Full Length Research Paper

The research of quadtree search algorithms for anti-collision in radio frequency identification systems

Bih-Yaw Shih[1], Ta-Wei Lo[2] and Chen-Yuan Chen[1,3,4]*

[1]Department and Graduate School of Computer Science, National Pingtung University of Education, No. 4-18, Ming Shen Rd., Pingtung 90003, Taiwan, R.O.C.
[2]Taiwan Power Company, Taiwan, R.O.C.
[3]Department of Information Management, National Kaohsiung First University of Science and Technology, 2 Jhuoyue Rd. Nanzih, Kaohsiung 811, Taiwan, R.O.C.
[4]Global Earth Observation and Data Analysis Center (GEODAC), National Cheng Kung University, No 1, Ta-Hsueh Road, Tainan 701, Taiwan, R.O.C.

Nowadays, Radio Frequency Identification (RFID) systems are widely used in commercial applications such as warehouse management, artificial intelligence, intelligent robot and automation control to identify the tagged goods or materials. When there is the existence of multiple tags in the interrogation field of a transponder, the arbitration algorithm for RFID system is used to arbitrate all the tags to avoid the collision problem. A splitting algorithm which is called Binary Search Tree (BST) is well-known for multi-tags arbitration. In this paper, a quadtree search algorithm is developed to avoid collision. Then, its performance is compared with binary search tree and binary search tree with cut-through according to cost, mean number of stages for successfully arbitrating an RFID device, during the arbitration process. Comparing with the traditional DFSA algorithm, the simulation results show that our model reaches better performance with respect to reducing the cost and tag reading time.

Key words: Radio frequency identification (RFID), arbitration problem, anti-collision, binary search tree, quadtree.

INTRODUCTION

Radio Frequency Identification (RFID) has been developed and used in many applications in the real world. A RFID system consists of a reader and tags which each tag contains a unique Tag ID. The reader can identify a tag according to its Tag ID and communicate with tags via radio frequency. In RFID system, the most important issues that affect the data integrity is the collision resolution between the tags while these tags transmit their data to the reader. In majority of tag anti-collision algorithm, Dynamic Framed Slotted Aloha (DFSA) has been employed as a popular collision resolution algorithm to share the medium when multiple tags respond to the reader's signal command. According to power supply, tags are categorized into two types: active and passive tags. An active tag is a tag with power

supply, it can emit RF signal to communicate with the reader actively, usually with longer access distance and better access time. A passive tag must have to listen to the signal emit from the reader and then respond to it. Both of these two types of tags are in widespread use in commercial applications.

When there is the existence of more than one tag in the interrogation field of a reader, the reader would send signals to each tag and all the tags would reflex signal with its Tag ID back to the reader at the same time. This may cause a collision problem and result in data loss, because the reader couldn't receive all the reflex signals simultaneously. However, the environment of multi-tags is very general in commercial applications and many researchers are dedicating in resolving this problem. Nowadays, several methods were developed for RFID anti-collision, including Time Division Multiple Access (TDMA), Space Devision Multiple Access (SDMA), Frequency Domain Multiple Access (FDMA) and Binary

