# PASSIVE AND ACTIVE ASSISTIVE WRITING DEVICES IN SUPPRESSING HAND TREMOR

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

Faculty of Mechanical Engineering
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MARCH 2017

*In the name of Allah, Most Gracious, Most Merciful*

*To my lovely spouse*

***Nurul Hikmah Binti Harun***

*To my beloved parents*

***Allahyarham Mohd Yusop Bin Aspar***

***Seti Zaharah Binti Sukeni***

*To my daughters*

***Allahyarhamah Aleesya Safiya***

***Afeeyah Soleha***

# ACKNOWLEDGEMENT

Alhamdulillah, all praise is due to Allah S.W.T, the Most Beneficent and the Most Merciful, who has taught me what I knew not.

I would like to express my deepest appreciation to my project main supervisor, Assoc. Prof. Dr. Mohd. Zarhamdy Md. Zain for all the advice, guidance and motivation given throughout this thesis. I also like to give my sincere thanks for giving me the opportunity to do the project on the development of Passive and Active Assistive Writing Devices in Suppressing Hand Tremor. This project has given me valuable experience especially in learning various aspects controllers, programming, and simulation. Special thanks also to my co-supervisor P.M. Dr. Mohamed Hussein for his inspiration, teaching, and advice.

I would like to further extend my gratitude to all lecturers, my laboratory mates, my friends, all suppliers and technicians who have assisted me directly and indirectly throughout the progress in completion of my project. I will not forget all opinions and supports given.

Last but not least, I would like to thank the Ministry of Higher Education Malaysia for providing me the MyBrain15 scholarship. I also would like to thank Universiti Teknologi Malaysia (UTM) for their continuous support in the research work.

Thank You.

# ABSTRACT

Patients with hand tremor disease frequently experience difficulties in performing their daily tasks, especially in handwriting activities. In order to prevent the ingestion of drugs and intervention of surgeries, a non-invasive solution was presented to improve their writing capabilities. In this study, there were two novel inventions of the hand-held device named as TREMORX and Active Assistive Writing Device (AAWD) with the approaches of passive and active elements respectively. For validation, the patient with tremor was assisted in using a normal pen and TREMORX to perform a handwriting task at the sitting and standing postures. For AAWD, the active suppressing element was the servo motor to control the hand tremor act on the writing tool tip and an accelerometer will measure the necessary parameters values for feedback control signal. The classic Proportional (P) controller and Proportional-Integral-Derivative (PID) were presented. The P controller was tuned with a meta-heuristic method by adjusting the parameters into several values to examine the response and robustness of the controller in suppressing the tremor. The evaluation was based on decreasing the coherence magnitude on the frequency response analysis. To optimise the performances, two types of Evolutionary Algorithms (EA) were employed which were Genetic Algorithm (GA) and Particle Swarm Optimisation (PSO). The optimisation techniques were integrated into the PID controller system to generate the optimum performances in controlling the tremor. For the simulation study, the parametric model representing the actual system of the AAWD was presented. The main objectives of this analysis were to determine the optimum value of PID parameters based on EA optimisation techniques. The determined parameters for both optimisations were then injected into the experimental environment to test and evaluate the performance of the controllers. The findings of the study exhibited that the PID controller for both EA optimisation provided excellent performances in suppressing the tremor signal act on the AAWD in comparison to the classic pure P controller. Based on the fitness evaluation, the GA optimisation significantly enhanced the PID controller performance compared to PSO optimisation. The handwriting performance using both TRREMORX and AAWD was recorded and from a visual justification, it showed that the quality of legibility was improved as compared with using normal handwriting devices. These outcomes provided an important contribution towards achieving novel methods in suppressing hand tremor by means of the invention of the handheld writing devices incorporated with intelligent control techniques.

# ABSTRAK

Pesakit dengan penyakit getaran tangan sering mengalami kesukaran dalam melaksanakan tugasan harian mereka, terutamanya aktiviti berkaitan penulisan tangan. Untuk mengelakkan pengambilan ubat-ubatan dan pembedahan, penyelesaian secara tidak invasif diperkenalkan untuk meningkatkan keupayaan penulisan. Dalam pembelajaran ini, terdapat dua rekaan novel alat bantuan penulisan dinamakan sebagai TREMORX dan Alat Bantuan Menulis Aktif (AAWD) dengan masing-masing mengunakan pendekatan elemen pasif dan aktif. Sebagai pengesahan, pesakit diminta menulis mengunakan pen biasa dan juga peranti TREMORX dalam dua keadaan postur yang berbeza iaitu duduk dan berdiri. Bagi AAWD, elemen penekan aktif adalah motor servo bertindak mengawal getaran tangan pada mata alat penulisan dan penderia pecutan akan mengukur nilai-nilai yang diperlukan sebagai maklumbalas kepada isyarat kawalan. Kawalan dari jenis berkadaran (P) dan berkadaran-kamiran-kebezaan (PID) dibentangkan dalam kajian ini. Pengawal P telah ditala dengan kaedah meta-heuristik dengan melaraskan nilai untuk mengkaji tindak balas dan keteguhan pengawal dalam proses mengurangkan getaran. Penilaian tersebut adalah berdasarkan kepada pengurangan magnitud bagi analisis sambutan frekuensi. Untuk mendapatkan keputusan yang optimum, dua jenis pengoptimuman dipilih dari jenis algoritma evolusi (EA) yang terdiri daripada algoritma genetik (GA) dan juga pengoptimuman kerumunan zarah (PSO) dan telah diintegrasikan ke dalam sistem pengawal PID. Bagi kajian simulasi, model parametrik yang mewakili sistem sebenar AAWD telah dibentangkan. Objektif utamanya adalah untuk menentukan nilai optimum parameter pengawal PID berdasarkan teknik pengoptimuman EA. Nilai parameter yang telah diperolehi kemudianya disuntik ke dalam pengawal melalui model eksperimen untuk diuji dan dinilai keberkesanannya. Hasil daripada kajian menunjukkan prestasi pengawal PID untuk kedua-dua teknik pengoptimuman adalah sangat baik jika dibandingkan dengan penerapan pengawal klasik P dalam mengurangkan getaran tangan. Berdasarkan pada penilaian antara kedua-dua teknik pengoptimuman ini, pengoptimuman bagi jenis GA menunjukkan prestasi yang cemerlang berbanding PSO. Bagi aspek kualiti tulisan menggunakan kedua-dua peranti TREMORX dan AAWD, kualiti kebolehbacaan tulisan bertambah lebih baik jika dibandingkan dengan mengunakan alat penulisan biasa. Secara keseluruhannya, hasil kajian ini memberi sumbangan penting dalam rekaan peranti menulis yang diintegrasikan dengan teknik kawalan pintar untuk mengurangkan getaran tangan.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| 3D | - | Three-dimension |
| AAWD | - | Active Assistive Writing Device |
| ABS | - | Acrylonitrile butadiene styrene |
| AD | - | Analog to Digital |
| AID | - | Accuracy Improvement Device |
| AR | - | Autoregressive |
| ARMA | - | Autoregressive moving average |
| ARMAX | - | Auto-regressive moving average type with exogenous |
| ARX | - | Auto-regressive with exogenous |
| ASAP | - | Apparatus to Sense Accuracy of Position |
| BMFLC | - | Band Limited Multiple Fourier Linear Combiner |
| CAD | - | Computer Aided Design |
| DAQ | - | Data acquisition |
| DAS | - | Data Acquisition System |
| DC | - | Direct Current |
| DOF | - | Degree of freedom |
| DRIFT | - | Dynamically Response Intervention of Tremor |
| DVB | - | Double Viscous Beam |
| EA | - | Evolutionary Algorithm |
| EKN | - | Neuropsychology Research Group |
| EMG | - | Electromyography |
| EMI | - | Electromagnetic Interference |
| ET | - | Essential Tremor |

