19th International Computer Science and Engineering Conference (ICSEC)
Chiang Mai, Thailand, 23-26 November, 2015

Adaptive Learning of Multi-finger Motion and Force Control

Adool Nimnon
School of Information Technology
Sripatum University, Thailand
Adool.n@gmail.com

Somrak Petchartee
Brownien Laboratory
Research and Development Department
CAT Telecom Public Company Limited
somrak.p@cattelecom.com

Thepparit Banditwattanawong
School of Information Technology
Sripatum University, Thailand
thepparit.ba@spu.ac.th

Abstract — **This paper is based on a prosthetic human organ targeting human arm with simulated / manipulated fingers with a highly related tendon driven mechanism with force sensing feedbacks. The control environment is mostly common to the both real and prosthetic human arms. It is a neural feedback based mechanism which is normally in human arms and here with this project it is integrated with "stall current sensing feedback system" possibly taken as a force feedback system literally. Based on support vector machine (SVM), this paper proposed an adaptive learning procedure intending to approximate the mapping among object positon and the corresponding joint displacement. Finally the application will run as smooth as possible with respect to the given objected environment with grabbing and releasing most common objects as well as improving the realistic projection, which is manipulating the human arm prosecution with more than 75% of possibility.**

Keywords— force control; multi-finger; polynomial kernel; robotic hand, SVM ;tendon drive;

I. INTRODUCTION

A cooperative system is where the manipulation of motion will be carried out in a path of simulation, controlled by the system designed to compute each and every motion for the particular instance.

The aiming usage of a cooperative system is basically change the space position relative to the space coordinates of an object. Simply it the translation or an object within a simulated coordinate system in the space. It also tracks down the instantaneous position with respect to the time it is played. This can be applied in relative motion environments as well as stationary objects itself.

Before coming into action it is necessary to invigilate the state of several stationary objects that should be jointly transferred by several separate manipulators. In this scenario it comes to a human hand manipulator in advance with the development of sensor feedback effects as well.

The most highlighted fact is to keep the motion more precisely moved in a pre-determined trajectory while not overshooting any instance causing severe damages to both the system and the object.

Human hands are the most powerful and sensible arm model that can be found on the earth up to now with the unique functioning. The redefinition of human arm can be manipulated by a robotic arm with the human like functioning synthetically given by a computing processor.

The major study will show the coverage of basic State Space solutions which integrates MIMO (Multiple-Inputs / Multiple-Outputs) and stability equations of motion in dynamic physics.

978-1-4673-7825-3/15/$31.00 ©2015 IEEE

The basic of a robot arm can be taken as the purpose of grabbing and releasing objects. The tension and friction to the grabbing object should be controlled using a unique sensing model. The human hand uses centralized nervous system with the finger skin accumulations. So the human brain automatically produces the signals to manipulate the hand fingers even to the grabbing object nature, ie: roughness, brittleness, smoothness and the temperature as well.

The synthetic manipulation should be included with at least 75% of the human signal processing to become an efficient and valuable item to the industrial robotic market.

Thus, the finger based robotic hands can be introduced with unique mechanisms. The Tendon-driven finger links can be much similar to the human finger mechanism and can be synthetically manipulated for a robotic finger with motion controls.

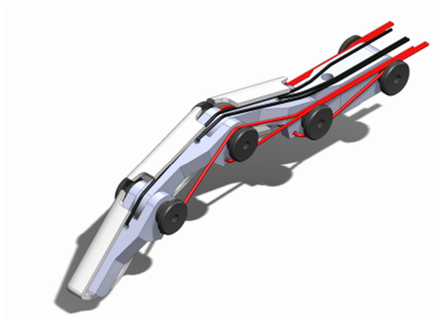

Figure 1.1: *Introduced tendon driven mechanism installation.*

This research project has under gone with this mechanism named, tendon-driven-finger robotic hand and the computational controlling.

II. LITERATURE REVIEW

The dexterity is all the way long challenge when a manipulated robotic instrumentation is being introduced. Here, in this case of manipulating the robotic finger hand the dexterity of the human finger hands has to be approached to the closer.

