# COMPLEXITY REDUCTION IN CONTROL OF HUMAN HAND PROSTHESIS FOR A LIMITED SET OF GESTURES

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Abstract: This paper carried out a statistical analysis of human finger's joint angles during hand specific daily activities, studying the correlations among the joints and applying a linear regression to express their correlations. The aim was to reduce the number of myoelectric sensors necessary in devices such as prosthesis, stands the current surgery difficulties and the problem of rejection, but without losing too many degrees of freedom. Measures were taken using our special hand movement acquisition system called HITEG data glove. As a preliminary work, we decided to limit the set of gestures performed to 9 of the most common movements of the human hand. The results shown that the number of sensors can be reduced from 14 to 7 with an acceptable error on the presumed value of each finger joint angle which can be as low as 10 degrees.

## 1 INTRODUCTION

Myoelectric prosthetic hands are used to replace functions of a natural hand lost by amputation. Motor functions of such myoelectric hands can almost be compared to that of a natural hand (Shadow Robot Company, 2003). They have a very high number of joints and actuators, which bring up to 20 Degrees of Freedom (DoF). Unfortunately this technology cannot be fully exploited by current hand prosthesis (Carrozza et al., 2003 - Micera et al., 2002 - Craelius et al., 1999). The main limitation regards the sensor system that allows to control the robotic hand: a set of myoelectric sensors is placed above the attachment of the prosthesis to the arm: every joint with an own DoF of the hand needs a specific myoelectric sensor, but placing 20 different myoelectric sensors is not only practically difficult: it also increments the possibility of a rejection. Hence only few myoelectric sensors can be reasonable used, and this affects the DoF available to perform a gesture.

The purpose of this work is to study the correlations among joint angles while performing most common and useful movements of the hand. If we discover that an articulation is strongly correlated to another one then we can express the former in function of the latter, reducing the necessary number of myoelectric sensors but still maintaining our purposes.

To measure the joint angles we used our hand movement acquisition system developed by the Health Involved Technical Engineering Group (HITEG), at the University "Tor Vergata" (Saggio et al., 2009). We limited the choice of gestures and movements we believe to be the most useful for an impaired person. We took the couple of joints that showed the best correlation and we calculated, by means of linear regression, the best approximation that allow to infer the position of a joint with respect to another one. It's important to stress that considering different sets of movements can lead to different results (Vinjamuri et al., 2010).

## 2 THE DATA GLOVE

For our experiment we adopted the so called HITEG-Glove as previous reported (Saggio et al., 2009) and shown in Fig. 1. It is constituted by 18 sensors, placed according to Fig. 2. This data glove has three sensors for each finger (3-14): one for measuring the Metacarpo Phalangeal (MCP) angle, one for the Proximal Interphalangeal (PIP) angle and one for the Distal Interpahlangeal (DIP) angle, while thumb is measured by only two sensors (1-2). There


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are also other four sensors to measure the angle between the fingers (15-18). With the overall acquisition system, the expected error in measuring each finger joint position is as low as 4 degree.

Figure 1: HITEG Glove.

## 3 SET OF POSTURES

To perform a consistent reduction of the complexity of the system we chosen a limited set of movements. This choice strongly affects the correlations that will be found in our analysis, and so it is very important to make a good selection among the most common and useful gestures. Missing some important movements could lead to spurious correlations while choosing useless movements that have no practical utilization could unintentionally prevent some possible reductions.

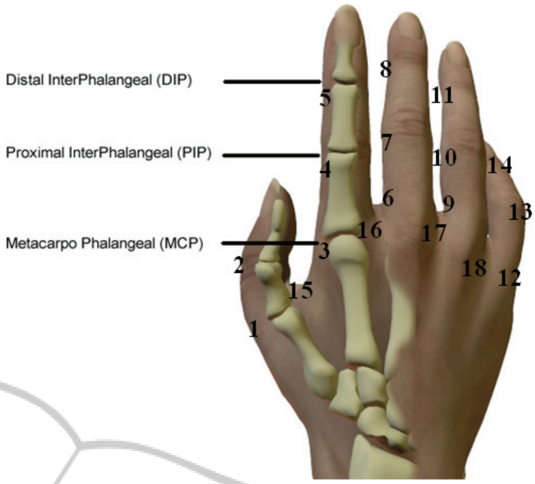


Figure 2: Position of the sensors over the hand articulations.

Keeping in mind this concept and considering that all transitions from a position to the next one are recorded and included in the analyzed dataset, we selected the positions discussed in the following paragraphs and shown in figure 3. Note that we excluded positions implying third and fourth finger moving independently: these positions are notoriously uncomfortable, usually avoided also by healthy people, and have no real practical utility. This exclusion will bring an obvious correlation between last two fingers: if we want to give the

Figure 3: Hand positions from A to I.

possibility to control separately these two fingers we just have to discard this correlation, which in our experiment is expressed by the couple 9-12: we will just need eight sensors in spite of seven.

