Grasping Force Controlling by Slip Detection for Specific Artificial Hand (ottobock 8E37)

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Abstract-*This paper presents a theoretical and experimental study to control grasping force of specific artificial hand (Otto Bock 8E37), which it uses by amputees. The hand has two rigid fingers actuated by a DC motor through a multi-gears system. The aim of this work is to give the amputees a feeling of slipping while the hand grasping an object. The mathematical model has been derived to simulate the hand mechanism and analyze the generated signal of contact force between fingertip and the grasped object through a slippage phenomenon. The experimental work consisted of modifying the artificial hand design to aid load cell mounting process in order to measure the grasping force indirectly, then acquiring the measured signal to the PC. An artificial neural network (ANN) was trained on the patterns of the force signals. These patterns were prepared by using force sensors with modified design of the artificial hand for detecting the slippage of the different shapes grasped object. The Neural Network training results have been evaluated and discussed under different conditions, which affect the controller operation such as network error, classification percentage and the response time delay*.

Keywords: *artificial hand, slip detection, grasping force, grasping control.*

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1.Introduction

In recent times, there are a wide employments of specific artificial hands by amputees, but there are many problems of controlling process. Namely, the most studies focus on the improving of grasping force control system. One of the important methods to control the grasping force is slip detection, which is depended in this work, where the slippage detection represents an important response that must be monitored at the initiation of the occurrence due to arm manipulating or any external load on the grasped object. So that slip detection enables to optimize the contact force between the artificial fingers and the object. The grasped object will slip when the contact force is low, and if it is high, the grasped object may be destroyed. Slip detecting activity is based on the multi-sensors to indicate the initiation stage of the slippage before overall slipping has been occurred by recognizing the grasping force behaviour when slippage occurring. [1] Ottobock hand model (8E37) shown in figure.1 which it has been used by amputees eventually. It consists of gripper, two Electromyographic (EMG) electrodes, control card and battery, when the muscle contract, an electrical signal is generated. The EMG electrodes transfer the electric signal to the controller card. The control card opens and closes the gripper. [2]There are many researchers focused on the design and control of artificial hand such as: Maeno, T et al [3] proposed a grasping force controller by using the strain distribution with respect to the stick/slip information on the elastic finger surface. The FE simulation and measurement have been used for the feasibility confirmation. Chen, P. et al. [4] proposed a method to control the grasping of the robotic hand by using the theory of possibility and partially-linearized neural network to detect slippage with the grasped object. The contact forces have been measured by a special tactile sensor called Double-Octagon Tactile Sensor (D.O.T.S) which measured the grasping force. Antfolk C. et al. [5] presented a simple sensory feedback system, passed on pressure in silicone pads filled by air in the stump in a closed-cycle system that connected with pads on the stump of the amputation. The method of sensing supposed on pressure transmitted from pads in the fingertips to pads in amputee stump. R. N. Scoot et al. [6] developed a system to provide the grasping force feedback which applied by an electric hand, Otto Bock hand, and was sensed by a strain gauge mounted on the index finger. Pylatiuk .C et al. [7] developed a force-feedback system to control grasping force. The strategy was when low force applied the vibration motor frequency was about 50Hz, at high force the frequency was about 80Hz, according to force

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sensor signal. Daisuke Gunji et al. [8] proposed a way for detecting the slip using the Center of Pressure (CoP) tactile sensors output. Which can measure the center position of a distributed load and the total force applied on the outer surface to the sensor. Briglen, L. et al. [9] used the elements of a tactile array (Force Sensing Resistor) with the actuator's encoder and potentiometers, since from the variation in the normal force value without any change in actuator torque, the slipping can be detected. A real-time control scheme was introduced, based on a fuzzy force control method. Nan Li et al. [10] present an explanation of prosthetic hand with a man-machine interface for actual grasping process. Amputees can operate the prosthetic hand by using their EMG signals and get a signal as a grasp force feeling through the feedback of the sensors based on the electrical stimulus of the surface. Ninu A. et al. [11] evaluated the activity of the controlling grasp strength by using a hand prosthesis work through a complete grasping series while changing the feedback parameters (e.g., closing velocity, grasping force), which were provided to the user direct by screen or through vibrotactile stimulation. Jorgovanovic .N et al. [12] investigate the human ability to control grasping action in a closed loop by using the feedback of the electro tactile signal. The goal was to minimize the forces then energy expenditure, and thereby avoid slipping.Our work aims to build a sensory feedback system passed on slip detection for an artificial hand (ottobock) to give the amputee a feeling of slipping when an object is grasped. This system is using a force sensor (load cell) fixed in the hand and artificial neural network to generate slippage signal according to contact force behavior which used to run a miniature vibrator motor as an alarming unit should be banded with amputee arm to give him a sensing of slippage when it occurs.

