RESPONSE SURFACE AND NEURO FUZZY METHODOLOGY FOR ROTATING MAGNETIC FIELD AND GMR ARRAY SENSOR FOR CRACK DETECTION IN FERROMAGNETIC PIPE

DAMHUJI BIN RIFAI

Doctor of Philosophy

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Electrical Engineering.

_____

(Supervisor's Signature)

Full Name : Dr Hadi Bin Manap

Position : Senior Lecturer

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_____

(Student's Signature)

Full Name :Damhuji Bin Rifai

ID Number : PEE 14005

Date :

RESPONSE SURFACE AND NEURO FUZZY METHODOLOGY FOR ROTATING MAGNETIC FIELD AND GMR ARRAY SENSOR FOR CRACK DETECTION IN FERROMAGNETIC PIPE

DAMHUJI BIN RIFAI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Engineering Technology

UNIVERSITI MALAYSIA PAHANG

JULY 2017

ACKNOWLEDGEMENTS

All praise to Allah for giving me the inner strength in completing the thesis. I am grateful and would like to express my sincere gratitude and appreciation to my supervisor, Associate Professor Dr. Ahmed N. Abdalla and Dr. Hadi Bin Manap for their support, invaluable guidance and continuous encouragement throughout this research. Besides, he has offered me invaluable helps in writing and publishing the research works..

My sincere thanks to my entire member staff at the Faculty of Electrical and Automation Engineering Technology at TATIUC for their help and support especially to Kharudin Ali, Mohd Tarmizi Ibrahim and Ruzlaini Ghoni.

I am obliged to all my family, especially my wife, Nurul Izzah Mohd Shah,my son, Muhammad Aqil and Muhammad Hakim my mother for their sacrifice, patience and understanding that were inevitable to make this research possible.

I also acknowledge TATIUC for supporting this work by short grant No. 9001-150 and for the lab equipment supported through Sensor Technology Lab.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C_i	Centre of the Gaussian Membership Functions
σ_i	Width of the Gaussian Membership Functions
^oC	Degree Celsius
μ	Conducting Material Permeability
$\mathring{A}$	Angstrom
a	Tuning Parameter
B	Vector of Tuning Parameters
I	Current
K	Kelvin
L	Inductance
R	Resistance
V	Voltage
X	Value of Design Variable
x_i	Design Parameter
Y	Vector of Observations
θ	Angle
σ	Conducting Material Conductivity
ω	Angular Frequency
B_θ	Azimuth Magnetic Field
B_r	Radial Magnetic Field

LIST OF ABBREVIATIONS

VT	Visual testing
AE	Acoustic emission
ANFIS	Adaptive neuro-fuzzy inference system
ANN	Artificial neural network
CNC	Computer numerical control
Cr	Cuprum
CTS	Copper tubing size
DAQ	Data acquisition
DC	Direct current
DSECT	Distributed System for Eddy Current Testing
ECT	Eddy current testing
Fe	Ferum
FEM	Finite element model
GMR	giant magneto resistance
MBE	Minimum bias estimator
MFL	Magnetic flux leakage
MRPC	Motorized rotating probe coil
MRPC	Motorized rotating probe coil
MSE	Mean squared error
MT	Magnetic particle testing
NDT	Destructive testing
NDT	Non-destructive testing
PT	Penetrant testing
PVC	Poly vinyl chloride
RPC	Rotating pancake coil
RSM	Response surface methodology
RT	Radiographic testing
RT	Radiographic testing
USB	Universal serial bus
UT	Ultrasonic testing

RESPONSE SURFACE AND NEURO FUZZY METHODOLOGY FOR ROTATING MAGNETIC FIELD AND GMR ARRAY SENSOR FOR CRACK DETECTION IN FERROMAGNETIC PIPE

DAMHUJI BIN RIFAI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Engineering Technology

UNIVERSITI MALAYSIA PAHANG

JULY 2017

ABSTRAK

Saluran paip digunakan untuk mengangkut minyak dan gas di dalam industri petroleum. Walaupun paip adalah lebih murah daripada lain-lain cara pengangkutan, penjimatan kos ini datang dengan risiko yang tinggi. Saluran paip adalah terdedah kepada kecacatan dan kakisan yang boleh menyebabkan kebocoran minyak dan gas yang seterusnya menyebabkan pencemaran dan kerosakan pada alam sekitar. Tumpahan minyak dan kebocoran gas serta kesannya pada alam sekitar menjadi kebimbangan yang utama di dalam industri minyak dan gas. Pemeriksaan berkala yang bertujuan untuk pengesanan awal terhadap kemerosotan struktur mekanikal saluranpaip adalah bagi memastikan integriti saluran paip dan operasi yang selamat. Ujian Arus Eddy (ECT) telah terbukti menjadi satu teknik yang berkesan untuk mengesan kecacatan yang berlaku di dinding paip. Dalam tempoh dua dekad yang lalu, tiga jenis Ujian Arus Eddy dibangunkan untuk pemeriksaan paip iaitu Kuar Gegelung Bobbin, Kuar Berputar dan Kuar Berjajar. Setiap satu daripada probe ini mempunyai kekurangannya. Kuar Gegelung Bobbin tidak sensitif kepada keretakan lilitan dan Kuar Berputar adalah perlahan dan melibatkan putaran mekanikal yang kompleks manakala Kuar Berjajar mempunyai resolusi yang rendah dan kos peralatan yang tinggi. Kajian ini membentangkan reka bentuk prob untuk ujian ECT baru. Prinsip operasi prob ECT yang dicadangkan adalah berdasarkan arus pusar yang terhasil di dalam sampel ujian dan gangguan medan magnet yang disebabkanolpenjalanan dan mengukur geh kecacatan. Sensor magnet berintangan besar (GMR) digunakan untuk mengukur medan magnet yang teraruh. Kuar ECT yang direka adalah terdiri daripada belitan tiga fasa yang berbentuk segi empat tepat dan jujukan sensor GMR yang diletakkan disekeliling kuar. Kuar ECT yang direka mempunyai kelajuan imbasan cepat dan sensitif kepada semua jenis kecacatan. Kecekapan kuar ECT yang direka adalah dipengaruhi oleh faktor rekabentuk seperti ketebalan gegelung pengujaan, bilangan sensor GMR yang digunakan, frekuensi arus tiga fasa yang digunakan untuk pengujaan gegelung dan diameter prob yang digunakan. Parameter ini mempengaruhi ketepatan kuar ECT mengesan kecacatan semasa pemeriksaan paip. Kaedah tindak balas permukaan (RSM) dan Adaptive Neuro-Fuzzy Inference Systems (ANFIS) digunakan untuk membangunkan model sistem ini. Pengoptimuman reka bentuk dilakukan untuk mendapatkan ketepatan yang tinggi semasa pengujian paip besi karbon dengan diameter 70 mm dengan menggunakan bilangan GMR sensor yang sedikit, ketebalan gegelung pengujaan dan diameter prob berada pada julat rekabentuk. Sistem ujian arus eddy (DSECT) dibangunkan untuk menilai kecekapan probe yang direka dalam pengujian kecacatan pada paip. Reka bentuk kuar disahkan menggunakan model Finite Element. Prototaip kuar ECT dibina untuk mengesahkan keputusan simulasi berkenaan dengan menggunakan kecacatan jenis paksi dan lilitan. Kuar yang direka mempunyai kelajuan imbasan yang tinggi. Hasil ujikaji menunjukkan reka bentuk kuar yang dibangunkan mempunyai ketepatan pengimbasan yang tinggi iaitu lebih dari 85 %. Perbandingan peratus perbezaan kesalahan adalah kurang dari 2%. Keputusan ini menunjukkan kebolehan kuar yang dicadangkan dalam mengesan kecacatan di dalam paip karbon besi.