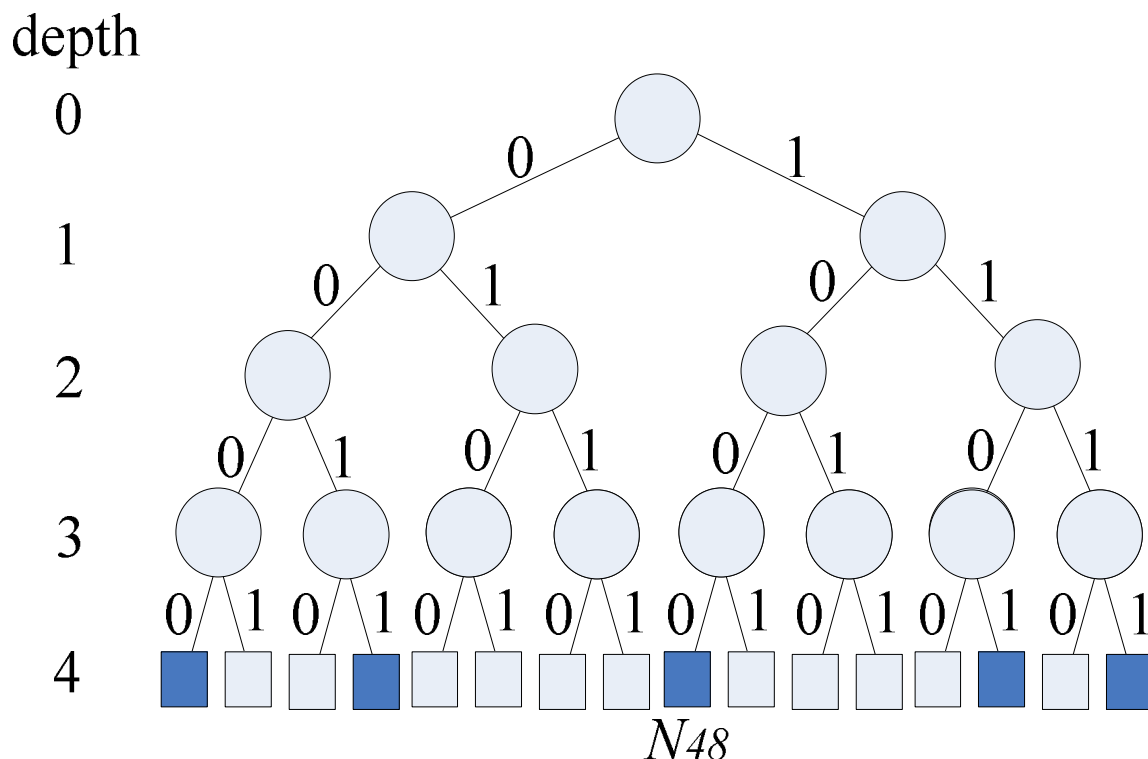---
*Corresponding author. E-mail: cyc@mail.npue.edu.tw.

Figure 1. The Binary Search Tree (m = 5, k = 4).

Search Tree (BST) algorithm. In this paper, a splitting-based algorithm called Quadtree search algorithm is developed to simplify the tree structure. The proposed model successfully reduces the searching cost to arbitrate the tags in RFID system.

Binary search tree algorithm

Owing to the shared wireless channel between tags and the reader in the process of communication, the tag collision arbitration is one of the significant issues for reducing the communication overhead. Binary search tree (BST) is the famous approach for RFID anti-collision, and it takes the advantage of easy implementation and low power consumed during the process (Hush and Wood, 1998). BST is developed from tree algorithm for packet broadcast channels by (Capetanakis, 1979). Figure 1 shows an example of binary tree whose depth is 4. Each tag corresponds to a leaf node in a BST. If there are 5 tags with Tag ID of 4 bits length in the system, the ID of tag N48 is 1000. The searching procedure of BST is stated as follows:

1. Begin with the root node N_{00}, and ask if there is zero, one or more than one tags in the subtree too.
2. If there is more than one tag in T_{00}, it means that a collision happened at N_{00}. Then ask two succeeding nodes, N_{10} and N_{11} to check whether there is zero, one or more than one tags in subtrees. If any collision happens in N_{11}, N_{10} waits and asks the same question to succeeding nodes of N_{11}. The process follows "first in, last out" rule.
3. Recursively, if there is any collision; repeat the same question to its succeeding nodes until there is no collision.

If only one node is waiting, repeat step 3. If more than one node is waiting, follow the "first in, last out" rule to resolve them. At the end of the process, each leaf will contain at most one tag. In the example of Figure 1, the order of tags is: 1111, 1101, 1000, 0011, 0000, which needs to search four stages to find a tag. Recently, several researches were conducted to improve tree algorithm. One of the many famous algorithms is BST with Cut-Through Operation, which simplifies the structure of BST first and then searches it (Wang, 2006). Wang (2006) showed that BST with Cut-Through operation can improve the efficiency by simplifying the tree structure.