Data acquisitions were performed measuring the nine basic movements described in the following, repeated 10 times by 5 different healthy persons 25-40 aged.

### 3.1 Position A: Open Hand

The open hand position is a fundamental position, useful in different occasions and can be a transition posture from one gesture to another.

### 3.2 Position B: Fist

Closing completely the hand in the fist posture, all the fingers and the thumb are almost in the maximum bent position. It is adopted, for example, any time we want to keep something small in our hand.

### 3.3 Position C: Index Finger Up

The index finger up position is the main gesture of the hand: it is used every time we want to point somewhere or somebody, or to press a button.

### 3.4 Position D: Index and Middle Finger Up with Thumb Closed

This fourth position, with the index and middle finger up with the other fingers bent.

### 3.5 Position E: Index and Middle Finger Up with Thumb Open

In this posture the thumb and the first two fingers are completely outstretched while the others are bent.

### 3.6 Position F: Hand Open, with Thumb Closed

This position represents the motion of thumb independently, while all fingers remain outstretched.

### 3.7 Position G: OK Sign

This posture represents the gesture that we do, as an example, to collect something with thumb and index finger, maintaining the others opened. It differs from the position used to hold a pen because the DIP of the index in this gesture is bent.

### 3.8 Position H: Grabbing an object

This position is what we do to grab and hold an object.

### 3.9 Position I: Holding a Pen

When holding a pen the DIP of the finger does not bend while the thumb is almost closed and the other fingers are relaxed.

## 4 STUDY OF CORRELATION

We asked every subject to repeat all the A-I postures in sequence 10 times, so obtaining a corresponding dataset of 450 x 14 sensors. For every couple of the 14 finger joint angles, we measured the Pearson product-moment correlation coefficient, which is expressed by the following formula:

$$\rho_{(X,Y)} = \frac{cov(X,Y)}{\sigma_X \sigma_Y} \quad (1)$$

where $cov(X,Y)$ is the covariance of the two random variables $X,Y$ that we are comparing, and $\sigma$ is the standard deviation.

In table I we reported all the correlation coefficients. Numbers indicate the joints as shown in Fig 2.

It's important to notice that if our aim is limited to a specific application, the number of correlations would be surely higher and the complexity achieved lower. For example if we want to develop a prosthesis capable just to grab and release objects we could relate every DIP and PIP to their respective MCP (e.g. angles 5 and 4 represented by angle 3).

An observation that we can do is that all joints from last two fingers are very highly correlated: this is clearly due to the fact that last two fingers always move together, in particular MCP, PIP and DIP of third finger (9, 10, 11) are correlated respectively with MCP, PIP and DIP of fourth finger (12, 13, 14).

Moreover, different articulations of the same finger are almost correlated: MCP is correlated with PIP. this is valid for the first finger (0.990), third finger (0.955) and fourth finger (0.986), but correlation seems less strong in second finger (0.832). Also PIP is correlated with DIP: this is strongly visible in the second, third and fourth finger but not in the index. We expected this result because the DIP of the index can bend (e.g. in position H) or not (e.g. in position I).

Table 1: Correlation coefficient for every couple of joint angles.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | | | | | | | | | | | | |
| 2 | .649 | 1 | | | | | | | | | | | | |
| 3 | .377 | .672 | 1 | | | | | | | | | | | |
| 4 | .357 | .644 | .990 | 1 | | | | | | | | | | |
| 5 | .429 | .470 | .889 | .851 | 1 | | | | | | | | | |
| 6 | .074 | .167 | .605 | .625 | .571 | 1 | | | | | | | | |
| 7 | .103 | .225 | .604 | .623 | .526 | .832 | 1 | | | | | | | |
| 8 | .018 | .293 | .697 | .703 | .650 | .862 | .983 | 1 | | | | | | |
| 9 | .088 | .110 | .319 | .341 | .362 | .770 | .546 | .519 | 1 | | | | | |
| 10 | .166 | .188 | .312 | .340 | .272 | .677 | .530 | .508 | .955 | 1 | | | | |
| 11 | .112 | .310 | .519 | .546 | .440 | .754 | .695 | .698 | .889 | .957 | 1 | | | |
| 12 | .117 | .107 | .400 | .406 | .474 | .778 | .584 | .585 | .979 | .943 | .911 | 1 | | |
| 13 | .104 | .160 | .357 | .372 | .400 | .758 | .591 | .579 | .987 | .973 | .933 | .986 | 1 | |
| 14 | .022 | .259 | .451 | .456 | .505 | .728 | .638 | .660 | .928 | .941 | .952 | .956 | .973 | 1 |

A visual representation of the correlation can be seen in Fig. 4-6, where the horizontal position of every point represents the value of the first angle considered (from 0° to 90°) and the vertical position represents the value of the second angle. Each reported point is placed in the degree Cartesian diagram, representing the reciprocal position of one joint with respect to another for each posture.