| | | |
|---|---|---|
| FDM | - | Fused Deposition Modeling |
| FEA | - | Finite Element Analysis |
| FFT | - | Fast Fourier Transform |
| FPGP | - | Five-point grip pen |
| FSR | - | Flexible Sensitive Resistor |
| GA | - | Genetic Algorithm |
| IAE | - | Integral of absolute error |
| LCAM | - | Linear Current Amplifier Module |
| LD | - | Laser displacement |
| LED | - | Light emitting diode |
| LS | - | Least square |
| LV | - | Laser velocity |
| LVCA | - | Linear Voice Coil Actuator |
| MEMS | - | Micro electromechanical system |
| MIMO | - | Multiple-input-multiple-output |
| MLE | - | Maximum likelihood |
| MRF | - | Magneto-Rheological Fluid |
| MSE | - | Means-square-error |
| NIV | - | Inversion in the velocity |
| OSA | - | One-step-ahead |
| P | - | Proportional |
| PCI | - | Peripheral-Component Interconnect |
| PD | - | Parkinson’s disease |
| PEM | - | Prediction-error method |
| PFC | - | Piezoelectric fiber composites |
| PID | - | Proportional-Integral-Derivative |
| PRBS | - | Pseudo random binary sequence |
| PSD | - | Position sensitive detectors |

| | | |
|---|---|---|
| PSD | - | Power Spectral Density |
| PSO | - | Particle Swarm Optimsation |
| PWM | - | Pulse Width Modulation |
| RLS | - | Recursive Least Square |
| RMS | - | Root mean square |
| SISO | - | Single- input-single-output |
| SPI | - | Serial Peripheral Interface |
| SUS | - | Stochastic Universal Sampling |
| TR | - | Transmissibility ratio |
| TREMORX | - | Named of passive device |
| UART | - | Universal Asynchronous Receive and Transmit |
| WC | - | Writer’s Cramp |
| WOTAS | - | Wearable Orthosis for Tremor Assessment and Suppression |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $A(z^{-1}), B(z^{-1})$ | - | Discrete system polynomial |
| $a$ | - | Acceleration |
| $c$ | - | Damper |
| $c_1$, $c_2$ | - | Acceleration Constant |
| $e$ | - | Error |
| $e_f$ | - | Filtered control |
| $\varepsilon(t_{i-1})$ | - | Prediction error |
| $\xi(t)$ | - | Residual error |
| $F$ | - | Force |
| $f(x)$ | - | Function of variable $x$ |
| $f(x_i^k)$ | - | Fitness value |
| $G_{best}$ | - | Global particle swarm optimizer |
| $J_m$ | - | Motor inertia |
| $K_t$ | - | Motor torque constant |
| $K_p$ | - | Proportional gain |
| $K_b$ | - | Back emf constant |
| $k_1$, $k_2$ | - | Stiffness of spring |
| $k$ | - | Spring |
| $K_d$ | - | Derivative gain |
| $K_I$ | - | Integral gain |
| $K_P$ | - | Proportional gain |
| $l$ | - | Length |
| $m$ | - | Mass |
| $N_p$ | - | Population size |
| $\theta$ | - | angle |
| $\phi$ | - | Regressors |

| | | |
|---|---|---|
| $\phi_{\varepsilon\varepsilon}(\tau)$ | - | Auto-correlation of residue |
| $\phi_{u\varepsilon}(\tau)$ | - | The cross-correlation between input and residual error |
| $\phi_{u^2\varepsilon^2}(\tau)$ | - | Cross-correlation of input square and residual square |
| $\phi_{u^2\varepsilon}(\tau)$ | - | Cross-correlation of input square and residuals |
| $\phi_{\varepsilon(\varepsilon u)}(\tau)$ | - | Cross-correlation of residuals and residuals-input |
| $\partial$ | - | Differentiation of direction |
| $P_{best}$ | - | Individual best position |
| $P_c$ | - | Probability crossover |
| $p_k^i$ | - | Best individual particle position |
| $P_m$ | - | Mutation rate |
| $R_a$ | - | Armature resistance |
| $r$ | - | Frequency ratio |
| $R$ | - | Polar coordinate |
| $r_1$, $r_2$ | - | random number |
| $r(t)$ | - | Set point |
| $S$ | - | Sum of square residue |
| $T_d$ | - | Derivative of time |
| $T_d$ | - | Time derivative |
| $T_i$ | - | Integral time |
| $T_f$ | - | Filter time constant |
| $t_i$ | - | Discrete time step |
| $t$ | - | Time |
| $u(.)$ | - | Set of input |
| $u(t_i)$ | - | Input signal |
| $u(t_k)$ | - | Controller output |
| $V_{\max}$ | - | Velocity maximum |
| $v_{k+1}^i$ | - | Velocity of particle swarm |
| $\omega_e$ | - | Excitation frequency |
| $\omega_{\max}$ | - | Inertia beginning parameter |