The success stories will be drawn here; The lightweight and small volume synthetic skeleton system is bonded by fiber string tendon drives connected to angular controlled sequence motor-actuators. This system is accumulated by small scale tendon transmission system which can produce more efficiency and higher angular displacement with small unit of actuated drive system. [1]

The linear driver pulleys inside the tendon driven system is lesser the motion sensitivity. So, the improvement of sensitivity drives to the path of enlightening the non-linear methods inside the mechanism. By replacing the linear driver pulley models inside the tendon drive module, with non-linear bending mechanics, the ultimate approach will be extra-coming to the highest sensitivity. This research approach gives the flexi-mechanism instead of usual tendon driven pulley mechanism. [2]

The special approach to replace my-o-electric hand which includes electrical drive motors inside each and every joints of the finger arm. This has to be eliminated since the weight of the drive system is non-affordable by the internal weight and forces. So, the research group investigated the methodology by manipulating the human prosthesis using the biological tendon systems. This is the well functioned combination of flexor digitorum and the extensive "digitorum" of the human arm manipulation. Following Figure 2.1 will clarify the biological structure to be manipulated. [3]

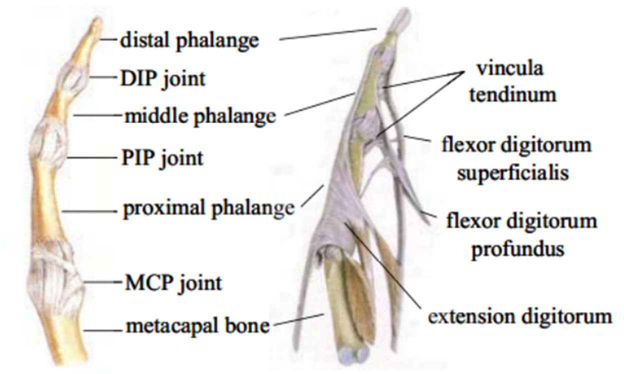

Figure 2.1: *Biological structure of the human finger mechanism.*

With accordance the PIP and MCP joints of the human finger structure, the electrical drive system is introduced by MCP puanelley and PIP bearing to be tensed by the fiber tendons which connects the driver motor at the root of mechanical finger. The supportive arm is hinged with two pulleys to maintain the sensitivity of the tensed tendon string. Following Figure 2.2 will clarify the description. [4]

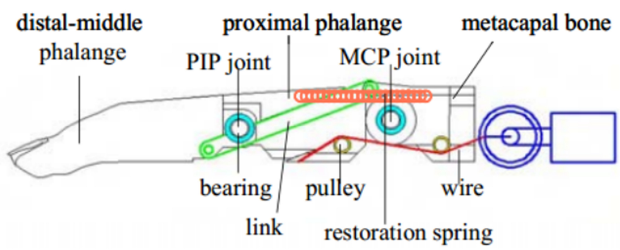

Figure 2.2: *PIP & MCP join mechanism and tendon connection.*

It's well known that the manipulation of human behaviors will be the most difficult phenomena that can be carried out by any scientific field. Here in this scientific and engineering manipulation of human hand to a robotic gesture hand, there will be a bunch of miss-matches and in-proper localization. So, by reading and understanding the previously testes prototypes and establishments by previous researchers we can fix some points from there references. We will lead to a way that this research project will come near to a best approach with respect to those references and knowledge gained.

III. Problem Statement

The Tendon-driven system is a tension based mechanical drive system for coupling and linking mechanics. This can be developed to sense the tension to the link-joints thus the tension at the fingertips can be measured using an electronics method at the end.

The mechanics of the implementation can be derived using simple engineering mechanics and with respect to the degree of freedom calibrations.

Using the elongated tensile stress the stalling current gain will measure up the applied tension to the fingertips and finally it produces an electrical signal to drive the particular motors/actuators.

Finally the problem of initiating the motion of finger joints can be derived like that and the controlling unit will data mine the stall current peaks. So that the tension (object grabbing) will be stated as the main function to the CPU that will detect the grab and release states.

This will have several limitations since the tension of the tendon strings can be elongated and the 2 motors will limit to the stall current barriers. So, the current sensors should be calibrated accordingly with respect to the particular tendon drive string considering the material nature and elongation of course.

The current sensing as the isolated implementation would not be enough. So, the tactile sensing part should be coming to the fingertips and grabbing body as well. This will re-calibrate the coming through error function of the driven system with the collaboration of stall current of tendon strings sensing inputs.

IV. Methodology

A. Mechanical Design

As per the project building and the proposal synthesized, the design has to be the major role which hoists the friction and dynamic movements according to the function given.

The proposed design is a 75% comparable replication of a human hand mechanical structure which moves much more exactly as the human hand gestures. Thus the variations of design technique have to be predefined under specific special conditions. Hence the design has undertaken the manufacturing of 3D printed arm and the fingers themselves. The following figure 4.1 will give a rough terminology of how the design went all along.