Quadtree algorithm

Quadtree is a finite elements method used to divide a region which contains multi-objects into many small
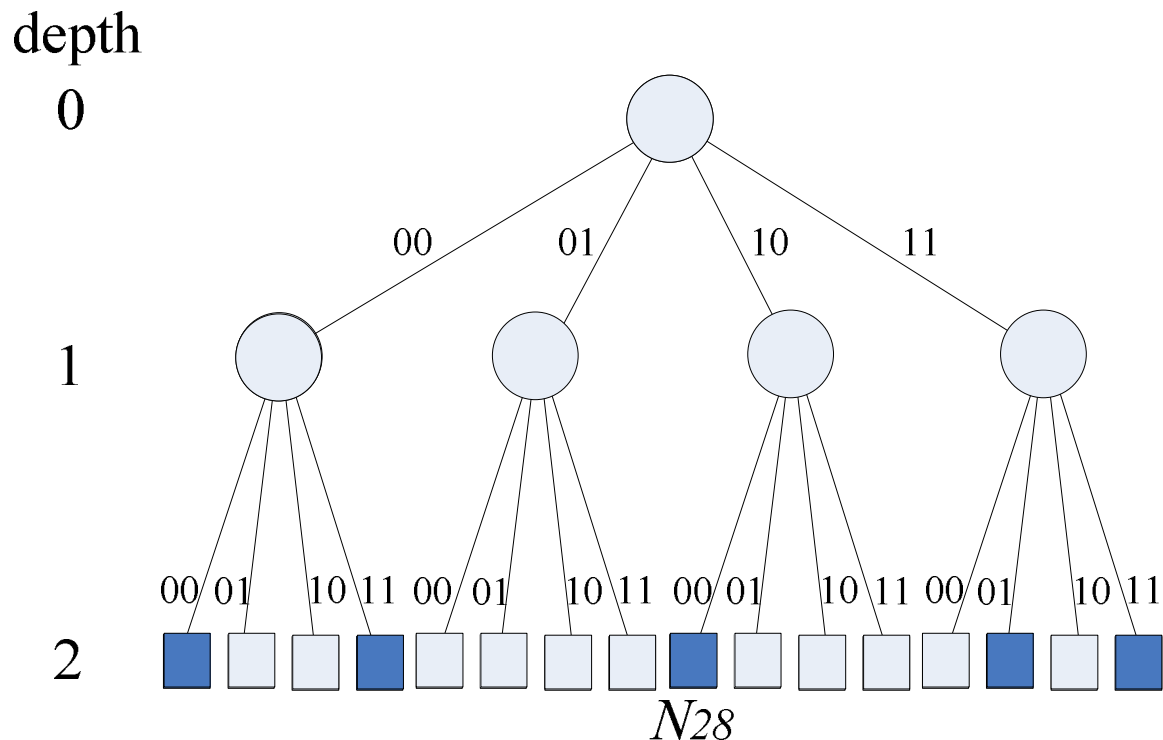
depth

0

Figure 2. The Quadtree (m=5).