| | | |
|---|---|---|
| $\omega_i$ | - | Inertia weight |
| $\omega_n$ | - | Natural frequency |
| $\omega_{\min}$ | - | Inertia end parameter |
| $\chi$ | - | Constriction factor |
| $x_k^i$ | - | Position of particle swarm |
| $\hat{y}(t)$ | - | Prediction equation |
| $y(t)$ | - | Process measurement |
| $y(t_i)$ | - | Output signal |
| $\hat{y}(t_i \mid x)$ | - | Predictor output |
| $y(t_i \mid x)$ | - | System output |
| $\psi_1(t)$, $\psi_2(t)$ | - | Correlation function |
| *y(.)* | - | Set of output |
| *y(t)* | - | Output signal |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 General Introduction

Unintentional continuous tremor is an abnormal phenomenon that happens in the human hand's body part. It perturbs daily life, generating a discomfort feel and resisting the human's normal daily activity. This kind of tremor disease has been attracting modern biomechanics researches that also take part in solving this issue. Information transfer by the patient may have created a future benefit to them by providing ideas to biomechanics engineer and later assist them in creating solutions with the mechanics techniques approach. Recently, with the emergence of modern biomechanics technology in the medical field, it has generated a virtuous reputation in improving the human life and treating those that suffer from other disabilities. Not limited to surgical intervention and ingestion of medicine, some cases require specific mechanical potential in order for them to be treated, like an orthopedic implant to the broken bones, an assistive device for rehabilitation process, and others. Specifically, people with hand tremor face difficulty while performing hand tasks, such as eating, holding objects and writing. Thus, this situation has embarked many researchers to come out with solutions that avoid high risk to the patient's life. In the context of engineering study, various research efforts have been proposed to eliminate or at least lessen the hand tremor by promoting non-invasive technique, either with the passive or active control approach. The non-invasive technique is such a low-risk category where there is no cause for future severity or any serious injury to the patients.

Even though the computer technology nowadays can ease the patient with their writing task prior to hand trembling, sometimes they still need to perform other tasks with their direct handwriting. The problem is, hand trembling may affect the handwriting quality and becomes worse when in severe tremor conditions. The invention of a passive device with a non-invasive technique is such a simple strategy in providing readable handwriting quality. Placing additional weightage to the writing device seemingly helps to reduce the trembling, by resisting the hand vibration, but it's not always tolerable due to the weight penalty. Another passive control approach is implementing the absorption of vibration material such as a spring or sponge to the device. However, this method only works at a narrow frequency assortment, requires a proper calculation for the material coefficient and has disadvantages for different levels and kinds of tremor. Due to the low cost of development, it will be a part of this research work.

In fact, the growing technologies and trends are helping the engineers to come out with better ideas and solutions by introducing an active tremor control, which can make the passive control strategies no longer attractive (Kenney *et al,* 2007). In contrast, active tremor control is stable, robust and generates more flexibility in regulating the actuator in an extensive tremor frequency range accordingly. Recently researches have been conducted in controlling tremor, but much more focus is made in the forearm. For handheld activity categories, a preliminary practice has been proposed by a group of researchers (Becker *et al,* 2008) in a tremor cancellation of the surgical handheld tooltip due to physiological tremor during operation by the doctor. Inspired from the ideas, the development of the proposed anti-tremor device seems to be realistic.

## 1.2 Research Background

Tremor diseases suffered by patients may also limit their hand movements. Hand tremor is the most common and visible symptom of Parkinson's disease. Patients experiencing this kind of movement in the arms and hands find performing daily tasks such as holding a bottle or writing on paper difficult. In addition, the patient may also feel embarrassed to face other people and worse, they prefer to stay indoors rather than going outside. Consequently, this may negatively impact their quality of life, mood and independence (Gao, 2004).

This kind of disease cannot be cured, but treatment may alleviate the symptoms. Parkinson's disease causes an imbalance in two brain chemicals that are vital in controlling normal movements (Morrison *et al*, 2008). These kinds of tremors can be classified into several frequency levels. Tremor frequency mostly depends on the pathophysiological mechanism and is fairly stable over time (Hellwig *et al.,* 2009).

In fact, there are many people who are suffering from tremor. The essential tremor is the most common form of tremor(Crowin Brown, 2008). In Malaysia, the total number of Parkinson’s (one of the tremor classification) patients in Malaysia is most likely to be 15,000 or even higher (Lai, 2009). Thus, Parkinson’s disease is under-diagnosed in Malaysia. The Parkinson’s patients that are seen in the hospitals and clinics are merely the “tip of the iceberg” (Pellegrini *et al*, 2004).

## 1.3 Problem Statement

To inhibit this movement disorder, some of the patients use modern treatment such as drug therapy, surgical treatment including thalamotomy and deep brain stimulation. These types of treatments may have their own weaknesses, especially for the long term period because the treatments involve using drugs and also surgery directly to the patient brain and provide high risks to the patient’s life. The drug medication may temporary alleviate or lessen the tremor. To prevent this kind of dangerous treatments, there are some approaches that can be used to treat these patients by presenting biomedical loading techniques.