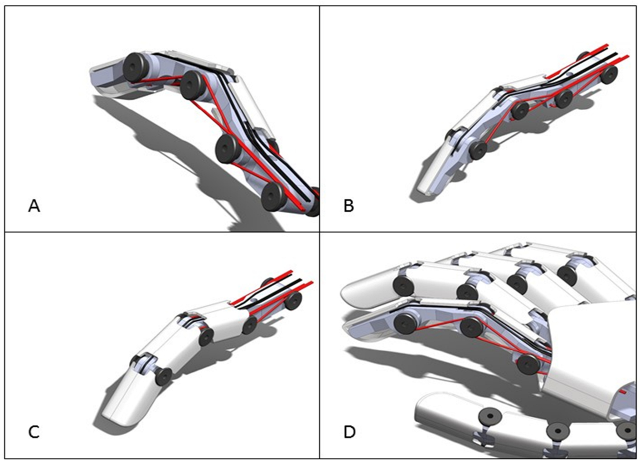

Figure 4.1: *The joint design of fingers and palm module 3D draw.*

Considering the descriptive expansion of Figure 4.1, the Figure 4.1.A-B show the side opened tendon fixation which can be driven smoothly between the joints of the finger. The "red" colored tendons will work as the flexor digitorums where described in the Literature Review. In the words of Mechanical perspective, it will bend the finger towards the palm by extending the tendon externally and separately where the each tendon drives each joint. The "black" tendons do the opposite sequentially. They can be named biologically, the extensor digitorums according to the Literature Review.

The Figure 4.1.C shows the overall completed finger with fully covered up casing where the ergonomics comes first, since the finger deals with extremely high sensitive medical organs and equipments.

The Figure 4.1.D shows the overall assembly with all 5 fingers together with the palm and joints. The tendons will go through the palm and then connects to the actuator panel which can be simulated using following Figure 4.2.

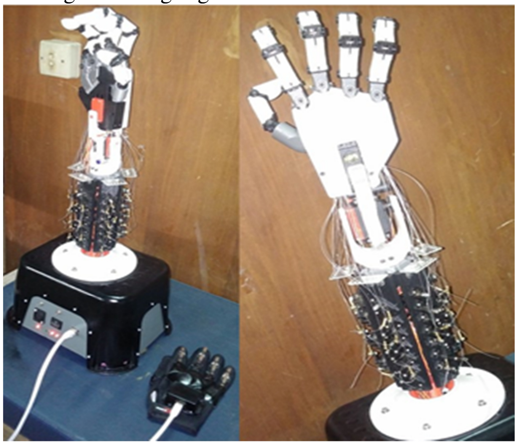

Figure 4.2: Full assembly of the working condition arm with glove controller.

The mainly focused part of manufacturing was to selection of materials to be used. The entire arm and the fingers were made of specially reinforced polycarbonate plastic fibers where the design was printed under special laboratory conditions. Then the tendons were found according to the reliability of elasticity which has to be evenly constant over the period of motion as well as the lifetime of the arm. Otherwise a huge catastrophe will occur in future as a design drawback. Thus the tendons were selected with Nylon material which has theoretically zero-extension.

The proposed methodology was to design the mechanism with 37 DOF system which can be divided as follow;

- 30 DOF – 5 Fingers' internal joints for bending.
- 5 DOF – 5 Fingers' waiving joints.
- 2 DOF – Palm motion in X-Y space plane.

Each joint consists of a radial actuator which connects a tendon to make the movement possible. The radial actuator converts the motions into linear actuating movements without making any conflictions and also zero-extensions (due to the material used for tendons).

In accordance with the non-conflicting and zero-extensive motions, each tendon has to be separated even for a single finger. That also separates the tendon extensive force and the finger joints can be moved with internal friction-free environment. This leads to the next part of the methodology more comprehensive, where the externally applied frictional forces has to be measured without any interference of internal dynamic frictional forces, thanks to the design overview.

B. Electrical and Electronics Instrumentation

As the mechanical implementation is waiting for a controller to manipulate the links and joints an actuator system has been instrumented to do the duty respectively. This actuator system consists of 37 micro servo gear motors to emphasize the motion calibration highly synchronized.

The derivation of the variable of motion on the actuators has been selected considering the angular motion of the tendon handler. The tendon handler is directly connected to the motors in the same plane of motion of the motor axle.

