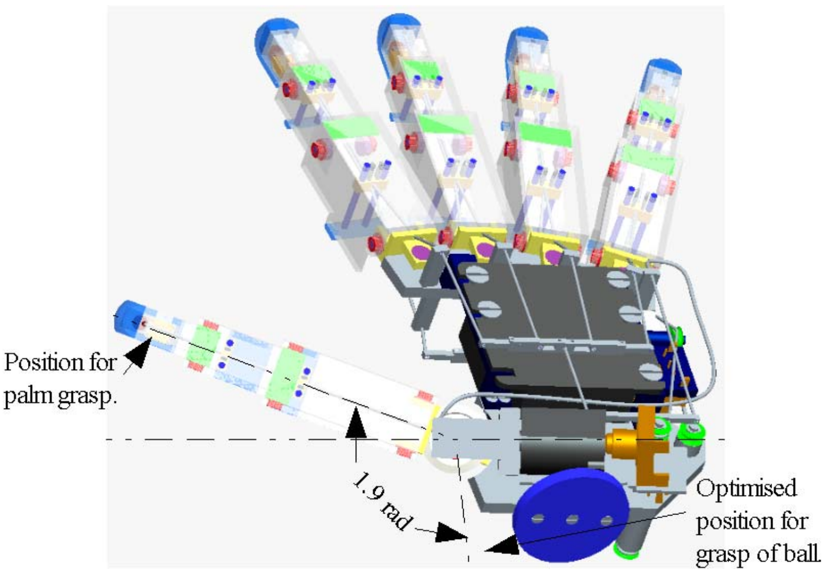

Figure 6.3: Measurement of Angle of Thumb Opposition

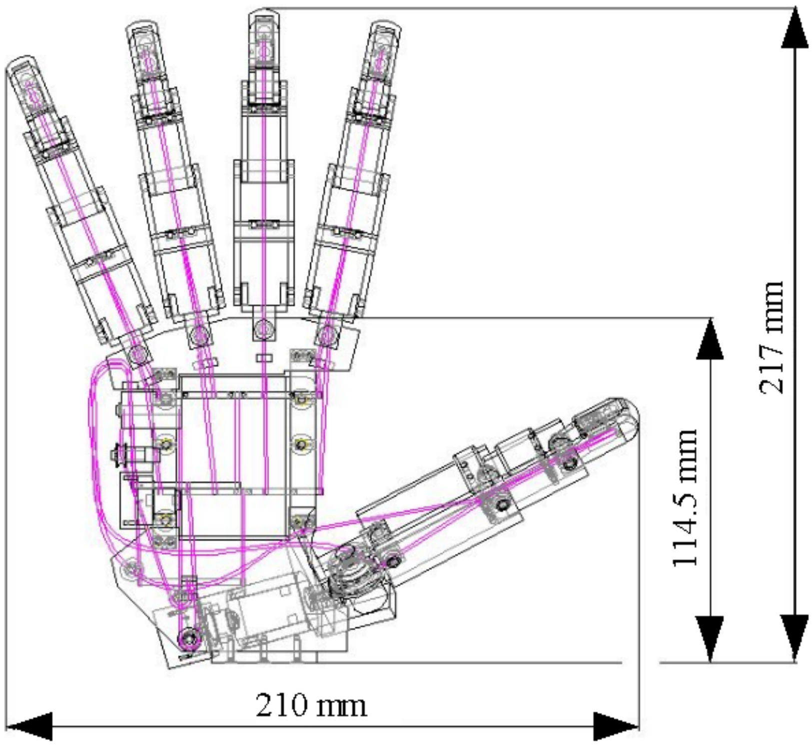

Figure 6.4: Overall Dimensions of 3D Model

Prototype, Control Scheme and Sensory System 7

7.1 Prototype

Prototype (Figure 7.1) was designed to verify kinematical principle described above and for implementation of simplified control system. (Figure 7.2) [95]