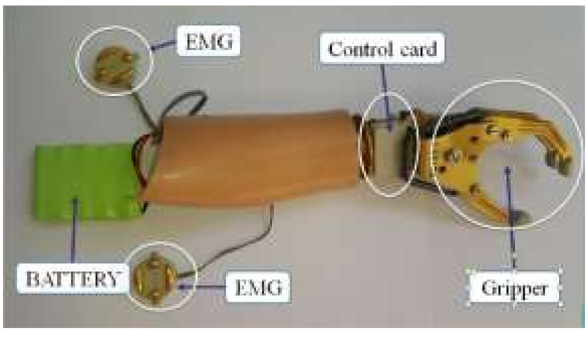

Figure 1: Ottobock (8E37) hand.

2. System Model and Simulation.

The system shown in figure. 2 represents a hand mechanism which it's composed from two rigid fingers actuated by DC motor through multi-gears system.The two fingers are joined by the link E which it transmits the actuator torque from finger to another. The mathematical model has been derived to find the relation between the grasping force on the fingertips and the force exerted on the link E which it's connected to the load cell as shown in figure.3. Namely, the grasping force is measured indirectly, without affecting by the contact region properties.

So that the sensed force is $f_s = F_E \cos(\theta_s)$.

The applied torque (τ) is transmitted to the fingers through the gears, so that the applied torque on the fingers will be:

$$\tau_1 = F_E \sin(\alpha)\, k \quad (1)$$

$$\tau_2 = \tau - F_E \sin(\psi)\, k \quad (2)$$

The general equation of the relation between applied torque and fingertip forces is [13]:

$$\tilde{\tau} = J^T R_c^{Tip} f_c \quad (3)$$

Where J^T is the jacobian matrix for the fingertip and finger joints [14]:

$$J^T = \begin{bmatrix} -L_1\sin(q_1) & L_1\cos(q_1) & 0 & 0 \\ 0 & 0 & -L_2\sin(q_2) & L_2\cos(q_2) \end{bmatrix} \quad (4)$$

And R_c^{Tip} is the rotational matrix between the finger tip and the contact surface of the grasped object [14]:

$$R_c^{Tip} = \begin{bmatrix} -\sin(\gamma) & \cos(\gamma) & 0 & 0 \\ \cos(\gamma) & \sin(\gamma) & 0 & 0 \\ 0 & 0 & -\sin(\gamma) & \cos(\gamma) \\ 0 & 0 & \cos(\gamma) & \sin(\gamma) \end{bmatrix} \quad (5)$$

The vector of the fingertip forces (F_{Tip}) is derived from the interaction with the grasped object, where these forces are related to the contact force vector (f_c) As follows:

$$F_{Tip} = R_c^{Tip} f_c \quad (6)$$

Where $f_c = \begin{bmatrix} f_{x1} \\ f_{y1} \\ f_{x2} \\ f_{y2} \end{bmatrix}$ and $f_{Tip} = \begin{bmatrix} f_{n1} \\ f_{t1} \\ f_{n2} \\ f_{t2} \end{bmatrix}$

The angle between fingertip and grasped object surface (γ) is very small, so that the following can be assumed: $\sin(\gamma) = 0$ $\cos(\gamma)=1$

$$\tilde{\tau} = J^T f_{Tip} = \begin{bmatrix} L_1\cos(q_1) & -L_1\sin(q_1) & 0 & 0 \\ 0 & 0 & L_2\cos(q_2) & -L_2\sin(q_2) \end{bmatrix} \quad (7)$$

$$\begin{bmatrix}\tau_1\\ \tau_2\end{bmatrix} = \begin{bmatrix} f_{n1}L_1\cos(q_1) - f_{t1}L_1\sin(q_1)\\ f_{n2}L_2\cos(q_2) - f_{t2}L_2\sin(q_2)\end{bmatrix} \quad (8)$$

From sub. Eq (1) and (2) in Eq (8):-

$$F_E\ \sin(\alpha)\,k = f_{n1}L_1\cos(q_1) - f_{t1}L_1\sin(q_1) \quad (9)$$

$$\tau - F_E\ \sin(\psi)\,k = f_{n2}L_2\cos(q_2) - f_{t2}L_2\sin(q_2) \quad (10)$$

From the mechanism design of ottobock hand, it can be assumed that the effect of the normal force (f_n) on the joint torque is very large in comparison with the tangential force (f_t) effect. So, the effect of tangential force can be neglected, then equation (9) will be:

$$f_{n1} = F_E\ \frac{\sin(\alpha)k}{L_1\cos(q_1)} \quad (11)$$

$$f_{n1} = f_s\ \frac{\sin(\alpha)k}{L_1\cos(q_1)\cos(\theta_s)} \quad (12)$$

Where (θ_s) is measured experimentally as will be explained in the next section, and(α , q_1) angles can be computed mathematically with respect of (θ_s) according to crossed four bar linkages analysis.