Fig. 4 represents a case of no correlation: angle 2 vs. 11 (DIP of the thumb vs. DIP of third finger). Fig. 5 represents a case of high correlation (MCP vs. PIP of fourth finger). Fig. 6 represents a case where there is a little correlation (0.605) but not enough to justify a reduction.

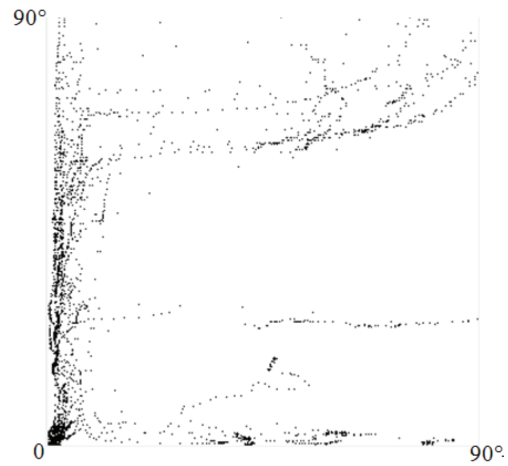


Figure 4: DIP of thumb versus DIP of third finger (2-11).

It's important to notice that if our aim is limited to a specific application, the number of correlations would be surely higher and the complexity achieved lower. For example if we want to develop a prosthesis capable just to grab and release objects we could relate every DIP and PIP to their respective MCP (e.g. angles 5 and 4 represented by angle 3).

All joints from last two fingers are very highly correlated: this is clearly due to the fact that last two fingers always move together, in particular MCP, PIP and DIP of third finger (9, 10, 11) are correlated respectively with MCP, PIP and DIP of fourth finger (12, 13, 14).

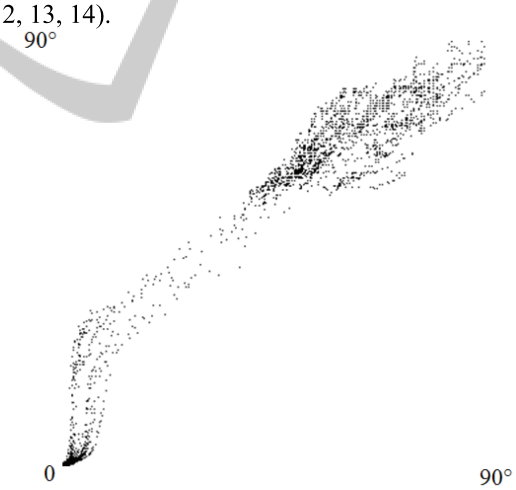


Figure 5: MCP vs. PIP of fourth finger (12-13).

Moreover, different articulations of the same finger are almost correlated: MCP is correlated with PIP. this is valid for the first finger (0.990), third finger (0.955) and fourth finger (0.986), but correlation seems less strong in second finger (0.832). Also PIP is correlated with DIP: this is strongly visible in the second, third and fourth finger but not in the index. We expected this result because the DIP of the index can bend (e.g. in position H) or not (e.g. in position I).

It can be noticed that the distribution in Fig. 5 is roughly a line with a negative offset. This means that the joint on the y axis started to move before the one on the x axis. These kind of relations can be analyzed in all diagrams to discover interesting and more precise correlations among the joints.

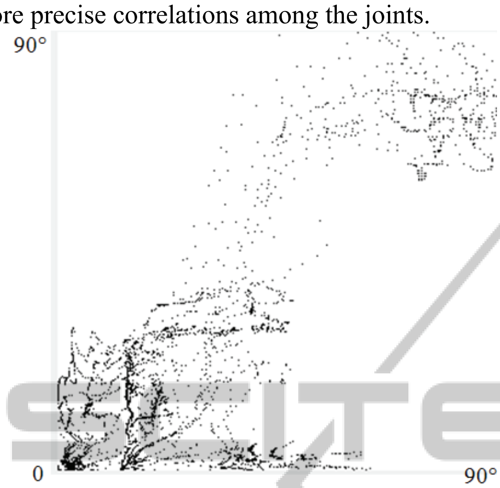


Figure 6: MCP if first finger vs. MCP of second finger (3-6).

## 5 REDUCTIONS

Basing on the study of the correlation on the previous section, we identified seven couple of variables that could be considered related, hence we could express one in function of the other.