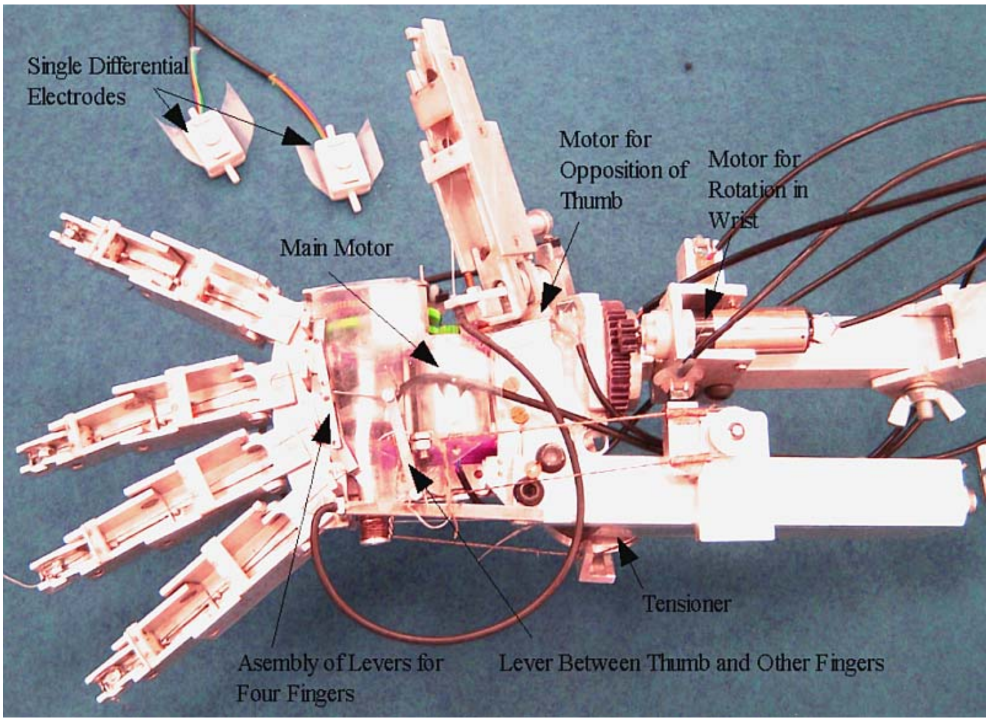

Figure 7.1: Prototype

Final design parameters of this device are: Degrees of freedom: 21; Number of DC motors: 3; Kind of DC motors – main: Como Drills 3Vdc, RE280, gearbox ratio: 1:256, – thumb: escap MA16 16M 18 208 486 0, – wrist: escap MA16 16C 11 207 365 0

Used materials: Main parts are from alloy of aluminum; bearings and sliders are from plastics; joint pins and assembly of lever from steel. As a strings have been used fish wire which has been found as an appropriate solution with regard to dimensionality and strength.

Dimensions: Approximately rough external dimensions of open hand from dorsal (or palmar) view are 210x217mm. (Figure 6.4)

Reached parameters: Time to close (close and open): 6s (12s); Force on the tip of index finger: see Discussion; Force of rude palmar grasp: see Discussion; Weight: 960g; Cost: somewhere around 150Eur (see Discussion).

There is probably only one part at Figure 7.1 what need some explanation and it is “Tensioner”. This is used for compensation of non equality of consumption of string during closing and opening. For closing less length of string is needed (palmar side) then for opening (dorsal side). This difference is around 2cm. Using of this complication bringing device should resolve innovation. (See chapter Innovations of Mechanism and Control Scheme)

7.2 Control Scheme and Sensory System

Electronic system is realized by a microcontroller (Atmel ATmega 128) and H-bridges for the drive of the DC motors. This board is able to communicate with a PC via a serial port so it is able to receive information about recognized grasp by the ANN (artificial neural network). The overall control scheme to be used for this prosthetic hand is shown in Figure 7.2 however it was implemented without feedback because sensory system is designed only (not implemented yet).

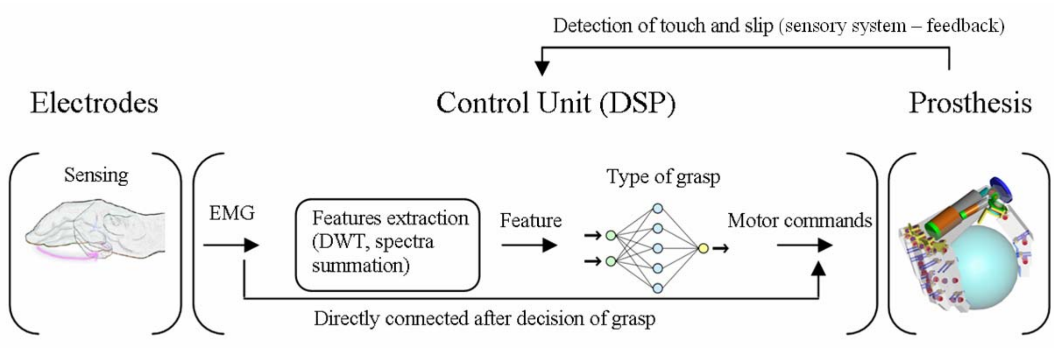

Figure 7.2: Control Scheme

Electrodes and Data Acquisition EMG electrodes are made by company Galatea (Russian production) for prosthesis “Miotea”. These electrodes are single differential. [55] The MES is by these electrodes full-wave rectified – the absolute value of each data point is used. One electrode was placed on the frontal side approximately between the musculus flexor carpi radialis and the musculus palmaris longus and the second electrode was placed on the dorsal side on the musculus extensor digitorum. (Figure 7.3) The signals from the electrodes are read by an AD acquisition card (ADLINK PCI -– 9114A — DG) with a sample rate of 2000Hz. Processing has been performed in Matlab – Data Acquisition Toolbox where is possible directly use this AD card with standard Matlab commands.