ABSTRACT

Pipelines are used to transport oil and gas in oil and gas industry. While pipes are cheaper than other means of transportation, this cost saving comes with a major price. Pipes are subject to defect and corrosion which in turn can cause leakage and environmental damage. Oil spills, gas leaks and their associated environmental problems has become a serious and major concern in the oil and gas industry. Periodic inspections aimed at timely detection and characterization of the degradation is a key element for ensuring pipeline integrity and safe operation. Eddy current testing has proved to be an effective technique to detect defects occurring in the pipe wall. In the past two decades, three types eddy current probes developed for pipe inspection include bobbin coil probe, rotating probe and array probe. Each of these probes has their own limitations. The bobbin coil probe is insensitive to circumferential cracks, and rotating probe is slow and involves complex mechanical rotation whereas the array probe has poor resolution and high cost of instrumentation. This study presents the design and validation of a new eddy current testing (ECT) probe. The operating principles of the probe is based on inducing eddy currents in the conducting test sample and measuring the perturbations in induced magnetic fields associated with the eddy currents. The sensor system utilizes a very low frequency rotating current excitation that is sensitive to deep embedded cracks of all orientations. An array of Giant Magnetoresistance (GMR) sensors are used to measure the induced fields. The probe is composed of three phase rectangular windings and array of GMR pickup sensor placed around the probe. The probe avoids mechanical rotation and has fast scan speed. The rotating field probe is sensitive to all orientation defects. The axial component of magnetic field along the carbon steel pipe due to a defect is measured by the pickup sensor. For rotating the magnetic ECT probe design, the sensitivity and efficiency of defect detection are essentially determined by the thickness of the excitation coil, the number of GMR sensors in the array sensor, the frequency of the three phase alternating current for the coil excitation, the diameter of the probe design that affect the distance of the lift-off during the inspection. This design parameter influences the level of accuracy of the detection of a defect during the inspection of a pipe. The Response Surface Methodology (RSM) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) is used to model the system and desirability function method to optimize the parameter probe design. The optimization was carried out in order to design and fabricate DSCET probe for optimum defect detection in 70 mm diameter carbon steel pipe by using a minimum number of GMR sensor, in range of excitation coil thickness and diameter of the ECT probe for optimum response of the axial and circumference defects detection. Distributed System for Eddy Current Testing (DSECT) is developed for evaluation of the probe design in pipe defect inspection. The probe design and performance are evaluated using an experimental validated finite element model. A probe prototype is built to validate the simulation results with respect to axial and circumference defects. The probe avoids mechanical rotation and has fast scan speed. Experimental result show the accuracy of the probe design inspection is more than 85% for size of defect 1.5 mm x 11.5 mm. While the comparison of predicted and experimental inspection results show a close agreement where percentage error is less than 2%. This results show the feasibility of proposed probes to detect a variety of defect in carbon steel pipe.

REFERENCES

Abidin, I., Umar, M., & Yusof, M. (2000). Advantages and Applications of Eddy Current Thermography Testing for Comprehensive and Reliable Defect Assessment. *Proceedings of 18th World Conference on Nondestructive Testing*, 16–20.

Acherjee, B., Kuar, A. S., Mitra, S., & Misra, D. (2012). Modeling and analysis of simultaneous laser transmission welding of polycarbonates using an FEM and RSM combined approach. *Optics and Laser Technology*, *44*(4):995–1006.

Adoko, A. C., & Wu, L. (2011). Fuzzy inference systems-based approaches in geotechnical engineering- a review. *Electronic Journal of Geotechnical Engineering*, *16:*1543–1558.

Aguila-Munoz, J., Espina-Hernandez, J. H., Perez-Benitez, J. a., Caleyo, F., & Hallen, J. M. (2013). Crack detection in steel using a GMR-based MFL probe with radial magnetization. *CONIELECOMP 2013, 23rd International Conference on Electronics, Communications and Computing*, 104–108.

Ai, Q., Liu, C. X., Chen, X. R., He, P., & Wang, Y. (2010). Acoustic emission of fatigue crack in pressure pipe under cyclic pressure. In *Nuclear Engineering and Design* , 240,:3616–3620.

Al-Sarkhi, A., & Hanratty, T. J. (2002). Effect of pipe diameter on the drop size in a horizontal annular gas-liquid flow. *International Journal of Multiphase Flow*, *28*(10):1617–1629.

Alper, M., Attenborough, K., Hart, R., Lane, S. J., Lashmore, D. S., Younes, C., & Schwarzacher, W. (1993). Giant magnetoresistance in electrodeposited superlattices. *Applied Physics Letters*, *63*(15):2144.

Amineh, R. K., Sadeghi, S. H. H., & Moini, R. (2003). Suppressing sensor lift-off effects on cracks signals in surface magnetic field measurement technique. *IEEE International Conference on Industrial Technology*, 360–363.

Angani, C. S., Park, D. G., Kim, C. G., Leela, P., Kollu, P., & Cheong, Y. M. (2010). The Pulsed Eddy Current Differential Probe to Detect a Thickness Variation in an Insulated Stainless Steel. *Journal of Nondestructive Evaluation*, *29*(4):248–252.

Arjomandi, K., & Taheri, F. (2011). Stability and post-buckling response of sandwich pipes under hydrostatic external pressure. *International Journal of Pressure Vessels and Piping*, *88*(4), 138–148.