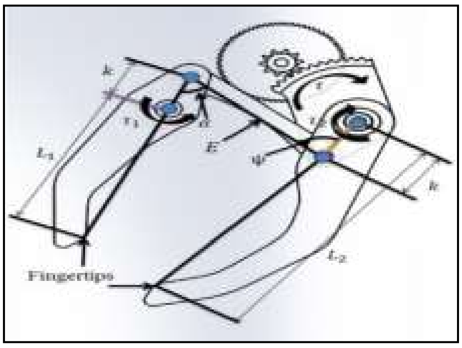

Figure 2: Schematic of ottobock.

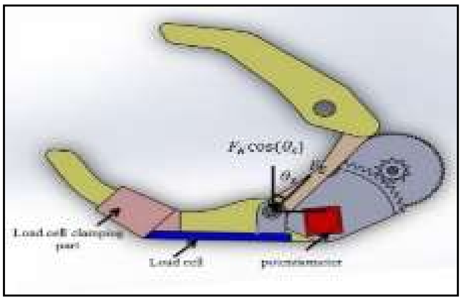

Figure 3: Load cell mounting with hand mechanism

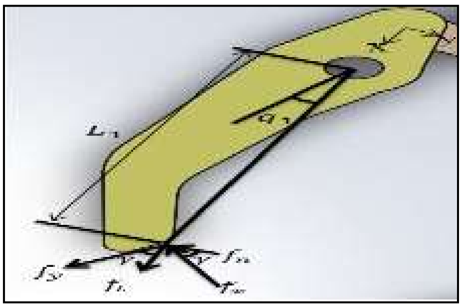

Figure 4: Applied force on the fingertip.

3. Experimental work.

The main aim of the experimental work was how to measure the force excreted on link E (F_E) by using a (load cell) and joint angle (θ_s ,α) by using a limited rotational potentiometer as shown in figure.5. The load cell clamping part is designed without affecting the artificial hand performance. The electrical circuit is built to connect the sensors with a PC through a data acquisition (NI daq 6009), and building the control program by using MATLAB/SIMULINK to analyze the measured signals and generates the feedback signal. Hence, the grasping force signal through slippage occurrence has been prepared as a training sample to learn a neural network, then detected the slippage phenomenon for different grasped object materials (wood, plastic and glass). Figure (7) shows a flow chart diagram for the system components connection.

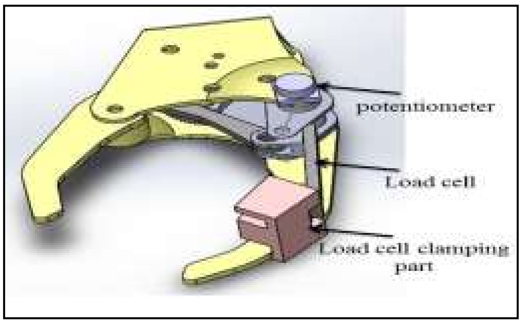

Figure 5: modified Hand model.

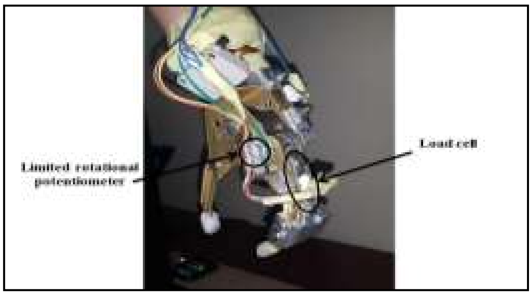

Figure 6: Specific hand with sensors.

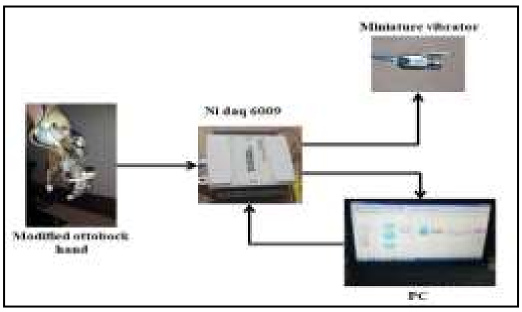

Figure 7: System connection diagram.