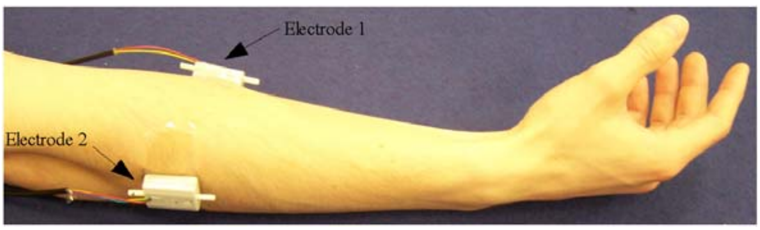

Figure 7.3: Placement of Electrodes

Feature Extraction and Classification All parts of program (from the data acquisition to the determination the type of grasp) are realized in Matlab. The threshold value for the start of the acquire data routine was determined to be 0.8V which is approximately 26% of maximal value of the signal. For data acquisition a 0.1s (200 samples) pretrigger time is used. The time for acquisition of the data set is 0.75s (750ms). This is quite longer than is usual but there is still some signal to measure. (Figure 7.4)

For the extraction input vector for the ANN the CWT (continuous wavelet transform) was used with the second order Gaussian wavelet: (7.1)

$$\Psi(x) = C_2 \exp^{x^2} \tag{7.1}$$

, where C_2 is such that $\left\|\Psi^{(2)}\right\|^2 = 1$; $\Psi^{(2)}$ is second derivative of $\Psi(x)$. This wavelet (7.1) was chosen on the basis of the MES character. [54]

For calculation normed wavelet coefficient for erasing phase lag we can use: (7.2)

$$W(a, b) = \left\| \frac{1}{\sqrt{|a|}} \sum_{n=-2a}^{Max-a} \overline{\Psi(n/a)} f(n-b) \right\| \tag{7.2}$$

, where a = Min, Min+1, ... , Max–1, Max and b = na, na+1, ... , -1, 0. Both formulas (7.1) and (7.2) are algorithms already implemented in Matlab. In this formula, Min and Max fix the frequency band extracted from EMG. In the experiments, Min is 6 and Max is 64.

The spectra summation can be defined as (7.3).

$$st(b) = \sum_{a=Min}^{Max} W(a, b) \tag{7.3}$$

In this case we get one dimensional row array from spectra summation with 1500 elements. This array was then sub divided into successive groups of 150 elements and the maximum value in each group was identified. This leaves a row array with ten elements from each electrode. (Figure 7.4)

Consequently it is made one twenty elements (two electrodes) column array which is the input vector for the ANN. The ANN is a feed forward back propagation neural network with three layers. The first layer has 25 neurons with log-sigmoid transfer function (logsig) the second layer has 15 neurons also with logsig and the output layer has only one neuron with a linear transfer function (purelin). The ANN is trained for outputs:

- Board palmar grasp
- General crud palmar grasp
- Grasp of spherical subjects
- Rotation in wrist

Two hundred data set was used for training of ANN for each motion. ANN was trained 600 epochs. The Levenberg-Marquardt algorithm (trainlm) learning algorithm was used with default settings by Matlab. The ANN after training on the first data sets still did not give good results therefore the ANN was trained for other 100 features and 300 epochs.