Arjun, V., Sasi, B., Chandra Rao, B. P., Mukhopadhyay, C. K., & Jayakumar, T. (2015). Optimisation of pulsed eddy current probe for detection of sub-surface defects in stainless steel plates. *Sensors and Actuators A: Physical*, *226*: 69–75.

Azizi, A. (2015). Investigating the controllable factors influencing the weight loss of

grinding ball using SEM/EDX analysis and RSM model. *Engineering Science and Technology, an International Journal*, *18*(2):278–285.

Baibich, M. N., Broto, J. M., Fert, A., & Van Dau, F. N. (1988). Giant magnetoresistance of (001) Fe/(001) Cr magnetic superlattices. *Physical Review Letters*, *61*(21):2472–2475.

Bernieri, A., Betta, G., Member, S., Ferrigno, L., & Laracca, M. (2004). An Automated Self-Calibrated Instrument for Nondestructive Testing on Conductive Materials, *53*(4): 955–962.

Bernieri, A., Betta, G., Member, S., Ferrigno, L., & Laracca, M. (2013). Improving Performance of GMR Sensors. *IEEE Sensors Journal*, *13*(11), 4513-4521.

Bhatti, M. S., Kapoor, D., Kalia, R. K., Reddy, A. S., & Thukral, A. K. (2011). RSM and ANN modeling for electrocoagulation of copper from simulated wastewater: Multi objective optimization using genetic algorithm approach. *Desalination*, *274*(1–3):74–80.

Biju, N., Ganesan, N., Krishnamurthy, C. V, & Balasubramaniam, K. (2013). Optimum frequency variations with coil geometry and defects in tone burst eddy current thermography (TBET). *Insight: Non-Destructive Testing and Condition Monitoring*, *55*(9), 504–509.

Birring, A. S. (1999). Selection of NDT Techniques for Inspection of Heat Exchanger Tubing Conventional Eddy Current. In *ASNT International Conference on Petroleum Industry Inspection*, 6:1–14.

Bouchalkha, A., Hamad, M. S., Al-Beloushi, K., Al-Qayedi, M., & Al-Hammadi, K. (2011). Design of an oil pipe inner surface inspection system. *2011 IEEE GCC Conference and Exhibition (GCC)*, 29–32.

Boyacioglu, M. A., & Avci, D. (2010). An adaptive network-based fuzzy inference system (ANFIS) for the prediction of stock market return: The case of the Istanbul stock exchange. *Expert Systems with Applications*, *37*(12):7908–7912.

Bubar, B. G. (2011). Welding and NDT. In *Pipeline Planning and Construction Field Manual* (pp. 357–378).

Cacciola, M., Megali, G., Pellicanó, D., & Morabito, F. C. (2011). A GMR–ECT based embedded solution for applications on PCB inspections. *Sensors and Actuators A: Physical*, *167*(1):25–33.

Cardoso, F. A., Rosado, L. S., Franco, F., Ferreira, R., Paz, E., Cardoso, S. F., … Freitas, P. J. P. (2014). Improved magnetic tunnel junctions design for the detection of superficial defects by eddy currents testing. *IEEE Transactions on Magnetics*, 50(11), 2–5.

Chao, W., Ya, Z., & Peng, G. (2013). GMR Based Eddy Current System for Defect Detection. *International Conference on Electronic Measurement & Instruments*

(ICEMI), 2:1052-1056.

Chen, B., Matthews, P. C., & Tavner, P. J. (2013). Wind turbine pitch faults prognosis using a-priori knowledge-based ANFIS. *Expert Systems with Applications*, *40*(17):6863–6876.

Chen, D.-W. C. D.-W., & Zhang, J.-P. Z. J.-P. (2005). Time series prediction based on ensemble ANFIS. *2005 International Conference on Machine Learning and Cybernetics*, *6*:18–21.

Chen, X., & Lei, Y. (2014a). Excitation current waveform for eddy current testing on the thickness of ferromagnetic plates. *NDT & E International*, *66*:28–33.

Chen, X., & Lei, Y. (2014b). Time-domain analytical solutions to pulsed eddy current field excited by a probe coil outside a conducting ferromagnetic pipe. *NDT & E International*, *68*: 22–27.

Chen, X., & Lei, Y. (2015). Electrical conductivity measurement of ferromagnetic metallic materials using pulsed eddy current method. *NDT & E International*, *75*:33–38.

Cordón, O. (2011). A historical review of evolutionary learning methods for Mamdani-type fuzzy rule-based systems: Designing interpretable genetic fuzzy systems. *International Journal of Approximate Reasoning*, *52*(6), 894-913.

Current, A. E., & Principle, T. (2012). Eddy Current Crack Extension Direction Evaluation based on Neural Network. *IEEE Sensors*, 1-4.

Daughton, J., Brown, J., Chen, E., Beech, R., Pohm, a., & Kude, W. (1994). Magnetic field sensors using GMR multilayer. *IEEE Transactions on Magnetics*, *30*(6):4608–4610.

Davoust, M.-È., Le Brusquet, L., & Fleury, G. (2010). Robust Estimation of Hidden Corrosion Parameters Using an Eddy Current Technique. *Journal of Nondestructive Evaluation*, *29*(3):155–167.

Dieny, B., Speriosu, V. S., & Metin, S. (1991). Thermal variation of the magnetoresistance of soft spin-valve multilayers. *Europhys. Lett.*, *15*, 227.

Diercks, D. (1996). Steam generator tube integrity program. *Nuclear Engineering and Design*, *165*(1–2): 143–149.

Dogaru, T., & Smith, S. T. (2001). Giant magnetoresistance-based eddy-current sensor. *IEEE Transactions on Magnetics*, *37*(5): 3831–3838.

Du, W., Dutt, A., & Scallion, K. (2010). Design of a GMR sensor array system for robotic pipe inspection. *IEEE Sensors*, 2551–2554.

Edalati, K., Rastkhah, N., Kermani, A., Seiedi, M., & Movafeghi, A. (2006). The use of radiography for thickness measurement and corrosion monitoring in pipes.

International Journal of Pressure Vessels and Piping, *83*(10):736–741.

Elshafiey, I., & Mohra, A. (2007). Evaluation Of Printed Circuit Board. *Journal of Circuits, Systems, and Computers*, *16*(6): 847–857.

Enokizono, M., Todaka, T., & Akita, M. (1993). Rotational Magnetic Flux Sensor with Neural Network for Non-destructive Testing, *29*(6):3195–3197.