A high correlation means that a graph like Fig. 5 is very near to be a line, so it can be expressed by the following equation:

$$y_i = ax_i + b + \varepsilon_i \tag{2}$$

where $x_i$ and $y_i$ are any of the couples of variables that we considered for the *i-th* observation, while $a$ and $b$ are coefficients that have to be evaluated in order to have the best fit, finally $\varepsilon$ is the error.

By means of the linear regression (Fisher R., 1925), we can minimize the quadratic error, and obtaining the values for $a$ and $b$:

$$b = \frac{cov(X,Y)}{\sigma_X^2} \tag{3}$$

$$a = \mu_Y - b\mu_X \tag{4}$$

where $cov(X,Y)$ is the covariance between $X$ and $Y$, $\sigma_X^2$ is the variance of $X$, $\mu_X$ is the mean value of $X$ and $\mu_Y$ is the mean value of $Y$. In table II we reported, for every couple of variables, coefficients $a$ and $b$, as well as the mean quadratic error that we obtain by substituting the real value with the value extrapolated with our linear function.

Table 2: Linear regression coefficients and mean error.

| *Joint couple* | *a* | *b* | *mean error [°]* |
|---|---|---|---|
| 3-4 | -0.0016 | 1.0097 | 3.12 |
| 7-8 | -0.0046 | 1.0353 | 5.05 |
| 10-11 | 0.0229 | 0.9041 | 8.43 |
| 13-14 | 0.019 | 0.9475 | 5.23 |
| 9-10 | 0.0605 | 1.050 | 9.84 |
| 12-14 | 0.0463 | 0.9963 | 7.67 |
| 9-12 | -0.0074 | 0.9343 | 5.41 |

In Figs 7-8 examples of regression lines are shown superimposed to the graph for 10-11 and 7-8 joints respectively, using the $a$ and $b$ coefficients in table II.

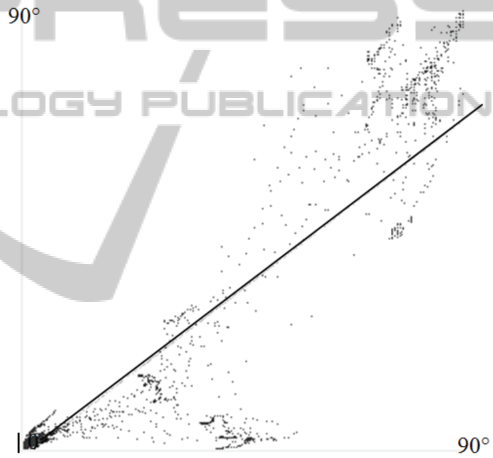


Figure 7: PIP vs. DIP third finger (10-11) with regression line.

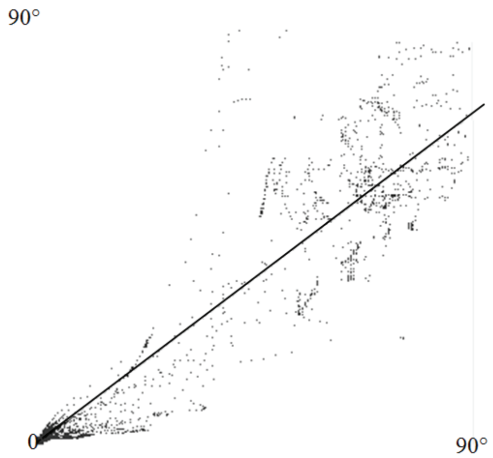


Figure 8: MCP if first finger vs. MCP of second finger (3-6).

Referring to Table II, the estimated mean error is in any case lower than 10°, value that is in any case comparable to the overall 4° error of the adopted acquisition system.

# 6 CONCLUSIONS

In this paper a statistical analysis has been carried out to discover the correlations among 14 joint angles in the hand on a restricted set of 9 static postures, that we took as the most common and useful. We found out that the values of seven joints can be computed basing on the values of the remaining seven, with an error lower than 10 degrees. This can lead to a important reduction of myoelectric sensors, from 14 to 7, useful for driving an artificial prostesys. This can be true for the most part of applications when it is not requested a very high degree of accuracy or a large number of DOF. For example robots or drones remote controlled that need high precision but few DOF could be driven by a hand wearable device with a small set of sensors. This research can also improve gesture recognition, reducing the complexity of the problem and improving the classification.

Vice versa, this work states a limit in hand controlled devices: we cannot use all of 14 finger joints to pilot a device with 14 DOF because some of the joints are not independent.

Future investigations can be done; In fact it can be carried out a similar study on the basis of supposition of non linearity between the finger joints, or it can be considered the relations among three or more articulations

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