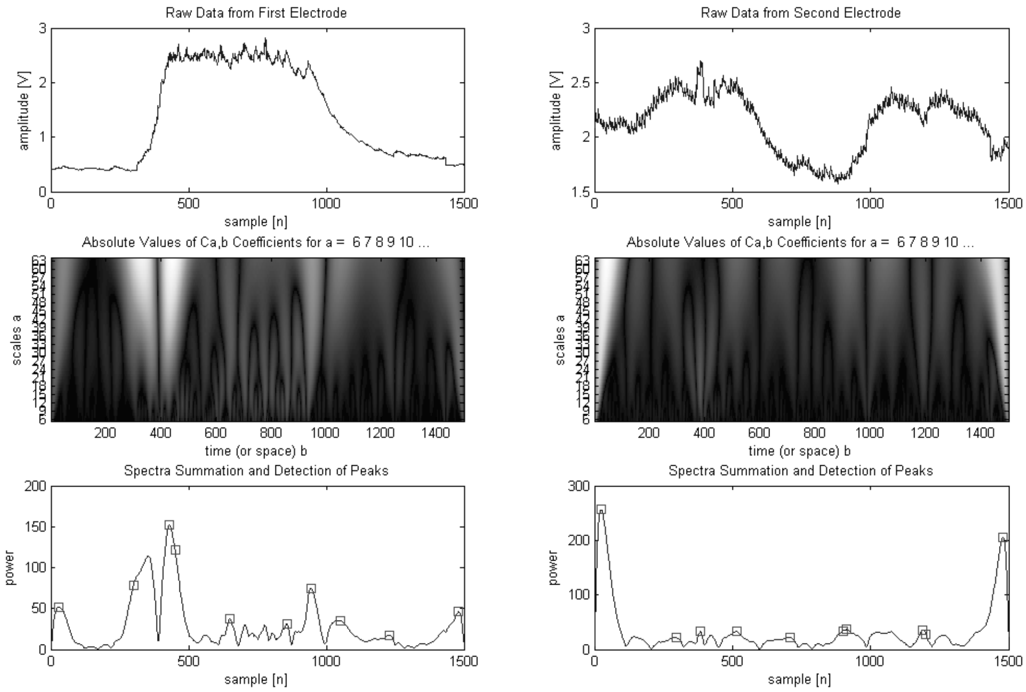

Figure 7.4: Feature Extraction

The current algorithm is: Watching data on Electrode 1, if its value is over the threshold 750ms data acquisition is started on both electrodes. From this data set CWT (described above), spectra summation and detection of peaks is performed and a 20 elements column vector for the ANN is constructed. Prompt for expected output is shown. ANN is simulated and if outputs match the result is sent on the serial port. (motion starts) Watching values on Electrode 1 is started again. If the results do not match the ANN output is not sent on serial port and again watching values on Electrode 1 begins.

The success of the ANN in correct recognition of a grasp is dependent on consistent strength of a contraction as well as on its duration (for each type of grasp). Other weakness of the proposed control scheme is in detection of peaks. The method used is only very simple. Only one maximum on the rigid interval division of analysed data is found and as you can see in Figure 7.4 some of the peaks are overlooked and some values are too close together (mostly peaks are only locals maxims on the appropriate interval) which can cause mislead of pattern recognition. The fruitfulness of the recognition of the desired grasp by the ANN is around 50%. Main disadvantage of this ralization is a delay. The time between the performed muscle contraction and the start of a motion of the mechanism is quite long (over one second). The idea of this control scheme is quite general known [18] however its implementation is unique and it is considered as a best start step to find out what direction follow in controlling of the hand prostheses. See chapter Discussion and Conclusions.

For effective and reliable hand it is necessary to implement some sensors. In connection with this work the first attempt to design sensory system has been done. [78] In way to maximalize simplicity of whole design, beginning with mechanical design and continuing with control and sensory scheme, this sensors are necessary and proposed:

- Slip (touch) sensor on finger tips. (based on piezoelectric principle)
- Touch sensor (flexible layer with contact sensors) in palm and palm side of fingers. (based on principle of electro active polymers)

Only these sensors are sufficient and even no motor encoders are necessary. Prosthesis in type of grasp is enough autonomous so for type of grasp only position of thumb is necessary to set up what can be solved by end switches. So operation of device is as follow: when position of thumb will be established the closing of hand with small current will start. In moment of touch detection the motion will stop and only if slipping is generating a signal the force (current) is going to increase up to its maximum – measurement of the current. Therefore only touch and slip detection is needed. However to make really effective and reliable prosthesis the temperature sensor should be added. If the hand should be used as a robotic device the sensors of position in each joints as well as sensor of force eventually torque on finger tips should be implemented too. Because any sensor have not been tested on prototype it can happened that sensors with different type operation principle will be finally used but the purposes of its implementation will be as given.

Innovations of the Mechanism and the Control Scheme

8

8.1 Innovation of the Mechanism

The low reliability of preliminary prototype and a lot of manufacture difficulties flow into major innovation of the mechanical principle. (Figure 8.1)