Expert, D. (2005). Multifactor RSM Tutorial (Part 1 – The Basics) Response Surface Design and Analysis. *Design Expert 9: User's Guide*, 1–53.

Fan, M., Huang, P., Ye, B., Hou, D., Zhang, G., & Zhou, Z. (2009). Analytical modeling for transient probe response in pulsed eddy current testing. *NDT and E International*, *42*(5):376–383.

Foong, K. C., Chee, C. T., & Wei, L. S. (2009). Adaptive network fuzzy inference system (ANFIS) handoff algorithm. In *Proceedings - 2009 International Conference on Future Computer and Communication*, 195–198.

Freitas, P. P., Silva, F., Oliveira, N. J., Melo, L. V., Costa, L., & Almeida, N. (2000). Spin valve sensors. *Sensors and Actuators, A: Physical*, *81*(1):2–8.

Fukutomi, H., Takagi, T., & Nishikawa, M. (2001). Remote field eddy current technique applied to non-magnetic steam generator tubes. *NDT and E International*, *34*:17–23.

Gao, P., Wang, C., Li, Y., Li, F., & Yan, Y. (2014). Defect Evaluation Using the Phase Information of an EC-GMR Sensor. In *IEEE International Instrumentation and Measurement Technology Conference*, 25-29.

García-Martín, J., Gómez-Gil, J., & Vázquez-Sánchez, E. (2011). Non-destructive techniques based on eddy current testing. *Sensors (Basel, Switzerland)*, *11*(3): 2525–65.

George, J., Pereira, L., Barthélémy, A., Petroff, F., Steren, L., Duvail, J., … Schroeder, P. (1994). Inverse spin-valve-type magnetoresistance in spin engineered multilayered structures. *Physical Review Letters*, *72*(3):408–411.

Ghafari, E., Costa, H., & Júlio, E. (2014). RSM-based model to predict the performance of self-compacting UHPC reinforced with hybrid steel micro-fibers. *Construction and Building Materials*, *66*:375–383.

Ghafari, S., Aziz, H. A., Isa, M. H., & Zinatizadeh, A. A. (2009). Application of response surface methodology (RSM) to optimize coagulation-flocculation treatment of leachate using poly-aluminum chloride (PAC) and alum. *Journal of Hazardous Materials*, *163*(2–3): 650–656.

Ghoni, R., Dollah, M., Sulaiman, A., & Ibrahim, F. M. (2014). Defect Characterization Based on Eddy Current Technique : Technical Review. *Advances in Mechanical Engineering*, *6*: 182496.

Gotoh, Y., Matsuoka, A., & Takahashi, N. (2011). Electromagnetic Inspection Technique of Thickness of Nickel-Layer on Steel Plate Without Influence of Lift-Off Between Steel and Inspection Probe. *IEEE Transactions on Magnetics*, *47*(5):950–953.

Grimberg, R., Savin, a., Radu, E., & Chifan, S. M. (2000). Eddy current sensor for non-destructive evaluation of metallic wires, bars and pipes. *Sensors and Actuators A: Physical*, *81*(1–3):224–226.

Guillaume, S. (2001). Designing fuzzy inference systems from data: An interpretability-oriented review. *IEEE Transactions on Fuzzy Systems*, *9*(3): 426–443.

Güler, I., & Übeyli, E. D. (2005). Adaptive neuro-fuzzy inference system for classification of EEG signals using wavelet coefficients. *Journal of Neuroscience Methods*, *148*(2): 113–121.

Gunawan, E. R., Basri, M., Rahman, M. B. A., Salleh, A. B., & Rahman, R. N. Z. A. (2005). Study on response surface methodology (RSM) of lipase-catalyzed synthesis of palm-based wax ester. *Enzyme and Microbial Technology*, *37*(7):739–744.

Hamia, R., Cordier, C., & Dolabdjian, C. (2014). NDT & E International Eddy-current non-destructive testing system for the determination of crack orientation. *NDT and E International*, *61*:24–28.

Hamzaoui, A. H., Jamoussi, B., & M'nif, A. (2008). Lithium recovery from highly concentrated solutions: Response surface methodology (RSM) process parameters optimization. *Hydrometallurgy*, *90*(1):1–7.

He, Y., Pan, M., Luo, F., & Tian, G. (2011a). Pulsed eddy current imaging and frequency spectrum analysis for hidden defect nondestructive testing and evaluation. *NDT & E International*, *44*(4):344–352.

He, Y., Pan, M., Luo, F., & Tian, G. (2011b). Reduction of Lift-Off Effects in Pulsed Eddy Current for Defect Classification. *IEEE Transactions on Magnetics*, *47*(12): 4753–4760.

Hellier, C. J. (2012). *Hanbook of nondestructive evaluation*. United States of America.

Hewidy, M. S., El-Taweel, T. A., & El-Safty, M. F. (2005). Modelling the machining parameters of wire electrical discharge machining of Inconel 601 using RSM. *Journal of Materials Processing Technology*, *169*(2):328–336.

Horan, P., Underhill, P. R., & Krause, T. W. (2013). Pulsed eddy current detection of cracks in F/A-18 inner wing spar without wing skin removal using Modified Principal Component Analysis. *NDT & E International*, *55*: 21–27.

Hossain, A., Pirkle, H., & Parker, R. (1996). Design and fabrication of GMR multilayers with enhanced thermal stability, *156*: 303–305.

Huang, C. (2014). Probe Lift-off Compensation Method for Pulsed Eddy Current Thickness Measurement. *3rd Asia-Pacific Conference on Antennas and Propagation*, 937–939.

Huang, H., Sakurai, N., Takagi, T., & Uchimoto, T. (2003). Design of an eddy-current array probe for crack sizing in steam generator tubes. *NDT and E International*, *36*(7), 515–522.

Huo, S., Wang, C., Cheng, S., & Song, X. (2011). Impedance analyzing for planar eddy current probe array. *International Conference on Information Science and Technology*, 995–999.

Jang, J.-S. R. (1996). Input selection for ANFIS learning. *Proceedings of IEEE 5th International Fuzzy Systems*, *2*:1493–1499.

Jarvis, R., Cawley, P., & Nagy, P. B. (2016). Current deflection NDE for the inspection and monitoring of pipes. *NDT and E International*, *81*, 46–59.

Jedlicska, I., Weiss, R., & Weigel, R. (2008). Increasing the measurement accuracy of GMR current sensors through hysteresis modeling. *IEEE International Symposium on Industrial Electronics*, 884–889.