regions to identify each object (Mark et al., 2000). Moreover, RFID techniques in soft computing and artificial intelligence have been successfully applied to various fields, such as robot manipulation (Hsiao et al., 2005a, b, c, d, e; Chen et al., 2011a, b; Chen and Huang, 2011; Shih et al., 2011a, b; Lee et al., 2011a, b, c), engineering application (Lu, 2003; Amini and Vahdani, 2008; Chang et al., 2008; Chen, 2006; Chen et al., 2008d, e; Trabia et al., 2008; Tu et al., 2008; Yang et al., 2008a; Shih et al., 2010b; Yeh and Chen, 2010; Cakiroglu et al., 2010; Kucuksille et al., 2010; Shamshirb et al., 2010; Uddin et al., 2010), architectural engineering (Chen et al., 2004; Chen et al., 2010i; Hsieh et al., 2006; Chen, 2010a, b, c; Hsu et al., 2010; Chen, 2011c, d, e; Chen et al., 2011c, d; Liu et al., 2011; Tang et al., 2011), satellite observations (Lin et al., 2009a, b; Lin and Chen, 2010b; Lin and Chen, 2011; Yeh et al., 2011), marine research (Chen et al., 2005a, 2005b; Chen et al., 2006a, b, c; Chen et al., 2007a, b, c, d, e, f, g, h; Chen et al., 2008a, b, c; Tseng et al., 2009; Chen, 2009b, c; Chen et al., 2009c; Chen, 2010d; Chen, 2011a, b, c), network optimization (Chen et al., 2009g; Chen and Chen, 2010b; Shih et al., 2010a, c; Kuo et al., 2010; Kuo et al., 2011; Kuo and Chen, 2011a, b), system development (Chen, 2009a; Chen et al., 2009a, b, d, e, f; Chen, 2010c; Chen et al., 2010a, c, d, f; Lin and Chen, 2010a; Shih et al., 2011d; Tseng et al., 2011), educational improvement (Chen et al., 2010b; Shih et al., 2010d; Shen et al., 2011;

Shih et al., 2011c; Chen, 2011f; Chen, 2012) and managements on leisure industries (Yildirim et al., 2009; Zhao et al., 2009; Tsai et al., 2008; Yang et al., 2008b; Yeh et al., 2008; Chen and Chen, 2010a; Chen et al., 2010e, g, h; Lee et al., 2010a, b; Chiang et al., 2010; Tsai and Chen, 2010; Tsai and Chen, 2011; Yu et al., 2011; Chen et al., 2011e, and (Chen et al., 2011d, 2011e, 2011f, 2011g, 2011h; Lee, 2010; Cheng et al., 2011; Chu et al., 2011; Chiou et al., 2011; Chen, 2011g, 2011h, 2011i; Kuo et al., 2011; Kuo and Chen, 2011; Lin and Chen, 2011; Liu et al., 2011a, 2011b; Lin et al., 2011b; Shen et al., 2011; Tang et al., 2011; Tsai and Chen, 2011a, 2011b; Chen, 2012a, 2012b, 2012c; Chen et al., 2012a, 2012b, 2012c, 2012d; Kuo and Chen, 2012a, 2012b; Lee and Chen, 2012; Lin et al., 2012a, 2012b; Lin and Chen, 2012; Liu et al., 2012a, 2012b; Su et al., 2012; Tseng and Chen, 2012; Tseng et al., 2012a, 2012b, 2012c; Yeh et al., 2012).