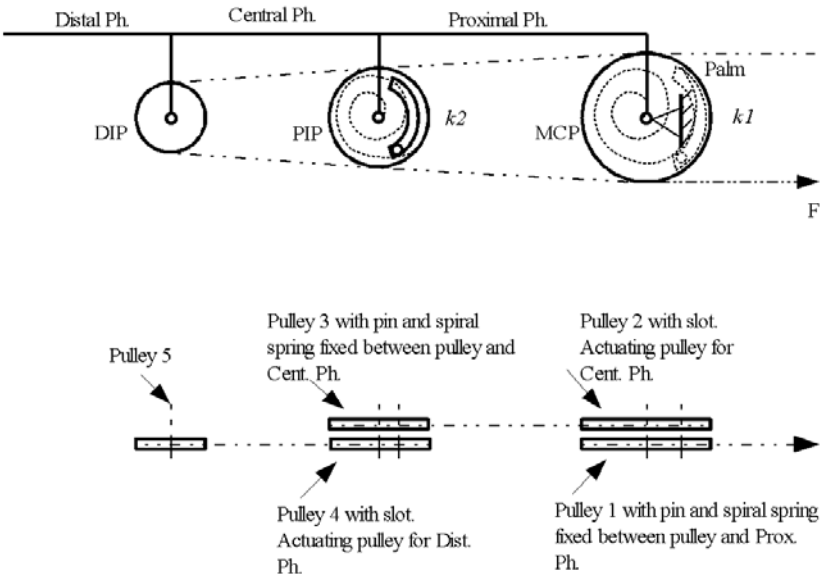

Figure 8.1: New Generation of Mechanical Principle for Fingers

Main difference from first principle is that rotary motion (pulleys) is used instead translation motion (string, sliders). Operation of this principle is as follow. Main force F is applied on Pulley 1 (P1) which share shaft with Pulley 2 (P2). Shaft is rigidly connected with phalange. Connection between P1 and shaft is realized by spiral spring (clock spring) and between P2 and shaft is free rotary connection. P1 is equipped with pin which moves in slot in P2. This slot is appropriate angle what is needed for full movement range of proximal phalange so when pin reaches end of slot P2 is going to move. Proximal phalange is on the end of its movement and movement of central ph. is started. This principle is spread over other joint. Pulley 5 is rigidly connected with distal ph.

Assembly of levers is replaced by system of pulleys. (Figure 8.2)

System consists of five pulleys which are on one shaft and connection between each pulley and shaft is again realized by spiral spring. If we want absolutely same behavior of

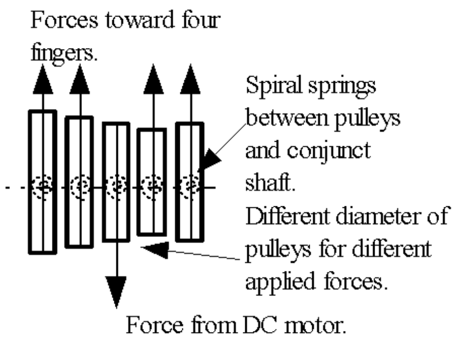

Figure 8.2: System of Pulleys

this system as behavior of assembly of levers all pulleys should have spiral spring however probably pulley connected toward main DC motor can be connected rigidly to shaft.

To get appropriate kinematic behavior (similar to human hand) it is "only" dependent on how will be designed dimensions of all pulleys and length and stiffness of spiral springs.

Equations related are: (source [96] and [27])

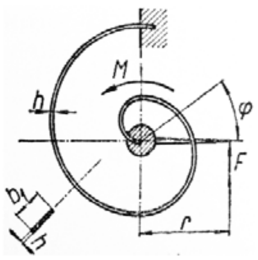

Figure 8.3: Spiral Spring [96]

Relation between angle latitude and stress in a spring can be expressed:

$$\varphi = \frac{F}{EJ} lr = 12 \frac{Flr}{Ebh^3} = 2 \frac{l}{h} \frac{\sigma_0}{E} \ [rad] \tag{8.1}$$

(recalculations to degrees: $\varphi^\circ = \frac{180}{\pi} \varphi \ [^\circ]$)

Relation between applied force and stress in a spring:

$$F = \frac{bh^2}{6} \frac{\sigma_0}{r} \ [N] \tag{8.2}$$

Equation 8.1 and 8.2 will be used just for tune of stiffness and angle latitude to insure kinematic properties of device:

$$k = \frac{M}{\varphi} = \frac{Fr}{\varphi} = \frac{bh^3}{12l} E \ [Ncm\, rad^{-1}] \tag{8.3}$$

, so these springs are not force springs but only kinematic one.

Innovation of whole mechanism is narrowly connected with its redesign that includes the hand to be more anthropomorphic in a shape. The tensioner will be substituted according new mechanical principle described above. (Figure 8.2) To get appropriate kinematic behavior of the novel principle (similar to human hand) is "only" dependent on how will be designed dimensions of all pulleys, length and stiffness of spiral springs. This will probably need a new optimization which can be closely connect with optimization contact forces of the prosthesis. [41] The thumb will get its own motor and after that a precious pinch grasp (were not implemented yet) will be possible to perform. The construction will need better rigidity if more powerful motors are used and this should make it comparable with other prosthesis from the view of forces. To enhance a modularity, produce ability and decrease costs the left and right hand will be possible to assemble from same basic components thus the similarity of the all fingers will remain and the parametric model based on kind of biometric dimensions will be used ([63] [1]) to easily redesign prosthesis for all dimension ranges – from child hood to adult hand size or for robotic anthropomorphic manipulators.