Jiang, H., Kwong, C. K., Law, M. C., & Ip, W. H. (2013). Development of customer satisfaction models for affective design using rough set and ANFIS approaches. In *Procedia Computer Science*, 22:104–112.

Jogschies, L., Klaas, D., Kruppe, R., Rittinger, J., Taptimthong, P., Wienecke, A., … Wurz, M. (2015). Recent Developments of Magnetoresistive Sensors for Industrial Applications. *Sensors*, *15*(11):28665–28689.

Jun, J., & Lee, J. (2009). Nondestructive evaluation of a crack on austenitic stainless steel using a sheet type induced current and a Hall sensor array. *Journal of Mechanical Science and Technology*, *22*(9):1684–1691.

Junior, F. R. L., Osiro, L., & Carpinetti, L. C. R. (2013). A fuzzy inference and categorization approach for supplier selection using compensatory and non-compensatory decision rules. *Applied Soft Computing Journal*, *13*(10):4133–4147.

Junjun, X., Naiguang, L., Udpa, L., & Udpa, S. S. (2011). Nondestructive Inspection Using Rotating Magnetic Field Eddy-Current Probe. *IEEE Transactions on Magnetics*, *47*(5):1070–1073.

Kaur, A., & Kaur, A. (2012). Comparison of Mamdani-Type and Sugeno-Type Fuzzy Inference Systems for Air Conditioning System. *International Journal of Soft Computing & Engineering*, *2*(2):323–325.

Khuri, A. I., & Mukhopadhyay, S. (2010). Response surface methodology. *Wiley Interdisciplinary Reviews: Computational Statistics*, *2*(2):128–149.

Kim, J., Yang, G., Udpa, L., & Udpa, S. (2010). Classification of pulsed eddy current

GMR data on aircraft structures. *NDT & E International*, *43*(2):141–144.

Kim, Y.-J., & Lee, S.-S. (2012). Eddy current probes of inclined coils for increased detectability of circumferential cracks in tubing. *NDT & E International*, *49*:77–82.

Kools, J. C. S. (1996). Exchange-biased spin-valves for magnetic storage. *IEEE Transactions on Magnetics*, *32*(4 PART 2):3165–3184.

Koshy, C. P., Rajendrakumar, P. K., & Thottackkad, M. V. (2015). Evaluation of the tribological and thermo-physical properties of coconut oil added with MoS2 nanoparticles at elevated temperatures. *Wear*, *330–331*, 288–308. http://doi.org/10.1016/j.wear.2014.12.044

Král, J., & Smid, R. (2011). Thickness Measurement Using Transient Eddy Current Techniques. *Instrumentation and Measurement Technology Conference (I2MTC),* 1-6.

Kral, J., Smid, R., Ramos, H. M. G., & Ribeiro, a. L. (2013). The lift-off effect in Eddy currents on thickness modeling and measurement. *IEEE Transactions on Instrumentation and Measurement*, *62*(7):2043–2049.

Krampfner, Y.D.; Johsnon, D.D. (1990). Flexible substrate eddy current coil arrays. *Review of Progress in Quantitative Nondestructive Evaluation, 7*, 471-478.

Kuhnt, S., & Rudak, N. (2013). Simultaneous Optimization of Multiple Responses with the R Package JOP. *Journal of Statistical Software*, *54*(9), 1-23.

Le, M., Kim, J., Sik Do, H., & Lee, J. (2014). 2-D vector field visualization of corrosion in a small-bore piping system using bobbin-type integrated Hall and GMR sensors arrays. *2014 IEEE Sensors Applications Symposium (SAS)*,38–41.

Lee, J., Jun, J., Kim, J., Choi, H., & Le, M. (2012). Bobbin-Type Solid-State Hall Sensor Array With High Spatial Resolution for Cracks Inspection in Small-Bore Piping Systems. *IEEE Transactions on Magnetics*, *48*(11): 3704–3707.

Lei, N., Udpa, L., Udpa, S., Zhiwei, Z., & Zeng, Z. (2010). Rotating field eddy current (RoFEC)-probe for steam generator inspection. *International Journal of Applied Electromagnetics & Mechanics*, *32*(3/4):1279–1285.

Lenssen, K. M. H., Adelerhof, D. J., Gassen, H. J., Kuiper, a. E. T., Somers, G. H. J., & Van Zon, J. B. a D. (2000). Robust giant magnetoresistance sensors. *Sensors and Actuators, A: Physical*, *85*:1–8.

Lenth, R. V. (2012). Response-surface methods in R , using RSM. *Journal of Statistical Software*, *32*(7): 1–17.

Li, D. Q., Jia, X., Wei, Z., & Liu, Z. Y. (2012). Box-Behnken experimental design for investigation of microwave-assisted extracted sugar beet pulp pectin. *Carbohydrate Polymers*, *88*(1):342–346.

Lopes Ribeiro, a., Ramos, H. G., & Couto Arez, J. (2012). Liftoff insensitive thickness measurement of aluminum plates using harmonic eddy current excitation and a GMR sensor. *Measurement*, *45*(9):2246–2253.

Lopez, L. a N. M., Ting, D. K. S., & Upadhyaya, B. R. (2008). Removing Eddy-Current probe wobble noise from steam generator tubes testing using Wavelet Transform. *Progress in Nuclear Energy*, *50*(7):828–835.

Lu, J., Huang, S., Pan, K., Qian, Z., & Chen, N. (2012). Development of characteristic test system for GMR sensor. *8th IEEE International Symposium on Instrumentation and Control Technology (ISICT) Proceedings*, 20–23.

Lu, T., Liu, S. M., & Attinger, D. (2013). Large-eddy simulations of structure effects of an upstream elbow main pipe on hot and cold fluids mixing in a vertical tee junction. *Annals of Nuclear Energy*, *60*, 420–431.

Mahmoodi, N. M., Soltani-Gordefaramarzi, S., & Sadeghi-Kiakhani, M. (2013). Dye removal using modified copper ferrite nanoparticle and RSM analysis. *Environmental Monitoring and Assessment*, *185*(12):10235–10248.

Maji, K., & Pratihar, D. K. (2010). Forward and reverse mappings of electrical discharge machining process using adaptive network-based fuzzy inference system. *Expert Systems with Applications*, *37*(12): 8566–8574.

Mook, G., Hesse, O., & Uchanin, V. (2007). Typical Depths of penetration. *Materialpruefung/Materials Testing*, *49*(5):258–264.

Morris, A. S., & Langari, R. (2012). *Measurement and instrumentation : theory and application*. US Patent 4,039,260.