4. Experimental Results and Discussion.

Experimental results show the performance of the neural network training and the evaluation of control system response to slippage occurrence when the hand grasps different objects. The Neural Network toolbox in Matlab has been used for pattern recognition [15]. The process of the first experiment starts with stable grasping of the object by the Otto bock hand. In this stage, the object is under its weight only, at this moment, the monitoring of the sensory signal is started, after that, the object is pulled down until starts to slip as shown in Figure(8). The ANN training was for a force signal without normalizing, but that show a poor response for slip detecting. Figure.9 shows unacceptable validation performed with 45 hidden layer size before signal treatment. Then the Grasping force has been normalized before preparing as input vectors to the neural network as shown in Figure (10)[16], so that the recognition of slipping will be more clear and the signal be limited within a small range. So that the input vector is normalize the grasping force, so the output be [0 1]. Signal 0 is referred to no slipping state and 1 to slipping state. The best performance for neural training was in 14 hidden layer size, which gives the best validation performance as shown in Figure (11).This force will be input to the neural network as a vector compound of (ten) elements. When the slippage occurs, the output of the artificial neural network will be$[1 \quad 0]^T$. Figure.12 shows the ANN response signal according to the slippage case.When the slippage occurred, the system control will run a miniature vibrator (shown in Figure (13)), which gives the amputees a feeling of slipping through banding this vibrator with healthy sensing area on his arm. The amputees should be trained before using this system. When vibration occurs, the amputees know that slippage is occurring.Figures (14), (15) and (16) show the system response when the slippage occurs with grasping a wood, plastic and glass objects respectively.The results show that the system operates according to grasping force behavior while the hand is grasping an object. The actuator torque was constant during the grasping process, but the grasping force shows a sudden decreasing. This phenomenon can be explained either by a local deformation of the object or by slipping. Both cases require a different grasping force modification. For instance, if the object is locally starting to deform. This leads to breaking down of the object. Breaking case causing a high sudden drop of grasping force so that the grasp forces should therefore be decreased, but slippage case causes low drop of it so that the grasping force should increase. Figures (14, 15 and 16) show normalized force behavior while the hand is grasping an object then slippage occurs. The cited figures show that the normalized force will be changed when the slipping occurs. The drop of normalized force means that there is actually decreasing in normal force on the fingertip. And because of that the normal force representing the contact force between fingertip and grasped object surface, the behavior of this force depends on surface type of the grasped object. The objects have different metals and hence they have different coefficients of friction, and causing a different behavior for the contact force while slipping. Also the figures show delay time for each experiment which it gives other indications about system response when the slippage occurs where the hand is grasping different objects. According to the results the implemented system shows good ability to detect slipping of different objects, which gives an indication that the system of the Otto bock hand has been functionally improved.

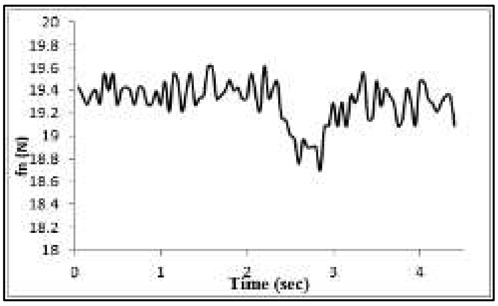

Figure 8: Actual normal force (f_n).

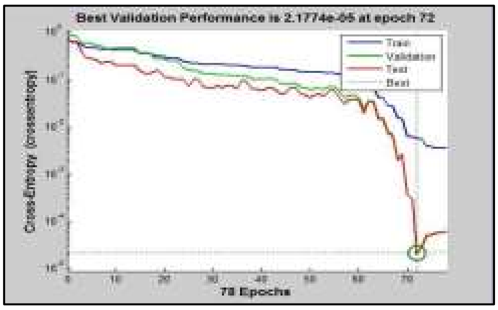

Figure 9: The performance of ANN with (10) input layer size and (45) hidden layer size before signal treatment.