8.2 Innovation of the Control Scheme

According to Figure 7.2 the preliminary control scheme can be divided into:

- EMG sensing.
- Signal conditioning, preprocessing, feature extraction and dimensionality reduction part.
- Pattern recognition part.
- Sensory system (internal feedback) part.

Therefore following innovations are proposed. Manufacture of better electrodes and use of more than two electrodes, probably three or four. [22] [92] In these papers is further more shown that the wavelet transform is giving most suitable feature extraction results in comparison with Mean absolute value (MAV), Mean absolute value slope (MAVLSP), Willison amplitude (WAMP), Variance of the EMG, Zero crossing (ZC), Slope sign changes (SSC), Waveform length (WL), Frequency ratio (FR), AR model, Cepstrum Analysis, Gabor transform or short-time Fourier transform (STFT), Wavelet Packet Transform (WPT). Therefore its alternative discrete wavelet transform (DWT) have to be used to perform algorithm on real DSP. There are some microconrollers which have DWT already implemented and from basic investigation it seams that four level decomposition should be enough. DWT will bring significant sample reduction. Other reduction of the number of samples and delay of whole controller will bring usage only short time of acquisition of steady state of EMG – 100ms. Application of an online learning methods for ANN is not way loosing idea. [62] The structure of the ANN (adjust number of neurons – more output neurons for better recognition if the grasp was distinguished right) will be changed and learning algorithms and parameters will be investigated more closely or combination with other “artificial inteligence” methods like AR or others mentioned before. [92] Innovation of control algorithm could involve summation (integral) of EMG for grasp speed control and can be defined like: $\overline{EMG} = \sum_{i=1}^{N} |EMG(i)|$. However sensory (device internal feedback) system is solved as a separate part its implementation into control scheme and algorithm is necessary.

It will see in future if there is any reason to use EMG for a controlling. [91] Usage of signals from residual nerves or brain seems to be better alternative at this time of scientists level of knowledge. This as well as feedback and connection toward body is more discussed in next chapter Suggested Areas of Future Work and Research alternatively in Discussion on the end of the thesis.

Suggested Areas of a Future Work and Research 9

Future work should include implementation of all points mentioned in chapter Innovations of Mechanism and Control Scheme. Other areas mentioned below have to be observed if valuable human – robotic device can be presented.

9.1 Other Input Signals for Controlling

There are some alternatives how to control robotic devices by the voice [37] or by signals obtained from the pressure of the foot [10] or some other alternatives of human computer interfaces are presented [4] [86]. Most of these alternatives are not related to the principle of natural hand control mechanism so in most cases it is difficult for user to adapt new device or it is not comfortable to use it.

Residual (Peripheral) Nerves

This alternative seems to be most natural connection of a prosthesis toward residual limb [20] and there are quite a lot of successful solutions published. [38] [35] [34] [44] Both direction communication between body and device can be created like in Figure 9.1

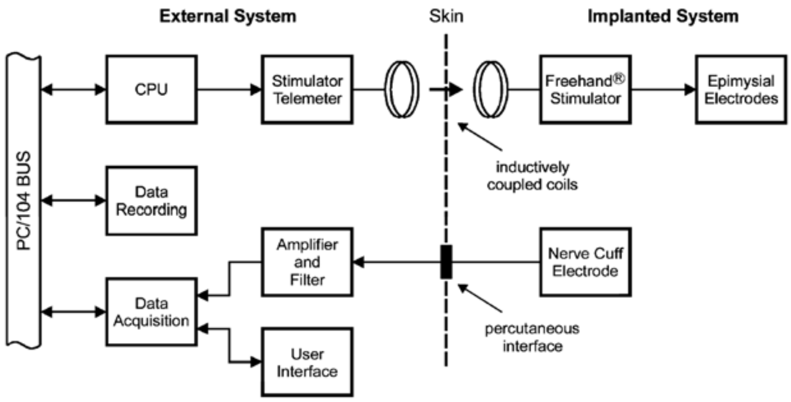

Figure 9.1: Block diagram of external and implanted system of the hand grasp neuroprosthesis. [38]

Brain

The times when the human brain was outside of man knowledge is over. [57] [48] [82] [59] Brain machines interfaces can be divided as Figure 9.2 shows.