The calculation is based on the following equation specially derived to this system since the normal voltage divider comes with noise cancellation functions as well with RC formulas. [7] The reason we have left the external noise cancellation since the servo motors themselves add the internal noise cancellation to the actuation. In order to eliminate unnecessary dilations to the system we have removed those noise cancellation from the basic voltage dividing formulas.

$$V_{Out} = V_{Sense} \times \left(1 + \frac{R2}{R1}\right) = R_{Sense} \times I_{Load} \times \left(1 + \frac{R2}{R1}\right) \quad (1)$$

The following figure 4.5 will describe how the special notations will work in the practice.

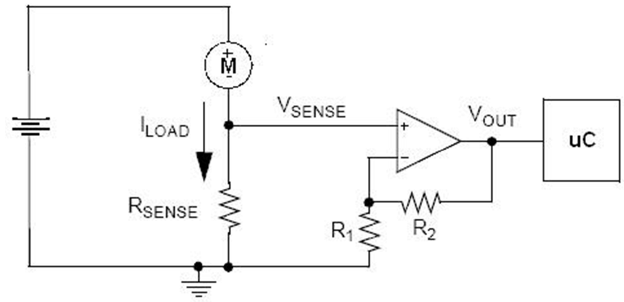

Figure 4.3: Current sensor circuitry with internal notations.

Instead of using the method of multiplexing we have created separate nodes for each servo motor to make the system work more productive as the analog multiplexing slows down the system baud rate drastically. [7][8] The runtime environment of this implementation is to detect the load applied to the link using the rise of voltage signal though the amplifiers then cuts off (stands hold) the Pulse-Width-Modulation (PWM) signal to the particular respected servo motor. [9] Hence the particular link will freeze while giving a constant pressure to the immobile object. This entire procedure is monitored by the giant computation unit which is described by the next sub-section.

Finger	Load	Mapped Servo Angles					
		Unit #1		Unit #2		Unit #3	
Thumb_L1	1.27	10	140	12	137	14	135
Thumb_L2	2.80	10	140	30	100	20	110
Thumb_L3	3.71	40	100	32	90	30	100
Index_L1	1.81	10	140	18	120	19	120
Index_L2	2.60	10	138	30	95	24	100
Index_L3	3.45	45	90	38	90	32	100
Middle_L1	2.13	10	140	20	100	28	100
Middle_L2	2.89	15	120	30	100	32	100
Middle_L3	3.81	48	100	38	100	30	110
Ring_L1	1.56	10	140	13	100	22	100
Ring_L2	1.98	13	138	25	100	30	100
Ring_L3	2.83	50	100	28	100	30	100
Little_L1	2.17	10	140	20	100	21	98
Little_L2	3.12	12	100	20	110	30	100
Little_L3	3.88	50	90	28	96	33	100

Table 1: *The L# defines the link number with respect to the given finger (manipulator). The load has been measured using the millivolt values produced to the analog input of the microcontroller.*

The above Table 1 will describe the Servo Motor values determined using the stress calculation with pre-determined variables using the method in Section 4.B. Each servo motor angle is used as the couple interrelated each other to extract and flex the particular link respectively.

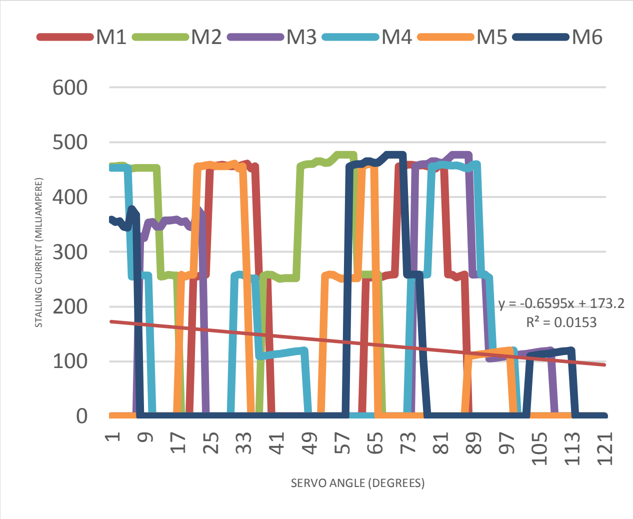

Figure 4.4: *Friction modeling graph for one finger with linearizing equation with active loading versus the servo rotation angle. This equation helped to build the linearization model inside the computation unit to make the system work more linear and time responsive with the movements.*

This controller gives much more precise readings to the Computation Control Unit as analog values, then the computation unit will execute the commands to the servo motors with respect to these readings as PWM signals. It also linearizes the execution with respect to the readings of Servo Stress measuring System. Thus the internal execution loop becomes closed and gives an error free environment to handle precisely as well as accurately.