Mott, N. F. (1936). The Electrical Conductivity of Transition Metals. *Proceedings of the Royal Society of London Series A Mathematical and Physical Sciences*, *153*(880):699–717.

Myers, R., Khuri, A., & Vining, G. (1992). Response surface alternatives to the Taguchi robust parameter design approach. *The American Statistician*, *46*(2):131–139.

Nestleroth, J. B. (2006). Pipeline in-line inspection - Challenges to NDT. *Insight: Non-Destructive Testing and Condition Monitoring*, *48*(9), 524-524.

Nogués, J., & Schuller, I. K. (1999). Exchange bias. *Journal of Magnetism and Magnetic Materials*, *192*(2):203–232.

Nolting, F., Scholl, a, Stohr, J., Seo, J., Fompeyrine, J., Siegwart, H., Padmore, H. (2000). Direct observation of the alignment of ferromagnetic spins by antiferromagnetic spins. *Nature*, *405*:767–9.

Oka, M., & Enokizono, M. (1996). A detection of backside crack using rotational magnetic flux sensor with search coils. *IEEE Transactions on Magnetics*, *32*(5 PART 2):4968–4970.

Park, D.-G., Angani, C. S., Rao, B. P. C., Vértesy, G., Lee, D.-H., & Kim, K.-H. (2013). Detection of the Subsurface Cracks in a Stainless Steel Plate Using Pulsed Eddy Current. *Journal of Nondestructive Evaluation*, *32*(4): 350–353.

Parkin, S. S. P. (1995). Giant Magnetoresistance in Magnetic Nanostructures. *Annual Review of Materials Science*, *25*(1): 357–388.

Parkin, S. S. P., More, N., & Roche, K. P. (1990). Oscillations in Exchange Coupling and Magnetoresistance in Metallic Superlattice Structures: Co/Ru, Co/Cr, Fe/Cr. *Physical Review Letters*, *64*(19): 2304–2307.

Pasadas, D. J., Ribeiro, A. L., Rocha, T. J., & Ramos, H. G. (2014). Open Crack Depth Evaluation Using Eddy Current Methods and GMR Detection. *Metrology for Aerospace (MetroAeroSpace)*, 117–121.

Pasadas, D. J., Ribeiro, A. L., Rocha, T. J., & Ramos, H. M. G. (2014). Remote field eddy current tube inspection using giant magneto-resistance sensors. *International Journal of Industrial Electronics and Drives 12*(3):167–173.

Pasadas, D., Rocha, T. J., Ramos, H. G., & Ribeiro, a. L. (2012). Evaluation of portable ECT instruments with positioning capability. *Measurement*, *45*(3): 393–404.

Pelkner, M., Neubauer, A., Reimund, V., Kreutzbruck, M., & Schütze, A. (2012). Routes for GMR-Sensor Design in Non-Destructive Testing. *Sensors*, *12*(12): 12169–12183.

Peluso, C. B. G., Iorio, M. V. A. De, & Penta, F. (2009). Detection of Magnetomechanical Effect in Structural Steel Using SQUIDs and Flux-gate Sensors. *Journal of superconductivity and novel magnetism*, *22*(8): 833–839.

Petit, F., Juraszek, J., Youssef, J. Ben, Teillet, J., Dekadjevi, D. T., & Gall, H. Le. (2005). Effect of annealing on the structural and magnetic properties of giant magnetostrictive multilayers. *Journal of Magnetism and Magnetic Materials*, *290–291 PA*, 839–842.

Poon, T. Y., Tse, N. C. F., & Lau, R. W. H. (2013). Extending the GMR current measurement range with a counteracting magnetic field. *Sensors (Basel, Switzerland)*, *13*(6):8042–59.

Porto, R. W., Brusamarello, V. J., & Azambuja, R. (2013). Design and Analysis of a GMR Eddy Current probe for NDT. *Seventh International Conference on Sensing Technology (ICST)*, 424-429.

Porwal, A., Carranza, E. J. M., & Hale, M. (2004). A hybrid neuro-fuzzy model for mineral potential mapping. *Mathematical Geology*, *36*(7):803-826.

Postolache, O. (2012). Uniform Eddy Current Probe based on GMR Sensor Array and Image Processing for NDT. *IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, 458-463.

Postolache, O., Lopes, A., & Ramos, H. G. (2013). GMR array uniform eddy current probe for defect detection in conductive specimens. *Measurement*, *46*(10):4369–4378.

Postolache, O., Ramos, H. G., & Ribeiro, A. L. (2008). Characterization of Defects in Aluminum Plates Using GMR Probes and Neural Network Signal Processing. *XVI-IMEKO TC4 Symposium, Florence-Italy*.

Postolache, O., Ramos, H. G., & Ribeiro, A. L. (2011). Computer Standards & Interfaces Detection and characterization of defects using GMR probes and arti fi cial neural networks. *Computer Standards & Interfaces*, *33*(2):191–200.

Prinz, G. a. (1998). Magnetoelectronics. *Science*, *282*:1660–1663.

Pu, J., Moore, P. R., & Wong, C. B. (2000). Smart components-based servo pneumatic actuation systems. *Microprocessors and Microsystems*, *24*(2):113–119.

Qiu, Z. C., Wang, B., Zhang, X. M., & Han, J. Da. (2013). Direct adaptive fuzzy control of a translating piezoelectric flexible manipulator driven by a pneumatic rodless cylinder. *Mechanical Systems and Signal Processing*, *36*(2):290–316.

Ramírez, E., Espina, J. H., Pérez, J. A., Caleyo, F., & Hallen, J. M. (2015). Some Particularities of EC Crack Detection in Aluminum Using an Asymmetrical GMR-Coil Configuration. *IEEE Latin America Transactions*, *13*(5):1331–1339.

Ramos, H. G., Ribeiro, A. L., Alegria, F., Postolache, O., & Diagram, A. B. (2006). Virtual Instrument to Detect Defects in Conductive Materials. *7th Conference on Telecomunications*,137-140.

Ramos, H. G., Rocha, T., Král, J., Pasadas, D., & Ribeiro, A. L. (2014). An SVM approach with electromagnetic methods to assess metal plate thickness. *Measurement*, *54*:201–206.

Ramos, H. G., Rocha, T., Ribeiro, A. L., & Pasadas, D. (2014). GMR Versus Differential Coils in Velocity Induced Eddy Current Testing. *Proceedings IEEE International Instrumentation and Measurement Technology Conference*, 915-918.