General overview of cortical neural prosthetics is published in [74]. Some attempts are done in evaluation of graphic data of brain activity. [56] (functional magnetic resonance imaging (fMRI) during operating of EMG prosthesis), [87] (modeling and decoding of motor cortical activity), [76] (classifying of EEG) Some construction of implantable brain

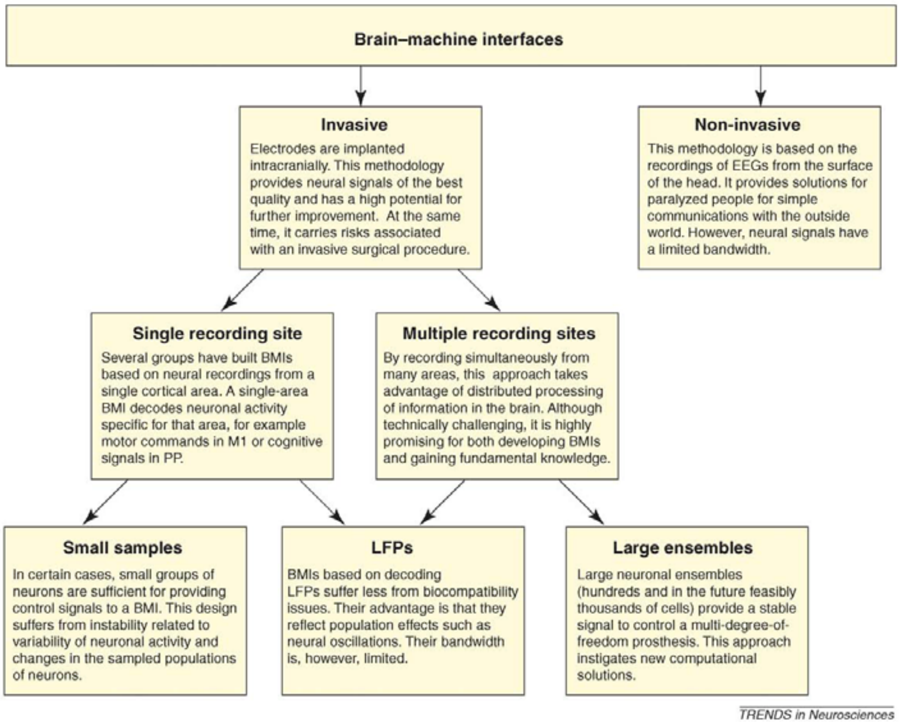

Figure 9.2: Classification of brain–machine interfaces. Abbreviations: BMI, brain machine interface; EEG, electroencephalogram; LFP, local field potential; M1, primary motor cortex; PP, posterior parietal cortex. [48]

electrodes can be found in [33], [40] or [89].To get faster progress in research of BMI (brain-machine interface) computer simulations are giving satisfactory results. [24] (simulation of human like controll), [19] (modeling for prototyping) Recent direction is in on-line adaptation of neuro-prostheses with neuronal evaluation signals because of brain and synaptic natural adaptations. [72]

Muscle Volume Changes

This is generally called myokinemetric or biomimetic control and can be used to improve EMG based systems. [31], [2], [42]

9.2 Feedback Toward Body

Feedback toward body which gives user information about state of prosthesis is one from really advance tasks. In fact that patient vision does not works as natural feedback the feedback on lower level can be realized by small vibrating (or thermal) board between soft tissue and residual limb. In case of osseointegration by applying vibrations on integrated pin. (osseo-perception) On a hi level the feedback can be realized by direct communication with the human neural system – connections on residual nerves [38] (see Figure 9.1) or by electrical stimulation[32].

9.3 Connection Toward Body

Connection of hand prostheses from not only technical view is summarized in [81]. Basically there are two ways how to connect prosthesis. First one by soft tissue ([68], [25]) and second one by so called osseointegration (integration of steel or ceramic pin directly into bone) ([61], [65])

10 Discussion and Conclusions

As a main goal of this work was to verify definitely authentic mechanical principle. Which is as well main contribution of whole research. The manufacture of the prototype and application of preliminary control scheme (second goal of the work) leads into major innovation – creating novel mechanical principle. Last goal of the work was in design of an applicable sensor system what has been done on satisfactory level too. A lot of improving suggestions is given as well as complex view on all problems related to prosthetic, and in detail on prostheses of the hand, areas.

Overall conclusion is that our research at this time is not in state of compare ability of device with any commercial product in cost or weight as well with any "competitive" device in force parameters because of low cost prototype solutions. To find other cooperators to build international multi discipline research team is necessary. [17]

Finally results published in this work are not only theoretical ideas and their usability can be utilize in prosthetic area as well as in robotics or industrial field.