C. Motion Calibration

Considering the prosthetic motion emulation, the title of 'Cooperative systems' comes in action. Considering the overall Degree of Freedom in relative with the palm we can eliminate the wrist joints for the calculations. Thus the object to be grabbed (immobile object) is acting relative to the World Co-ordinate System (WCS) of the five fingers respectively. The object will be assigned with its own virtual coordinate system for the reference.

The cooperative manipulators roles a major portion in motion calibration here. In this research we are taking count of the Euler's angles in vector frame of WCS. [5][6] Since the contact points to the victim object ratio is 5:1 in this case, we are deriving the object position in three-dimensional space (3D Space coordinate system) with reference to the WCS. Following figure give more contrast to the explanation.

To give the more clarity on the calculations and deriving formulas, we have given the object the number "0" and the manipulators will have the numbers "1" to "n" in the WCS. Here in this case the manipulators will have maximum number of "5" which means "n=5" hereafter.

The action of the derivation of formula to the electrical actuating system smoothly depends on the selected approximation here in this motion calibration. The best assumption we have come across here is the object is relatively rigid and the manipulators will eliminate the extensive forces due to the elasticity of the immobile object.

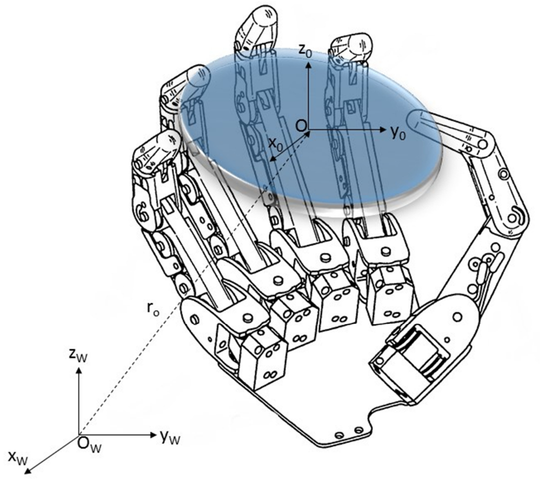

Figure 4.5: *Cooperative work of the fingers on an object.*

Considering this scenario, the cooperative system consists of 6 elements. The immobile object is assigned with "0" and the manipulators (finger contacts) will have "1, 2, 3, 4, 5" in series and 'w' to the support. The immobile object's position is predefined with the help of center of the mass and given by the three coordinates,

$$\boldsymbol{r_o} = \boldsymbol{col}(\boldsymbol{r_o^{x_w}}, \boldsymbol{r_o^{y_w}}, \boldsymbol{r_o^{z_w}}) \tag{2}$$

and with reference to the Euler's angles of the coordinate frame attached to the object where the WCS act as the true reference. This external coordinate system and the vector of its instantaneous orientation can be given by,

$$\boldsymbol{\mathcal{A}_o} = \boldsymbol{col}(\boldsymbol{\psi_o}, \boldsymbol{\theta_o}, \boldsymbol{\varphi_o}) \tag{3}$$

Hereafter we can obtain a six component vector for each manipulator as well as the immobile object.

$$\boldsymbol{Y_i} = \boldsymbol{col}(\boldsymbol{r_i}, \boldsymbol{\mathcal{A}_i}) = \begin{bmatrix} \boldsymbol{r_i} \\ \boldsymbol{\mathcal{A}_i} \end{bmatrix} = \begin{bmatrix} \boldsymbol{r_i^{x_w}} \\ \boldsymbol{r_i^{y_w}} \\ \boldsymbol{r_i^{z_w}} \\ \boldsymbol{\psi_i} \\ \boldsymbol{\theta_i} \\ \boldsymbol{\varphi_i} \end{bmatrix} \in \boldsymbol{R^6} \tag{4}$$

Likewise the $\boldsymbol{Y_1}$, $\boldsymbol{Y_2}$, $\boldsymbol{Y_3}$, $\boldsymbol{Y_4}$, $\boldsymbol{Y_5}$ can be derived in the same way since every calculation is made with respect to the WCS where all the vector components are constant when the amplitude is zero.