Recently, there are devices developed by researchers to improve this kind of problem, but they are focused on the passive method and some of the devices are not fully tested to the actual hand tremor. Figure 1.1 depicts the writing quality of a patient with using normal pen become worst. Even though current computer technology may ease them but in certain condition or situation they still require to perform normal handwriting task in their daily life, especially signing the document, filling the form and etc. The improvement of handwriting quality seem to be impossible to achieve without using specific writing device that are able to attenuate the unwanted tremor signal.

**Figure 1.1:** Parkinson's patient with hand tremor

## 1.4 Research Objectives

The objectives of this research are as follows:

1. A new modelling and analysis of mechatronics design of the passive and active device was proposed to improve the handwriting task in tremor behaviour. The design will be assessed based on the behaviour of the handwriting task activity.

2. To simulate and verify on experimental rig for the active device response. The experimental rig was an approach to emulate the actual behaviour of tremor patient in the handwriting task.

3. An analysis of a conventional PID controller scheme for the active device to improve the handwriting task in tremor behaviour. The control scheme included an optimisation technique using a genetic algorithm and particle swarm to optimise the parameters' controller behaviour.

## 1.5 Scope of the Study

The scope of this research is described as follows:

1. Development of passive device was based on the vibration absorption mechanism.

2. The miniature servo motor type was used as an actuator for the active tremor control device and the magnitude movement is limited to ±10 mm peak to peak excitation.

3. The types of controller selected in this research were Proportional controller (P) and Proportional-Integral-Derivative (PID).

4. The study was based on the Parkinson's patients behaviour on the handwriting tasks with the coherence frequency amplitude is within 8 Hz to 9 Hz.

5. The Evolutionary Algorithm (EA) optimisations considered in this study were GA and PSO to optimise the proposed controller parameters. The performance of the proposed controller was based on an investigation of the most dominant frequency generated while conducting an experimental test.

6. The ARX model and least square (LS) estimation method was used in the system modelling for the active handheld device.

## 1.6 Research Contributions

This research has arisen several contributions as follows:

1. Novelty in designing the passive tremor writing device (TREMORX) and the active device.

2. The design and fabrication of a test-rig that was able to resemble the actual behaviour of the tremor patient while performing the handwriting task.

3. The implementation of Active Assistive Writing Device incorporated with the conventional control scheme (PID) controller with artificial intelligent control ( GA and PSO) techniques were included in this research to optimise the parameters of the controller. The simulation and real-time implementation of the controller technique was investigated. A comparative assessment of the performance of the techniques in terms of coherence level of vibration reduction and time response specifications was presented.

## 1.7 Methodology of the Study

Figure 1.2 depicts the research strategies flowchart in conducted in this research study. First, an introduction as well as a literature study will be present. This literature review will discuss on the human hand tremor, classification and measure of involuntary hand tremor. This literature section will describe the previous researches done in developing a passive device and also the modelling system of an active device. Finally, an attempt was made to come out with the problem statement.

This research also made use of both hardware and software. For hardware, the selection of a suitable transducer had been made in order to measure the tremor data under several considerations in terms of cost, physical specification, reliability, and sensitivity. A circuit driver was designed and fabricated to drive the transducer linked to the computer base. This selective transducer and the driver will be tested to the actual hand tremor to validate the performance.

The fabricated devices had been made and to validate their performance, the passive devices were tested with the tremor patients and several conditions had been made by assisting the respondents to perform writing tasks in the seating and standing postures. Also, for active writing device, an appropriate actuator needed to be configured. The actuator must have enough block force to oppose the tremor from the hand by means to eliminate the unwanted signal.

The active tremor device will experiment on a test-rig that was able to resemble actual tremor handwriting. For the active tremor device, the data measured from the device's performance during the experiment by injecting the PID controller parameters determine through simulation works based on implementation of GA and PSO optimisation.