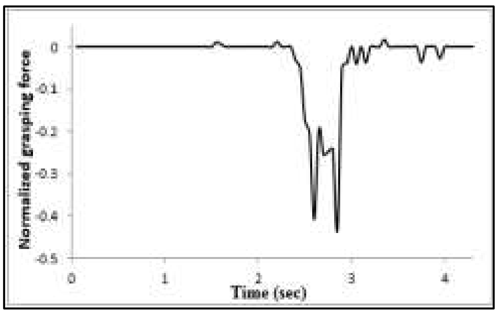

Figure 10: Grasping force after normalizing

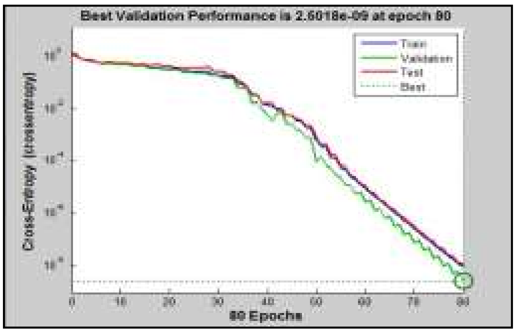

Figure 11: The performance of ANN with (10) input layer size and (14) hidden layer size after signal treatment.

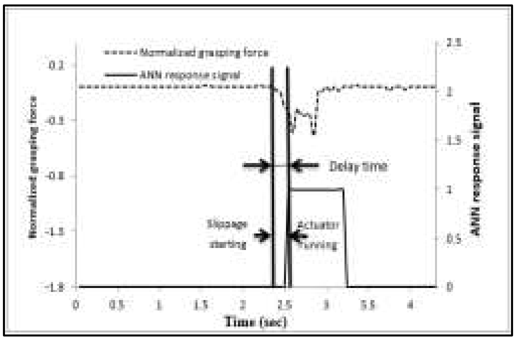

Figure 12: Slippage signal with normalized grasping force.

Figure 13: Miniature vibrator.

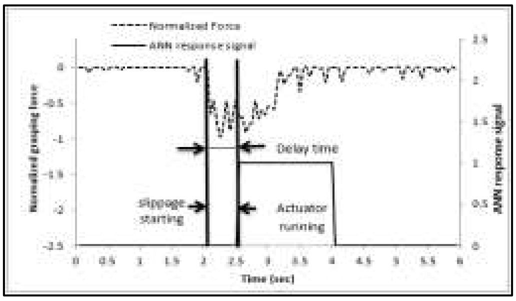

Figure 14: Control system response while grasping a wooden object.

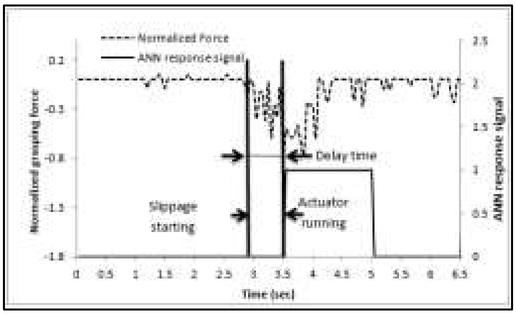

Figure 15: Control system response while grasping a plastic object.

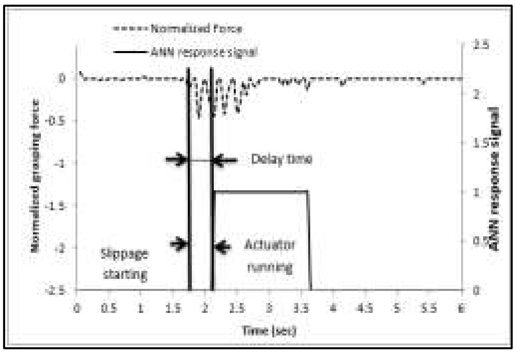

Figure 16: Control system response while grasping a glass object.

5. Conclusion.

The grasping force of specific artificial hand (Otto bock 8E37) has been controlled to detect slipping. This based on studying the hand mechanism and driving a mathematical model to find the relations between hand mechanism and grasped object. Then building a sensory feedback system that generates a slipping signal and then run the miniature vibrator to give the amputee a feeling with slippage. The ANN is utilized to detect slip through recognizing the grasping force behavior while slippage occurring. The results show that the grasping force will decline when the slippage occur. This behavior differs according to the grasped object surface metal, because that depends on the coefficient of friction for each metal. The system show ability to detect slippage for different objects which give an improvement of Otto bock hand function has been achieved.

Nomenclature

f_s=effective force on the force sensor (N).
θ_s=joint angle of the link E with load cell (deg).
(k, L_1, L_2) = geometrical dimensions of hand mechanism (mm).
τ = actuator torque (N.mm).
(τ_1, τ_2) = fingers torque.
$\tilde{\tau}$ = torque vector (N.mm).
J = Jacobean matrix.
(q_1, q_2) = finger 1 and 2 joint angles (deg).
R_c^{Tip} = rotation matrix between contact frame and fingertip frame.
f_c = Contact force vector (N).
f_{Tip} = Fingertip force vector (N).
f_n = normal contact force (N).

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