Since the vector formulas of the mechanical motion of all the fingers and the immobile object have been derived, we may go further with the analysis of electrical drive unit synchronization where the rest of the methodology drives towards. Up to now, the system works as an independent prosthetic arm without external electrical actuators. Simply the meaning, this part of the system can be used as a replacement of any prosthetic arm rest where the actuation will be carried out by any sub-methodology. This is the most important usage of this research, where anyone can use a part or the entire system of this project in future implementations or developments.

The main purpose of implementing a Servo Stress measuring system was to protect the immobile object when grabbing and releasing by the manipulators since they don't provide any mechanical protection to the object.

In order to start analyzing the inverse kinematics problems associated with robot hands, let a single contact finger be investigated. The problem considered here is the solution of the linear equation presented by rewrite from DH matrix which can be rewritten for a single finger as below:

$$\begin{bmatrix} cos\boldsymbol{\theta}_j & -cos\boldsymbol{\alpha}_j sin\boldsymbol{\theta}_j & sin\boldsymbol{\alpha}_j sin\boldsymbol{\theta}_j & \boldsymbol{a}_j cos\boldsymbol{\theta}_j \\ sin\boldsymbol{\theta}_j & cos\boldsymbol{\alpha}_j cos\boldsymbol{\theta}_j & -sin\boldsymbol{\alpha}_j cos\boldsymbol{\theta}_j & \boldsymbol{a}_j sin\boldsymbol{\theta}_j \\ 0 & sin\boldsymbol{\alpha}_j & cos\boldsymbol{\alpha}_j & \boldsymbol{d}_j \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

The Denavit-Hartenberg method can be applied to make derivations of DH Matrix to solve the mechanical joint motion equations. This method has been implemented in the NTU hand and following figure and the equation will give the rough sketch about their methodology in advance.

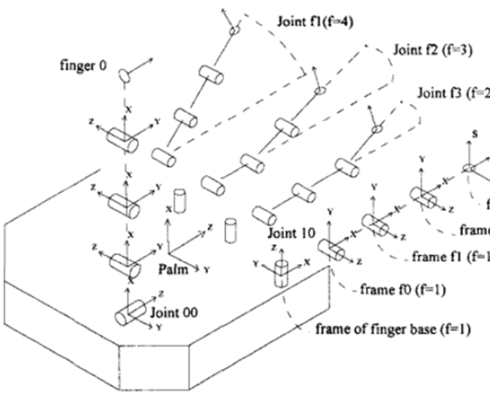

Figure 4.6: *The coordinate from of the NTU hand and the DH Matrix related.*

D. PID Joint Control

Due to the finger movement joint and the actuation motor is connected by a straight tendon which does not transfer any forces other than the partial energy consumption due to the internal friction. There should be two assumptions before taking the calculations forward.

1. The actuation system is composed with Servo Motors (DC) with a high reductions gear.
2. The Finger link (element) has a negligible moment of inertia.

Regarding this implementation we could produce the derivation of actuator characteristics by following equation in advance.

$$\boldsymbol{J_m \theta''_1 + D_m \theta'_1 = T_m} \quad (6)$$

where;
$\boldsymbol{\theta}_1$= Angular displacement of the actuator.
$\boldsymbol{J_m}$= Effective inertia of the actuator.
$\boldsymbol{D_m}$= Effecting damping about the $\boldsymbol{\theta}_1$axis.
$\boldsymbol{T_m}$= Motor input torque which is evaluated at the output gear's shaft.

E. Object to Joint Space Mapping

Obviously, planar motion can be analyzed as particular case of the general 6-DOF motion by the mapping among object position and the corresponding joint displacement. The inverse kinematics mainly consists of solving for particular joint configuration in terms of given coordinate system as Figure 4.6.

The solution adopted for contact force can be proposed as the results of minimizing the square criterion

$$\boldsymbol{I_f} = \boldsymbol{f_c^T} W \boldsymbol{f_c}, \quad (7)$$

expecting the solution in the form

$$\boldsymbol{f_c = W^{-1}H^T(HW^{-1}H^T)^{-1}F_0} \quad (8)$$

Where, the vector of forces at contact points $\boldsymbol{f_c}$, $\boldsymbol{W}$ = **diag** ($\boldsymbol{w_1}$,..., $\boldsymbol{w_n}$) is the weighting matrix; $\boldsymbol{F_0}$ is the force vector at the object mass center (MC), and $\boldsymbol{H}$ is the unit matrices, resulting from the relation $\boldsymbol{F_0 = \Sigma f_c = Hf_c}$. To start analyze the inverse kinematics of robot fingers; a single contact finger should be investigated. The problems being considered is the solution of the linear equation presented by above equation which can be rewritten for a combination of a single finger formed as matrix.