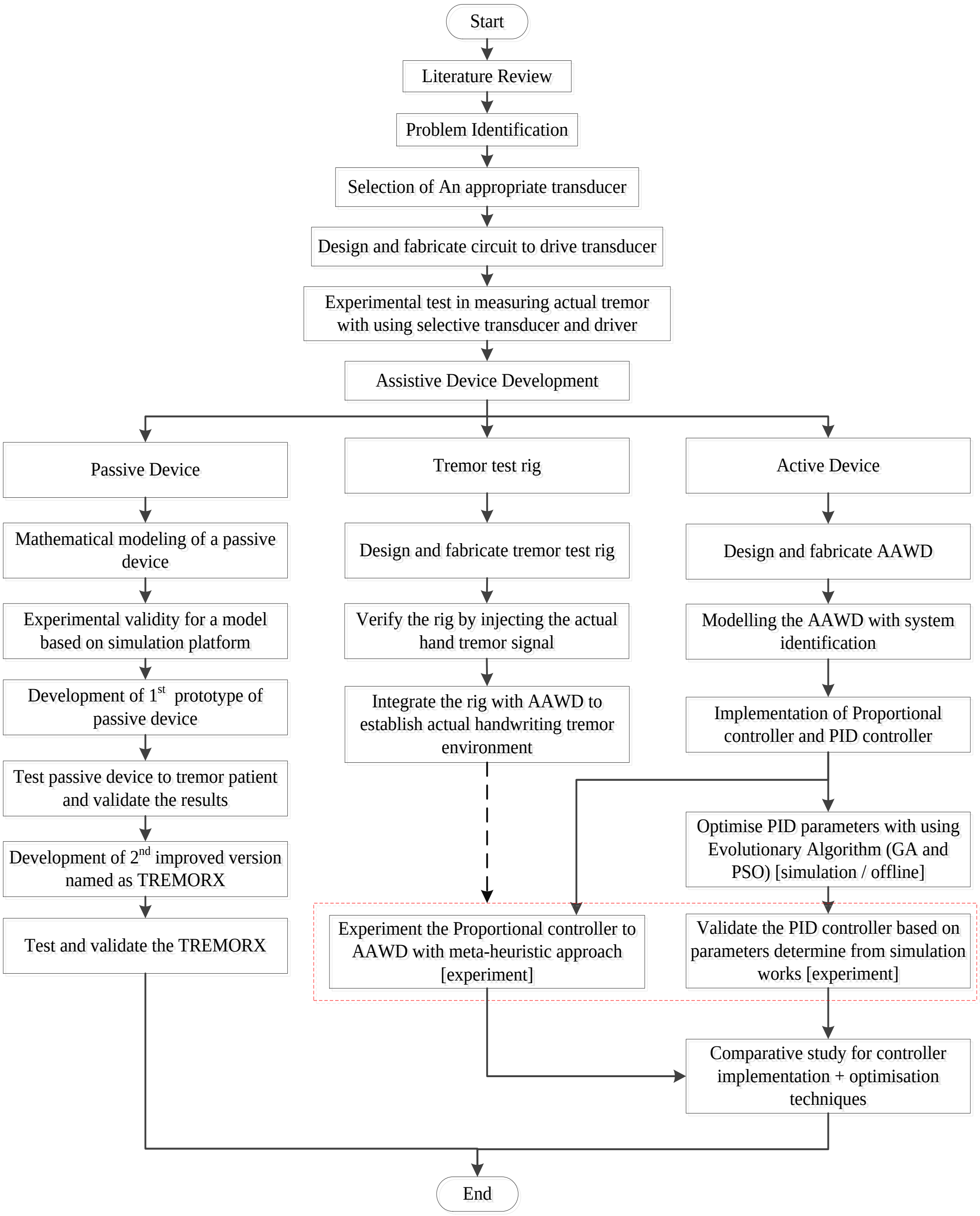


**Figure 1.2:** Research strategies flowchart

## 1.8 Organisation of the Thesis

This thesis is divided into 6 chapters. A brief introduction of each chapter in this thesis is presented as follows:

**Chapter 1** presents an overview of the research problem. It involves the background and problem statement of the research. The objectives of the study and contributions are also mentioned. The methodology and organisation of the thesis are described in this chapter.

**Chapter 2** is devoted to a literature study of the human hand tremor including the types of tremor, medication and implication, and also a brief description about the behaviours. Then, the chapter moves on to discuss about previous researches conducted in developing biomechanical devices that aimed to prevent hand tremor interruptions while performing hand activities. The transducer and actuator used in these studies are discussed. The biomechanical devices that comprised of existing passive device and active device will also be addressed in this chapter.

**Chapter 3** The active tremor device will experiment on a test-rig that was able to resemble actual tremor handwriting. For the active tremor device, the data measured from the device's performance during the experiment by injecting the PID controller parameters determine through simulation works based on implementation of GA and PSO optimisation.

**Chapter 4** The active tremor device will experiment on a test-rig that was able to resemble actual tremor handwriting. For the active tremor device, the data measured from the device's performance during the experiment by injecting the PID controller parameters determine through simulation works based on implementation of GA and PSO optimisation.

**Chapter 5** The active tremor device will experiment on a test-rig that was able to resemble actual tremor handwriting. For the active tremor device, the data measured from the device's performance during the experiment by injecting the PID controller

## REFERENCES


Adeli, H. and Cheng, N. T. (1993). Augmented Lagrangian Genetic Algorithm for Structural Optimization. *Journal of Aerospace Engineering*, 6 (4): 315-328.

Aguilar, L. G., Davidson, A., Jankovic, J., & Ondo, W. G. (2008). Characteristics of Archimedean spiral drawings in patients with psychogenic tremor. Retrieved From https://www.bcm.edu/departments/neurology/pdf/poster_ pdcmdc_ Archim edeanSpiralPsychogenicTremor.pdf

Alander, J. T. (1992). On Optimal Population Size of Genetic Algorithms. CompEuro '92 .*Proceedings in Computer Systems and Software Engineering*, May 4-8. The Hague, Netherlands: IEEE, 65-70.

Aldebrez, F. M., Alam, M. S. and Tokhi, M. O. (2005). Input-Shaping with GATuned PID for Target Tracking and Vibration Reduction. *Proceedings of the International Symposium on Intelligent Control & 13th Mediterranean Conference on Control and Automation*, Limassol (Cyprus). 27-29 June 2005. 485-490

Altınten, A., Ketevanlioğlu, F., Erdoğan, S., Hapoğlu, H. and Alpbaz, M. (2008). Self-tuning PID Control of Jacketed Batch Polystyrene Reactor using Genetic Algorithm. *Chemical Engineering Journal*, 138 (1–3): 490-497.

Ang, W. T., Khosla, P. K., & Riviere, C. N. (2003). Design of All-Accelerometer Inertial Measurement Unit for Tremor Sensing in Hand-held Microsurgical Instrument. In *IEEE International Conference on Robotics and Automation* (pp. 1781–1786).

As'arry, A. (2007*). Intelligent Active Force Control of Human Hand Tremor using Smart Actuator*. Universiti Teknologi Malaysia, Malaysia. Master Thesis.

Astrom, K. J. and Hagglund, T. (1988). *Automatic Tuning of PID Controllers:* Instrument Society of America.

Astrom, K. J. and Hagglund, T. (1995*). PID Controllers: Theory, Design, and Tuning:* Instruments Society of America.Åström, K. J. and Wittenmark, B. (1973). On Self Tuning Regulators. *Automatica*, 9 (2): 185-199.

Åström, K. J., and Eykhoff, P. (1971). System identification—A survey. *Automatica*, 7(2), 123–162.

Astrom, K. J., Hagglund, T., Hang, C. C. and Ho, W. K. (1993). Automatic Tuning and Adaptation for PID Controllers - A Survey. *Control Engineering Practice,* 1 (4): 699-714.

Badie Sharkawy, A. (2010). Genetic Fuzzy Self-tuning PID Controllers for Antilock Braking Systems. *Engineering Applications of Artificial Intelligence*, 23 (7): 1041-1052.

Baur, B., Schenk, T., Frholzer, W., Scheuerecker, J., Marquardt, C., Kerkhoff, G., & Hermsdrfer, J. (2006). Modified pen grip in the treatment of Writer's Cramp. *Human Movement Science*, 25(4-5), 464–473.