Ribeiro, a. L., Ramos, H. G., Pasadas, D. J., & Rocha, T. J. (2012). Current around a crack in an aluminum plate under nondestructive evaluation inspection. *2012 IEEE International Instrumentation and Measurement Technology Conference Proceedings*, 1635–1639.

Rifai, D., Abdalla, A., Ali, K., & Razali, R. (2016). Giant Magnetoresistance Sensors: A Review on Structures and Non-Destructive Eddy Current Testing Applications. *Sensors*, *16*(3): 298.

Rocha, T. J., Ramos, H. G., Lopes Ribeiro, a., & Pasadas, D. J. (2015). Magnetic sensors assessment in velocity induced eddy current testing. *Sensors and Actuators A: Physical*, *228*:55–61.

Rocha, T. J., Ramos, H. G., Lopes Ribeiro, a., Pasadas, D. J., & Angani, C. S. (2015). Studies to optimize the probe response for velocity induced eddy current testing in aluminium. *Measurement*, *67*:108–115.

Romano, D., Varetto, M., & Vicario, G. (2004). Multiresponse robust design: a general framework based on combined array. *Journal of Quality Technology*, *36*(1), 27.

Rosado, L. S., Cardoso, F. A., Cardoso, S., Ramos, P. M., Freitas, P. P., & Piedade, M. (2014). Sensors and Actuators A : Physical Eddy currents testing probe with magneto-resistive sensors and differential measurement. *Sensors & Actuators: A. Physical*, *212*:58–67.

Sabri, N., Aljunid, S. A., Salim, M. S., Badlishah, R. B., Kamaruddin, R., & Abd Malek, M. F. (2013). Fuzzy inference system: Short review and design. *International Review of Automatic Control*, *6*(4): 441–449.

Safizadeh, S., & Hasanian, M. (2011). Gas Pipeline Corrosion Mapping Using Pulsed Eddy Current Technique. *International Journal of Advanced Design and Manufacturing Technology*, *5*(1):11–19.

Sharma, N., Khanna, R., & Gupta, R. (2013). Multi quality characteristics of WEDM process parameters with RSM. In *Procedia Engineering* ,64:710–719.

Sharma, S., Malik, A., & Satya, S. (2009). Application of response surface methodology (RSM) for optimization of nutrient supplementation for Cr (VI) removal by Aspergillus lentulus AML05. *Journal of Hazardous Materials*, *164*(2–3): 1198–1204.

Singh, W. S., Rao, B. P. C., Thirunavukkarasu, S., & Jayakumar, T. (2012). Flexible GMR Sensor Array for Magnetic Flux Leakage Testing of Steel Track Ropes. *Journal of Sensors*, *2012*.

Sinha, K., Saha, P. Das, & Datta, S. (2012). Extraction of natural dye from petals of Flame of forest (Butea monosperma) flower: Process optimization using response surface methodology (RSM). *Dyes and Pigments*, *94*(2): 212–216.

Siritaratiwat, A., Hill, E. ., Stutt, I., Fallon, J. ., & Grundy, P. . (2000). Annealing effects on GMR multilayer films. *Sensors and Actuators A: Physical*, *81*(1–3): 40–43.

Smetana, M., & Strapacova, T. (2013). Detection capabilities evaluation of the advanced sensor types in Eddy Current Testing, (3): 247–249.

Sued, M. K., Pons, D., Lavroff, J., & Wong, E. H. (2014). Design features for bobbin friction stir welding tools: Development of a conceptual model linking the underlying physics to the production process. *Materials & Design*, *54*: 632–643.

Sullivan, S. P., Cecco, V. S., Obrutsky, L., & Lakhan, R. (1997). Validating Eddy Current Array Probes for Inspecting Steam Generator Tubes. *NDTnet*, *3*:29-35.

Sundararaghavan, V., & Balasubramaniam, K. (2005). A multi-frequency eddy current inversion method for characterizing conductivity gradients on water jet peened components. *NDT & E International*, *38*(7):541-547.

Tamburrino, a., Udpa, L., & Udpa, S. S. (2010). Pulsed Eddy-Current Based Giant Magnetoresistive System for the Inspection of Aircraft Structures. *IEEE Transactions on Magnetics*, *46*(3): 910–917.

Tavana, M., Azizi, F., Azizi, F., & Behzadian, M. (2013). A fuzzy inference system with application to player selection and team formation in multi-player sports. *Sport Management Review*, *16*(1): 97–110.

Theodoulidis, T., & Bowler, J. R. (2010). Interaction of an eddy-current coil with a right-angled conductive wedge. *IEEE Transactions on Magnetics*, *46*(4): 1034–1042.

Thirunavukkarasu, S., Rao, B. P. C., Jayakumar, T., & Raj, B. (2011). Techniques for processing remote field eddy current signals from bend regions of steam generator tubes of prototype fast breeder reactor. *Annals of Nuclear Energy*, *38*(4): 817–824.

Tian, G. Y., Li, Y., & Mandache, C. (2009). Study of lift-off invariance for pulsed eddy-current signals. *IEEE Transactions on Magnetics*, *45*(1): 184–191.

Tian, G. Y., & Sophian, A. (2005a). Defect classification using a new feature for pulsed eddy current sensors. *NDT & E International*, *38*(1):77–82.

Tian, G. Y., & Sophian, A. (2005b). Reduction of Lift-Off Effects for Pulsed Eddy Current NDT. *NDT and E International*, *38*(4): 319–324.

Translation, I., On, J., & In, M. (1992). Non-Destructive Testing with Magnetic Sensor Using Rotational Magnetic Flux. *IEEE translation journal on magnetics in Japan*, *7*(3):241-249.

Tsymbal, E. Y., & Pettifor, D. G. (2001). Perspectives of giant magnetoresistance. *Solid State Physics - Advances in Research and Applications*, *56*(3): 113–237.

Type, T. M., Mbti, I., & Briggs, I. (1985). Myers-Briggs Type Indicator (MBTI). *New York*, *60*, 2–5.

Vacher, F., Alves, F., & Gilles-Pascaud, C. (2007). Eddy current nondestructive testing with giant magneto-impedance sensor. *NDT & E International*, 40(6), 439-442.

Vieux-Rochaz, L. (2000). A new GMR sensor based on NiFe/Ag multilayers. *Sensors and Actuators A: Physical*, *81*(1–3):53–56.

Wan, J., Huang, M., Ma, Y., Guo, W., Wang, Y., Zhang, H., … Sun, X. (2011). Prediction of effluent quality of a paper mill wastewater treatment using an adaptive network-based fuzzy inference system. *Applied Soft Computing Journal*, *11*(3): 3238–3246.