In order to find the best mapping between the object position of motion parameters $\boldsymbol{Y_i}$ and the associated hand joints $\boldsymbol{\theta_{ij}}$ (finger $\boldsymbol{i}$ and joint $\boldsymbol{j}$) is a crucial issue that has been investigated heavily in the literature. The mechanism which is being examined here, there is a mapping which can be trained and classified. Once this mapping is established, it can be utilized for the hand controller instead of using the heavy computation on inversed kinematics. This learning mechanism is established via a supported vector machine (SVM).

Hand Displacement Training Patterns

Our approach is to let a SVM learn the linear functional relating the entire hand joints positions and displacements to grasped object. This is done by considering the inverse kinematic of hand, in addition to the interaction between hand fingers and the object being grasped and manipulated.

Once a robot hand controller receives stall current sensing on which the hand motion has to be made, then the controller will recalculates a trajectory through the inverse kinematics again. The Supported Vector Machine can be seen as general parametric models that learn to represent the joint motions relationship in terms of object displacement in the form of the fingertip position.

Figure 4.7: *Cooperative work of the fingers on an object.*

SVM will be used for approximating a function from a set of available training data. For our control system, the relation which will be used to train the SVM'S metric is defined as some training patterns of object position $\boldsymbol{r_o = col(r_o^{x_w}, r_o^{y_w}, r_o^{z_w})}$, instantaneous orientation $\boldsymbol{\mathcal{A}_o = col(\psi_o, \theta_o, \varphi_o)}$

$$\boldsymbol{\theta_{ij} = svm(r_o^{x_w}, r_o^{y_w}, r_o^{z_w}, \psi_o, \theta_o, \varphi_o)} \quad (9)$$

where;
$\boldsymbol{\theta_{ij}}$= Joint angle $\boldsymbol{j}$ of the finger $\boldsymbol{i}$.

Obtaining the best results with SVMs, it requires an understanding of their workings. SVMs belong to the general category of kernel methods, a kernel function computed by doing dot product in some possibly high-dimensional feature space. In the feature space, $\boldsymbol{F}$, this expression takes the form;

$$\boldsymbol{f(y)} = \sum_{i=i}^{n} \boldsymbol{\alpha_i} \Phi(\boldsymbol{x_i})^T \Phi(\boldsymbol{y_i}) + b \quad (10)$$

$\boldsymbol{\alpha_i}$ is known as the dual variable of the decision boundary and $\boldsymbol{b}$ is called the bias.

$$\boldsymbol{K}(\boldsymbol{x_i}, \boldsymbol{y_i}) = \Phi(\boldsymbol{x_i})^T \Phi(\boldsymbol{y_i}) \tag{11}$$

Both are called *hyperparameters*. Training an SVM finds the large-margin hyperplane, i.e., sets the values of the parameters. The soft-mar-gin constant and any parameters the kernel function depend on degree of a polynomial kernel.

To express the incremental learning (adaptive leaning), Once a trained SVM have done, and then we wish to add more training pairs or remove to/from the training set. During the training period, the controller will set the $\boldsymbol{\alpha_i}$ which correlate to these training pairs to zero without changing any other values and repeat the training algorithm again. In order to train the SVM and measure its performances, an objective function must be defined to provide an unambiguous numerical rating of system performance. For this frame work, cost functions have been investigated, where the sum of squares error minimized.

The maximum effort will be applied to cover up the mechanically derived five fingers with electrical sensitive drive systems isolated using the programmed Xilinx Zynq-7020 FPGA. The cover-up process in this project will be taken as the scope by referring the Figure 4.7. The real work-out has been carried out to fulfill those situations using the manipulated hand. The actual and final approach has been compared in more than 75% of possibility: There were several barriers after improving while achieving the scoped goals. The keys is using a high speed processing device with MIMO enabled input rails. This can be done with an FPGA precisely. The dilation between calculations and motion calibrations can be eliminated using this implementation.

V. RELATED APPLIANCES

The future can be taken into the count of present innovations. This system is basically targeting remote immobile duties such as military based experiments where the human lives are mostly counted as losses; and tele-medicine applications where the patients have to be treated all the way alone in home where the consultant is located in far away from home.