Becker, B. C., Tummala, H., and Riviere, C. N. (2008). Autoregressive Modeling of physiological tremor under microsurgical conditions. In *Conference proceedings : Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference* (Vol. 2008, pp. 1948–1951).

Billings, S. A. (1983). Identification of nonlinear Systems, *Research report no. 232*, Department of Automatic Control and Systems Engineering, The University of Sheffield, UK.

Billings, S. A. and Voon, W. S. F. (1986). Correlation Based Model Validity Tests for Non-linear Models. *International Journal of Control*, 44 (1): 235-244.

Billings, S. A., Jamaluddin, H. B. and Chen, S. (1992). Properties of Neural Networks with Applications to Modelling Non-linear Dynamical Systems. *International Journal of Control*, 55 (1): 193-224.

Chambers, L. D. (1995). *Practical Handbook of Genetic Algorithms:* CRC Press, Inc.

Charles, P. D., Esper, G. J., Davis, T. L., Maciunas, R. J., and Robertson, D. (1999). Classification of tremor and update on treatment. *American Family Physician*, 59(6), 1565–1572.

Clerc, M. (1999). The Swarm and the Queen: Towards a Deterministic and Adaptive Particle Swarm Optimization. *Evolutionary Computation*, 1999. CEC 99. *Proceedings of the 1999 Congress* on. 1999. 1951-1957.

Crowin Brown. (2008). Hand Tremor - Causes and Symptoms of Hand Tremor. Retrieved from http://ezinearticles.com/?Hand-Tremor---Causes-and-Symptoms-of-Hand-Tremor&id=1105959

De Moura Oliveira, P. B. (2005). Modern Heuristics Review for PID Control Optimization: a Teaching Experiment. *Proceeding of International Conference on Control and Automation*, Budapest, Hungary. 26-29 June 2005. 828-833.

Diaz-Gomez, P. A. and Hougen, D. F. (2007). Initial Population for Genetic Algorithms: A Metric Approach. *Proceedings of the 2007 International Conference on Genetic and Evolutionary Methods*, June 25-28, Las Vegas, Nevada, USA: 43-49.

Eberhart, R. C. and Shi, Y. (2001). Tracking and Optimizing Dynamic Systems with Particle Swarms. *Evolutionary Computation*, 2001. *Proceedings of the 2001 Congress* on. May 27-30. Seoul: IEEE, 94-100.

EBME. (2014). Electromyography. Retrieved from http://www.ebme.co.uk/articles/ Clinical-engineering/30-electromyography-emg

Gao, J. B. (2004). Analysis of amplitude and frequency variations of essential and Parkinsonian tremors. *Medical and Biological Engineering and Computing*, 42(3), 345–349.

Graham, B. B. (2000). *Using an Accelerometer Sensor to Measure Human Hand Motion. Electronics.* Massachusetts Institute of Technology. Bachelor Thesis.

Graham, S., and Weintraub, N. (1996). A review of handwriting research: Progress and prospects from 1980 to 1994. *Educational Psychology Review,* 8(1), 7–87.

Guessas, L. and Benmahammed, K. (2011). Adaptive back stepping and PID Optimised by Genetic Algorithm in Control of Chaotic. *International Journal of Innovative Computing, Information and Control,* 7 (9): 5299-5312.

H2W Technologies, I. (2008). Moving Magnet Non-Comm DC Voice Coil Linear Actuator - NCM02-10-012-2JB. Available at: http://www.h2wtech.com/

Harik, G. R. and Lobo, F. G. (1999). A Parameter-less Genetic Algorithm. *IEEE Transactions on Evolutionary Computation.* 258-265.

Hasançebi, O. and Erbatur, F. (2000). Evaluation of Crossover Techniques in Genetic Algorithm Based Optimum Structural Design. *Computers and Structures*, 78 (1–3): 435-448.

Hassan, M. F., Mailah, M., Junid, R., and Alang, N. A., (2010). Vibration suppression of a handheld tool using intelligent Active Force Control (AFC). In *WCE 2010 - World Congress on Engineering 2010* (Vol. 2, pp. 1636–1641).

Hassan, M. K., Azubir, N. A. M., Nizam, H. M. I., Toha, S. F. and Ibrahim, B. S. K. K. (2012). Optimal Design of Electric Power Assisted Steering System (EPAS) Using GA-PID Method. *Procedia Engineering,* 41: 614-621

Hellwig, B., Mund, P., Schelter, B., Guschlbauer, B., Timmer, J., and Lücking, C. H. (2009). A longitudinal study of tremor frequencies in Parkinson's disease and essential tremor. *Clinical Neurophysiology,* 120(2), 431–435.

Holland, J. H. (1975). *Adaptation in Natural and Artificial Systems:* University of Michigan Press.

Hunker, C. J., and Abbs, J. H. (1990). Uniform frequency of parkinsonian resting tremor in the lips, jaw, tongue, and index finger. *Movement Disorders : Official Journal of the Movement Disorder Society*, 5(1), 71–7.

Hussein , M., As ' arry , A., Zain, MZ. Md ., and Mailah, M. (2009). Experimental Study of Human Hand-arm Model Response. In *6th International Symposium on Mechatronics and its Applications (ISMA)* (pp. 427–432).

Huusom, J. K., Poulsen, N. K., Jørgensen, S. B., and Jørgensen, J. B. (2010). ARX-model based model predictive control with offset-free tracking. *Computer Aided Chemical Engineering*, 28(C), 601–606.

Jadhav, A. M. and Vadirajacharya, K. (2012). Performance Verification of PID Controller in an Interconnected Power System Using Particle Swarm Optimization. *Energy Procedia*, 14 (0): 2075-2080.

Jain, T. and Nigam, M. J. (2008). Optimisation of PD-PI Controller Using Swarm Intelligence. *Journal of Theoretical and Applied Information Technology*, 4 (11): 1013-1018.

Kadefors, R., Areskoug, A., Dahlman, S., Kilbom, A., Sperling, L., Wikström, L., and Öster, J. (1993). An approach to ergonomics evaluation of hand tools. *Applied Ergonomics*, 24(3), 203–211.