And definitely on the end let me cite [91] where conclusion about current and future state of prostheses control has been well expressed. "In the last thirty years, many research efforts have been carried out in the myoelectric control field. Several techniques have been developed to control multifunctional prosthetic devices, and many of them showed promising results. Moreover, these techniques could be also applied in other fields, not only in the control of myoelectric prostheses. However, despite all these efforts, EMG signal analysis seems to be quite limited in the number of possible functions that can be restored by using a few electrodes. Moreover, the EMG signal cannot provide any feedback to the user. A possible solution to overcome the limits of the EMG-based approach could be the realization of an interface between the peripheral nervous system (PNS) and the artificial device (i.e., a "natural" neural interface [NI]) to record and stimulate the PNS in a selective way. Recent developments in the technology of electronic implants and in the understanding of nerve functions have made it possible to fabricate selective neural interfaces that work by interchanging information between the nervous system and computerized artificial instruments. A biocompatible neural interface can restore some sensory feedback to the user by stimulating in an appropriate way the afferent nerves and can allow motor control of the prosthesis based on a "natural" ENG-based control. This will be possible by focusing appropriate research efforts on the technological development of the neural interface and on the characterization of the PNS afferent signals in response to mechanical and proprioceptive stimuli. When the patient receives sensory feedback from the stimulation of the afferent nerves, and the prosthetic device is controlled directly through the efferent nerves, the user will again be able to "feel" the hand as part of the body. In conclusion, with these considerations in mind, two solutions for controlling hand prostheses could be envisaged. On the one hand, EMG-controlled prostheses could represent a "cheap" solution (i.e., low cost and noninvasive) for the restoration (even if partial) of some hand functions. On the other hand, a multifunctional "cybernetic" hand prosthesis with ENG-based control would be a more sophisticated solution. It is worth noting that this situation is already present in the field of neuroprostheses, where we can find the noninvasive solution -— e.g., the ”Handmaster System“ which comprises a hand-forearm orthosis containing an array of electrodes connected to a portable electronic microprocessor-controlled unit, and which is designed for simple and independent positioning by the patient; and the invasive solution —- e.g., the ”Freehand System“, which consists of a pacemaker-like stimulator implanted in the chest, which sends electrical impulses from an external control/power source through lead wires to eight electrodes implanted in the muscles of the forearm and hand.”

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List of Abbreviations

3D	Three Dimensional
AD	Analog – digital
ANN	Artificial Neural Network
AR	Autoregresive Model
BMI	Brain Machine Interface
CWT	Continuous Wavelet Transform
DC	Direct Current
DIP	Distal Interphalangeal
DSP	Digital Signal Processor
DWT	Discrete Wavelet Transform
EEG	Electroencephalogram
EMG	Electromyogram
fMRI	Functional Magnetic Resonance Imaging
FR	Frequency Ratio
FSR	Force Sensor Resistor
LFP	Local Field Potential
M1	Primary Motor Cortex
MAv	Mean Absolute Value
MAVLSP	Mean Absolute Value Slope
MCP	Metacarpophalangeal
MES	Myoelectrosignal
NI	Neural Interface
P1	Pulley 1
P2	Pulley 2
PC	Personal Computer
PIP	Proximal Interphalangeal
PNS	Peripheral Nervous System
PP	Posterior Parietal Cortex
SSC	Slope Sign Changes
STFT	Short-time Fourier Transform
VLR	Variable Learning Rate
WAMP	Willison Amplitude
WL	Wavelet Length
WPT	Wavelet Packet Transform
ZC	Zero Crossing

Curriculum Vitae

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Education

2004 - 2008 Brno University of Technology, Faculty of Electrical Engineering and Communication, Department of Power Electrical and Electronic Engineering Postgraduate degree. (PhD.)
1999 - 2004 Brno University of Technology, Faculty of Mechanical Engineering, Institute of Solid Mechanics, Mechatronics and Biomechanics. Master degree. (Ing.)
1995 - 1999 High industrial school in Bruntal - Maintaining and operating of vehicles

Projects

Sep. 2005 - Jun. 2006 *Centre for Robotics and Automation - University of Salford*
The Control of Anthropomorphic Prosthesis Hand as a Prosthetic Aid. (manufacture and control of the first prototype)
2004 *Institute of Solid Mechanics, Mechatronics and Biomechanics - Brno University of Technology*
The Design of Fingers Anthropomorphic Prosthesis Hand.
Oct. 2003 *Installation of a Heating Pump Air - Water*
2001 *Renovation of a motorcycle Jawa 250 type 559. (year of manufacture 1968)*

Work experience

Jan. 2008 - to date *FEI Company*
System Engineer. Implementation and testing of new hardware and software features for SEM (scanning electron microscope).
Oct. 2007 - Dec. 2007 *Honeywell Turbo Technologies*
Test Engineer. Testing and benchmarking of rotary electric actuators for turbochargers.
Sep. 2006 - Feb. 2007 *DS Machining Services (UK company)*
CNC programmer, setter, operator of HAAS milling machines.
Summer 2002 *Advanced Plastics s. r. o.*
Part time work in department of construction injection mould for injection of plastic materials.