Wei, L., Guoming, C., Xiaokang, Y., Chuanrong, Z., & Tao, L. (2013). Analysis of the lift-off effect of a U-shaped ACFM system. *NDT & E International*, *53*: 31–35.

Wong, H., Bajaj, V., Moan, G., Huterer, M., & Poidevin, C. (1990). The role of leak-before-break in assessments of flaws detected in CANDU pressure tubes. *International Journal of Pressure Vessels and Piping*, *43*(1–3):23–37.

Wu, Y., Cao, Z., & Xu, L. (2011). A simplified model for non-destructive thickness measurement immune to the lift-off effect. *Instrumentation and Measurement Technology Conference (I2MTC)*,1-4.

Xie, R., Chen, D., Pan, M., Tian, W., Wu, X., Zhou, W., & Tang, Y. (2015). Fatigue Crack Length Sizing Using a Novel Flexible Eddy Current Sensor Array. *Sensors*, *15*(12):32138–32151.

Xu, X., Liu, M., Zhang, Z., & Jia, Y. (2014). A Novel High Sensitivity Sensor for Remote Field Eddy Current Non-Destructive Testing Based on Orthogonal Magnetic Field. *Sensors (Basel, Switzerland)*, *14*(12): 24098–24115.

Xu, Z., Wu, X., Li, J., & Kang, Y. (2012). Assessment of wall thinning in insulated ferromagnetic pipes using the time-to-peak of differential pulsed eddy-current testing signals. *NDT & E International*, *51*:24–29.

Yadegari, a. M., Moini, R., Sadeghi, S. H. H., & Mazlumi, F. (2010). Output signal prediction of an open-ended rectangular waveguide probe when scanning cracks at a non-zero lift-off. *NDT & E International*, *43*(1):1–7.

Yamanaka, A., Kashima, T., Nago, S., Hosoyama, K., Takao, T., Sato, S., & Takeo, M. (2002). Coil bobbin composed of high strength polyethylene fiber reinforced plastics for a stable high field superconducting magnet. *Physica C: Superconductivity and Its Applications*, *372–376*(PART 3), 1447–1450.

Yang, G., Dib, G., Udpa, L., Tamburrino, A., Udpa, S. S., & Eddy, A. (2015). Rotating Field EC-GMR Sensor for Crack Detection at Fastener Site in Layered Structures. *IEEE Sensors Journal*, *15*(1):463–470.

Yang, G., Zeng, Z., Deng, Y., Liu, X., Udpa, L., & Dib, G. (2012). Sensor-tilt invariance analysis for eddy current signals. *NDT & E International*, *52*:1–8.

Yang, S., Tian, G. Y., Abidin, I. Z., & Wilson, J. (2011). Simulation of Edge Cracks Using Pulsed Eddy Current Stimulated Thermography. *Journal of Dynamic Systems, Measurement, and Control*, *133*(1): 011008,

Ye, C., Huang, Y., Udpa, L., & Udpa, S. S. (2016). Novel Rotating Current Probe With GMR Array Sensors for Steam Generate Tube Inspection. *IEEE Sensors Journal*, *16*(12), 4995-5002.

Yin, W., Binns, R., Dickinson, S. J., Davis, C., & Peyton, A. J. (2007). Analysis of the Liftoff Effect of Phase Spectra for Eddy Current Sensors. *IEEE Transactions on Instrumentation and Measurement*, *56*(6):2775–2781.

Yin, W., Member, S., & Xu, K. (2015). A Novel Triple-Coil Electromagnetic Sensor for Thickness Measurement Immune to Lift-Off Variations. *IEEE Transactions on Instrumentation and Measurement*, *65*(1), 164-169.

Yin, W., Withers, P. J., Sharma, U., & Peyton, A. J. (2009). Noncontact characterization of carbon-fiber-reinforced plastics using multifrequency eddy current sensors. *IEEE Transactions on Instrumentation and Measurement*, *58*(3): 738–743.

Yu, Y., Yan, Y., Wang, F., Tian, G., & Zhang, D. (2014). An approach to reduce lift-off noise in pulsed eddy current nondestructive technology. *NDT & E International*, *63*:1–6.

Zaoui, A., Menana, H., Feliachi, M., & Berthiau, G. (2010). Inverse problem in nondestructive testing using arrayed eddy current sensors. *Sensors (Basel, Switzerland)*, *10*(9):8696–704.

Zemalache, K. M., & Maaref, H. (2009). Controlling a drone: Comparison between a based model method and a fuzzy inference system. *Applied Soft Computing*, *9*(2): 553–562.

Zeng, Z., Deng, Y., Liu, X., Udpa, L., Udpa, S. S., Koltenbah, B. E. C., Steffes, G. (2011). EC-GMR Data Analysis for Inspection of Multilayer Airframe Structures. *IEEE Transactions On Magnetics*, *47*(12):4745–4752.

Zhang, Y., Li, Q., Zhang, Y., Wang, D., & Xing, J. (2012). Optimization of succinic acid fermentation with Actinobacillus succinogenes by response surface methodology (RSM). *Journal of Zhejiang University SCIENCE B*, *13*(2):103–110.

Zhao, J., Tian, W., Zhang, Q., Pan, M., Hu, J., Chen, D., & Luo, F. (2013). Designs of Slope Magnetic Flux Guides for 3-Axis Magnetic Sensor. *IEEE Transactions on Magnetics*, *49*(10): 5301–5303.

Zhu, W., Shen, H., & Chen, W. (2009). New Method for Suppressing Lift-Off Effects Based on Hough Transform. *2009 International Conference on Measuring Technology and Mechatronics Automation*, 653–656.

PUBLICATIONS

1. Rifai, D., Abdalla, A., Ali, K., & Razali, R. (2016). Giant Magnetoresistance Sensors: A Review on Structures and Non-Destructive Eddy Current Testing Applications. Sensors, 16(3), 298.

2. Rifai, D., & Abdalla, A. N. (2015). Defect Signal Analysis for Nondestructive Testing. ARPN Journal of Engineering and Applied Sciences, 11(4), 1–14.

3. Rifai, D., Abdalla, A. N., Khamsah, N., & Aizat, M. (2016). Subsurface Defects Evaluation using Eddy Current Testing. Indian Journal of Science and Technology, 9(March).

4. Rifai, D., Abdalla, A., Ali, K., Razali R. Faraj, Moneer (2017).An Eddy Current Testing Platform System for Pipe Defect Inspection Based on an Optimized Eddy Current Technique Probe Design. Sensors, 17,579