Kantha, A. S., Utkarsh, A., and Kumar, J. R. (2015). Hybrid genetic algorithm-swarm intelligence based tuning of continuously stirred tank reactor. *9th International Conference on Industrial and Information Systems, ICIIS 2014*. 1-6.

Kanthalakshmi, S. and Manikandhan, V. (2010). Genetic Algorithm Based Self Tuning Regulator. *International Journal of Engineering Science and Technology*, 2 (12): 7719-7728.

KDS model USA, (2015). KDS N300 servo for kds innova 450BD/SD helicopter model. Available at http://www.kdsmodelsusa.com/KDS-N300-SERVO-for-KDS-INNOVA-450BD-SD-Helicopter-p/kds-n300.htm

Kennedy, J. (2006). In Search of the Essential Particle Swarm. *Evolutionary Computation*, 2006. *CEC 2006. IEEE Congress on*. Vancouver, BC: IEEE, 1694-1701.

Kenney, C., Diamond, A., Mejia, N., Davidson, A., Hunter, C., & Jankovic, J. (2007). Distinguishing psychogenic and essential tremor. *Journal of the Neurological Sciences*, 263(1-2), 94–99.

Kim, T.-H., Maruta, I. and Sugie, T. (2008). Robust PID Controller Tuning Based on the Constrained Particle Swarm *Optimization. Automatica,* 44 (4): 11041110.

Kistler. (2007). *Accelerometer Calibrator Type 8921*. Available at http://www.kistler.com/PE_enex/13_Productfinder/App.8921Y26.7/Reference-shaker.html (accessed: November 16, 2011).

Kotovsky, J. and Rosen, M. J. (1998). A Wearable Tremor-suppression Orthosis. *Journal of Rehabilitation Research and Development,* 35 (4): 373-387.

Kotovsky, J., and Rosen, M. J. (1998). A wearable tremor-suppression orthosis. *Journal of Rehabilitation Research and Development,* 35(4), 373–387.

Lai, L. T. (2009). *World Parkinson's Day 2009 - Speech of Minister of Health* Available at: http://www.lloydtan-trust.com/index.php?page=events _sub&type=event_2_3 (accessed: 3 August 2012).

Lee, C.H. and Chang, F.K. (2010). Fractional-order PID Controller Optimization via Improved Electromagnetism-like Algorithm. *Expert System Application*, 37 (12): 8871-8878.

Lind, M., Kallio, P. and Koivo, H. N. (1998). Linear Motion Miniature Actuators. *The 2nd Tampere International Conference on Machine Automation.* September 15 -18. Tampere, Findland.

Liu, W., Chung, I.-Y., Liu, L., Leng, S. and Cartes, D. A. (2011). Real-time Particle Swarm Optimization based Current Harmonic Cancellation. *Engineering Applications of Artificial Intelligence,* 24 (1): 132-141.

Ljung, L., and Shina, N. K. (1989). System Identification Theory for User. *Automatica*, 25(3), 475–476.

Loureiro, R. C. V, Belda-Lois, J. M., Lima, E. R., Pons, J. L., Sanchez-Lacuesta, J. J., and Harwin, W. S. (2005). Upper limb tremor suppression in ADL via an orthosis incorporating a controllable double viscous beam actuator. In *Proceedings of the IEEE 9th International Conference on Rehabilitation Robotics* (Vol. 2005, pp. 119–122).

Loureiro, R. C. V., Belda-Lois, J. M., Lima, E. R., Pons, J. L., Sanchez-Lacuesta, J. J., and Harwin, W. S., (2005). Upper Limb Tremor Suppression in ADL via an Orthosis Incorporating a Controllable Double Viscous Beam Actuator. *IEEE 9th International Conference on Rehabilitation Robotics (ICORR 2005),* June 28 - July 1. USA: IEEE, 119 - 122.

Man, K. F., Tang, K. S. and Kwong, S. (1996). Genetic Algorithms: Concepts and Applications [in Engineering Design]. Industrial Electronics, *IEEE Transactions on*, 43 (5): 519-534.

Maneski, L. P., Jorgovanovi, N., Ili, V., Doen, S., Keller, T., Popovi, M. B., & Popovic, D. B. (2011). Electrical stimulation for the suppression of pathological tremor. *Medical and Biological Engineering and Computing*, 49(10), 1187–1193.

Manto, M., Rocon, E., Pons, J., Belda, J. M., and Camut, S. (2007). Evaluation of a Wearable Orthosis and an Associated Algorithm for Tremor Suppression. *Physiological Measurement*, 28 (4): 415 - 425.

Manto, M., Topping, M., Soede, M., Sanchez-Lacuesta, J., Harwin, W., Pons, J., Williams, J., Skaarup, S., and Normie, L. (2003). Dynamically Responsive Intervention for Tremor Suppression. *IEEE Engineering in Medicine and Biology Magazine*, 22 (3): 120 - 132.

Michalewicz, Z. (1996). *Genetic Algorithms + Data Structures = Evolution Programs:* Springer, New York, USA.

Miller, B. L. and Goldberg, D. E. (1995). Genetic Algorithms, Tournament Selection, and the Effects of Noise. *Complex Systems*, 9 (3): 193-212.

Miotto, G. A., Andrade, A. O., and Soares, A. B. (2007). Measurement of tremor using digitizing tablets. In *V Conferencia de Estudos em Engenharia Eletrica (CEEL)*.

Morrison, S., Kerr, G., and Silburn, P. (2008). Bilateral tremor relations in Parkinson's disease: Effects of mechanical coupling and medication. *Parkinsonism and Related Disorders*, 14(4), 298–308.

Naritomi, K. (2009). *Design and Production of Tremor Pen*. California State University, Sacramento.

National Instruments. (2008*). NI PCI-6259*. Available at: http://sine.ni.com/nips/cds/print/p/lang/en/nid/14128 (accessed: November 16, 2011).