This research project is basically covers tele-medicine applications. [12] The military level implementations will not be accessible here at this stage since the product is very high sensitive and not compatible with managing highly critical military tasks. Finally, we develop the concept of adaptive support vector machines that can learn from incremental data.

The usage can be count by the well-practiced physicians who can contribute their career experiences in sake of the development of this kind of technological advancements as well.

VI. CONCLUSION AND FURTHER WORKS

With the current designed, even though the system internally interrupt the loop when force feedback controller activates, and holding the object; the user still cannot feel any feedback other than seeing it visually. Thus there has to be an actuating device implanted on the human glove controller unit to make the feeling goes to that actuator and human can feel it while doing the manipulation.

Furthermore, installing tactile sensors on the fingers will lead a very accurate and precise data readings and environment feedbacks as well. During the methodology we have eliminated environment stiffness effects due to the lack of derivative variables. Thus installing tactile sensing device will eliminate all those issues and can go for a proper calculations and computations as well. The system overall is satisfied at this research stage since the given design has been improvised using a bunch of mathematical and computational formulae to make the proceedings flow reliably. The system responds real time and it is more than applicable for related appliances to be integrated.

For the evolution, the system can be designed more robustly in order to overcome a very few design bugs when the real time motion comes forward. The linearization can be optimized using several mathematical implementations with tuning mechanics as well. Changing the materials of tendons will solve the linearity issues as well, eliminating the extensive errors while making the link movements.

The controller can be improvised using Support Vector Machine (SVM) technology to overcome more gigantic issues with steady state vector models (friction modeling). [13] This will lead to the State space studies with a step forward inclusive of data mining and machine learning techniques. This is the big advancement that this project can be delivered with proper manner to serve better for future.

VII. REFERENCES

[1] Jung, S. yoon, Kang, S. kyun, Lee, M.-J., & Moon, I. (2007, Oct). Design of robotic hand with tendon-driven three fingers. In Control, automation and systems, 2007. iccas '07. International conference on (p. 83-86).

[2] Shirafuji, S., Ikemoto, S., & Hosoda, K. (2014). Development of a tendon-driven robotic finger for an anthropomorphic robotic hand. 33(5), 677-693.

[3] Lee, Y.-T., Choi, H.-R., Chung, W.-K., & Youm, Y. (1994, Oct). Stiffness control of a coupled tendon-driven robot hand. Control Systems, IEEE, 14(5), 10-19.

[4] Shin, Y. J., Lee, H. J., Kim, K.-S., & Kim, S. (2012, Dec). A robot finger design using a dual-mode twisting mechanism to achieve high-speed motion and large grasping force. Robotics, IEEE Transactions on, 28(6), 1398-1405.

[5] Biedenharn, L. C.; Louck, J. D. (1981), Angular Momentum in Quantum Physics, Reading, MA: Addison–Wesley, ISBN 978-0-201-13507-7.

[6] Rose, M. E. (1957), Elementary Theory of Angular Momentum, New York, NY: John Wiley & Sons (published 1995), ISBN 978-0-486-68480-2.

[7] Beckwith, R.E. (June 1968). "Continuous Financial Processes". The Journal of Financial and Quantitative Analysis 3 (2): 113–133. JSTOR 2329786.

[8] Bates, Regis J; Bates, Marcus (2007), Voice and Data Communications, ISBN 9780072257328.

[9] Ming Lei; Soleymani, M.R., "Diversity–Multiplexing Tradeoff of the Half-Duplex Slow Fading Multiple-Access Relay Channel Based on Generalized Quantize-and-Forward Scheme," Wireless Communications Letters, IEEE , vol.4, no.1, pp.74,77, Feb. 2015.

[10] Schönung, A.; Stemmler, H. (August 1964). "Geregelter Drehstrom-Umkehrantrieb mit gesteuertem Umrichter nach dem Unterschwingungsverfahren". BBC Mitteilungen (Brown Boveri et Cie) 51 (8/9): 555–577.

[11] Lipfert, Hermann (August 2007). MIMO OFDM Space Time Coding – Spatial Multiplexing, Increasing Performance and Spectral Efficiency in Wireless Systems, Part I Technical Basis (Technical report).

[12] Sachpazidis, Ilias (10 July 2008). "Image and Medical Data Communication Protocols for Telemedicine and Teleradiology (dissertation)". Darmstadt, Germany: Department of Computer Science, Technical University of Darmstadt.

[13] Cortes, C.; Vapnik, V. (1995). "Support-vector networks". Machine Learning 20 (3): 273. doi:10.1007/BF00994018.