Nize, T. A. C., Broeders, M. E. A. C., & Folgering, H. T. M. (2004). Tremor side effects of salbutamol, quantified by a laser pointer technique. *Respiratory Medicine*, 98, 844–850.

Panigrahi, B. K., Ravikumar Pandi, V. and Das, S. (2008). Adaptive Particle Swarm Optimization Approach for Static and Dynamic Economic Load Dispatch. *Energy Conversion and Management*, 49 (6): 1407-1415.

Pellegrini, B., Faes, L., Nollo, G., and Schena, F. (2004). Quantifying the contribution of arm postural tremor to the outcome of goal-directed pointing task by displacement measures. *Journal of Neuroscience Methods*, 139(2), 185–193.

Quanser Consulting. (2002*). Linear Current Amplifier Module.* Available at: http://quanser.com/english/html/solutions/power_units_LCAM.asp (accessed: November 16, 2012).

Rajesh, R. J., and Kavitha, P. (2016). Camera gimbal stabilization using conventional PID controller and evolutionary algorithms. *IEEE International Conference on Computer Communication and Control, IC4 2015*, 1–6.

Rakheja, S., Wu, J. Z., Dong, R. G. and Schopper, A. W. (2002). A Comparison of Biodynamic Models of the Human Hand-arm System for Applications to Hand-held Power Tools. *Journal of Sound and Vibration* 249 (1): 55-82.

Ramli, M. S., and Rahmat, M. F. (2008). Servomotor Control Using Direct Digital Control and State Space Technique. *Jurnal Teknologi*, 49(D), 45–60.

Rao, K. S., and Mishra, R. (2014). Comparative study of P, PI and PID controller for speed control of VSI-fed induction motor. *International Journal of Engineering Development and Research*, *2*(2), 2321–9939.

Reeves, C. R. (1995). *Modern Heuristic Techniques for Combinatorial Problems*. London: McGraw-Hill.

Rissanen, S. M., Kankaanpää, M., Meigal, A., Tarvainen, M. P., Nuutinen, J., Tarkka, I. M., and Karjalainen, P. A. (2008). Surface EMG and acceleration signals in Parkinson's disease: Feature extraction and cluster analysis. *Medical and Biological Engineering and Computing*, 46(9), 849–858.

Salarian, A., Russmann, A., Vingerhoets, H., Dehollain, F.J.G., Blanc, C., Burkhard, Y., and Aminian, P.R. (2003). An ambulatory system to quantify bradykinesia and tremor in Parkinson's disease. In *4th Annual IEEE Conf on Information Technology Applications in Biomedicine* (pp. 1434–1443).

Saravanakumar, G., Wahidhabanu, R. S. D. and George, V. I. (2006). Robustness and Performance of Modified Smith Predictors for Processes with Longer Dead-Times. *International Journal on Automatic Control and System Engineering*, 6 (3): 41-46.

Shaheed, M. H., & Tokhi, M. O. (2002). Dynamic modelling of a single-link flexible manipulator: parametric and non-parametric approaches. *Robotica*, 20(1), 93–109.

Shi, Y. and Eberhart, R. (1998). A Modified Particle Swarm Optimizer. IEEE *International Conference on Evolutionary Computation*, May 4-9, Anchorage Alaska: IEEE, 69-73.

Shi, Y. and Eberhart, R. C. (1999). Empirical Study of Particle Swarm Optimization. *Evolutionary Computation,* 1999. CEC 99. Proceedings of the 1999 Congress on Vol. 3. July 6-9. Washington, DC: IEEE, 1945-1950.

Siores, E. and Swallow, L. (2006). *Apparatus for the Detection and Suppression of Muscle Tremor.* U. K. Patent. GB2,444,393.

Smaga, S. (2003). *Tremor. American Family Physician*, 68(8), 1545–1553.

Soderstrom, T., & Stoica P. (1989*). System Identification*. Prentice-Hall Englewood Cliffs,.

Swallow, L. and Siores, E. (2009). Tremor Suppression Using Smart Textile Fibre Systems. *Journal of Fiber Bioengineering and Informatics,* 1 (4): 261 - 266.

Tracy, T. (2009). *Vibration reducing pen for people with tremors*. Sacramento: California State University, Davis. Master Thesis.

Vaillancourt, D. E., and Newell, K. M. (2000). The dynamics of resting and postural tremor in Parkinson's disease. *Clinical Neurophysiology,* 111(11), 2046–2056.

Wakasa, Y., Tanaka, K., Akashi, T. and Nishimura, Y. (2010). PSO Based Simulteneous Tuning Method for PID Controllers and Dead-Zone Compensator and its Application to Ultrasonic Motors. *International Journal of Innovative Computing, Information and Control,* 6 (10): 4593-4604

Wilson, S. S. (2005). Understanding the PRBS signal as an optimum input signal in the wavelet-correlation method of system identification using multiresolution analysis. In *Conference Proceedings - IEEE Southeastcon* (pp. 39–44).

Wu, F. G., and Luo, S. (2006). *Design and evaluation approach for increasing stability and performance of touch pens in screen handwriting tasks. Applied Ergonomics* (Vol. 37).

Zain, M. Z. M. (2005). *Modelling and Intelligent Control of Flexible-link Manipulators.* University of Sheffield. PhD Thesis

Zain, B. A. M., Tokhi, M. O. and Toha, S. F. (2009). PID-based Control of a Single-Link Flexible Manipulator in Vertical Motion with Genetic Optimisation. *Third UKSim European Symposium on Computer Modeling and Simulation,* Athens, Greece 25-27 Nov. 2009 355-360.

Zhang, D., Poignet, P., Widjaja, F. and Tech Ang, W. (2011). Neural Oscillator Based Control for Pathological Tremor Suppression via Functional Electrical Stimulation. *Control Engineering Practice*, 19 (1): 74-88. Zhao

Zhao, S. Z., Iruthayarajan, M. W., Baskar, S. and Suganthan, P. N. (2011). Multi-objective Robust PID Controller Tuning using two lbests Multi-objective Particle Swarm Optimization. *Information Sciences,* 181 (16): 3323-3335.