It is similar to BST which splits a set of objects into small subsets. A Quadtree is a rooted tree whose internal nodes have four children. The four branches of an internal node are labeled as 00, 01, 10 and 11 from left to right. Figure 2 shows an example of a BST. Each of the leaves corresponds to a tag whose tag ID is the bit stream consisting of the labels of branches from root to the leaf itself. For example, N28 is equal to N48 in Figure 1 which represent the tag with ID 1000. The Psuedo Code of constructing a BST and quadtree are
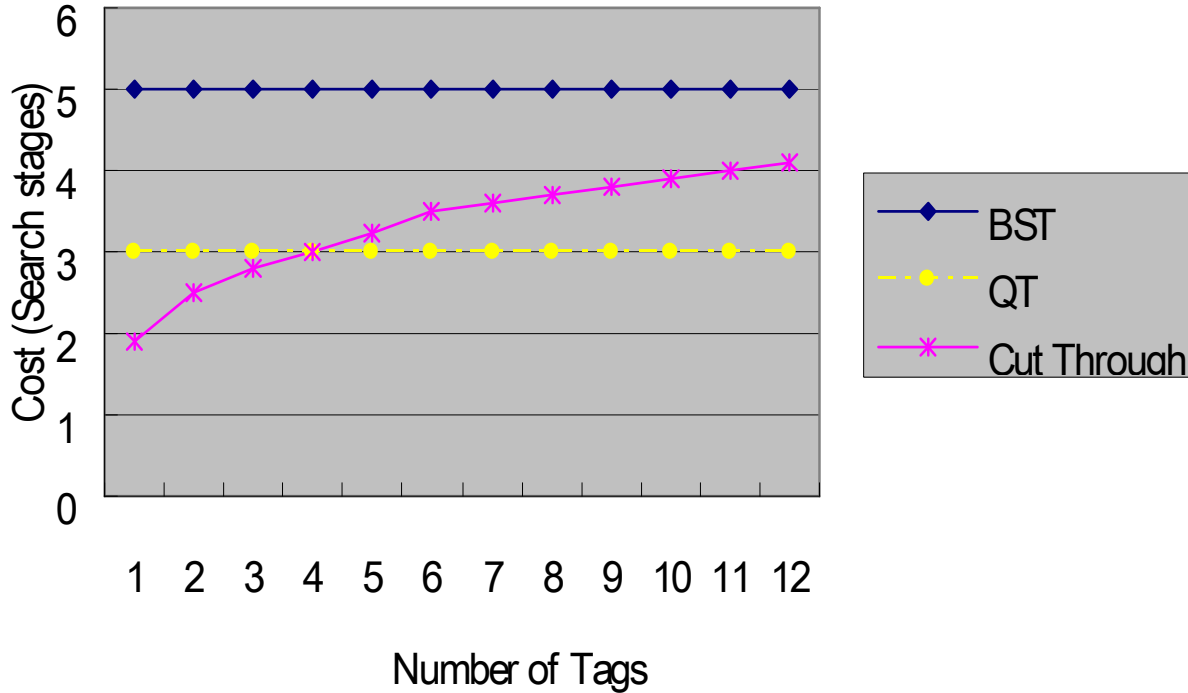
Figure 3. The cost with different m (n = 32).

respectively shown in Appendix 1 and 3. QT is a quadtree and DaDa+1 is the bit stream consists of ath and a+1th bits. The algorithm will insert each node to the appropriate position according to the DaDa+1. The four subtrees from left to right is defined as 1st ,2nd ,3rd and 4th subtree of quadtree. The searching process is the same as that in BST. Quadtree needs $\log_4 n$ stages to represent all tags which the number of stages is half of the depth of BST. Eventually, it is helpful for reducing cost and searching time during arbitration process.

Performance analysis

The performance is evaluated based on the cost consuming during the arbitration process. The cost is defined as average stages needed to find a tag successfully which is directly proportional to the depth of the search tree (3rd). Here, the average stages needed of BST, Quadtree and BST with Cut-Through are defined as:

$$L_{BST}, \ L_{QT} \ \text{and} \ L_{Cut-Through}$$

Assume that there are at most n possible tags and m tags exist in the field of reader. Then the 3rd, $L_{BST} =$ $\log_2 n = k$, $L_{QT} = \log_4 n = k/2$ and $L_{Cut-Through} =$

$$\sum_{j=1}^{k} j \times \frac{\displaystyle\sum_{i=1}^{2^{k-j}} C(2^{k-j}, j) \times C(2^k - 2^{k-j+1}, m-i-1)}{C(n-1, m-1)} \ . \ \text{Since} \ L_{QT} =$$

L_{BST} /2, the cost of Quadtree is obviously fewer than BST. The numerical result will show that the computational load of Quadtree is better than k stages of BST and $L_{Cut-Through}$ stages of BST with Cut-Through.

Numerical result of cost with different depth of tree is shown in Figure 3. The quadtree is better than BST and BST with Cut-Through. When the depth of tree is greater than 5, the quadtree would be obviously better than both of them. Numerical result of cost with different number of tags (m) is shown in Figure 4. BST has the worst performance in this evaluation. Obviously, quadtree outperforms significantly the BST and BST with Cut-through when m ≥ 4.

CONCLUSIONS

The anti-collision mechanism is an important part of the Radio-Frequency Identification (RFID) technology. An improved splitting-based algorithm, called Quadtree search algorithm, is successfully developed to simplify the structure of tree. The novelty of the proposed approach reveals that the Quadtree reduces half the number of stages of BST. Therefore, it is useful for
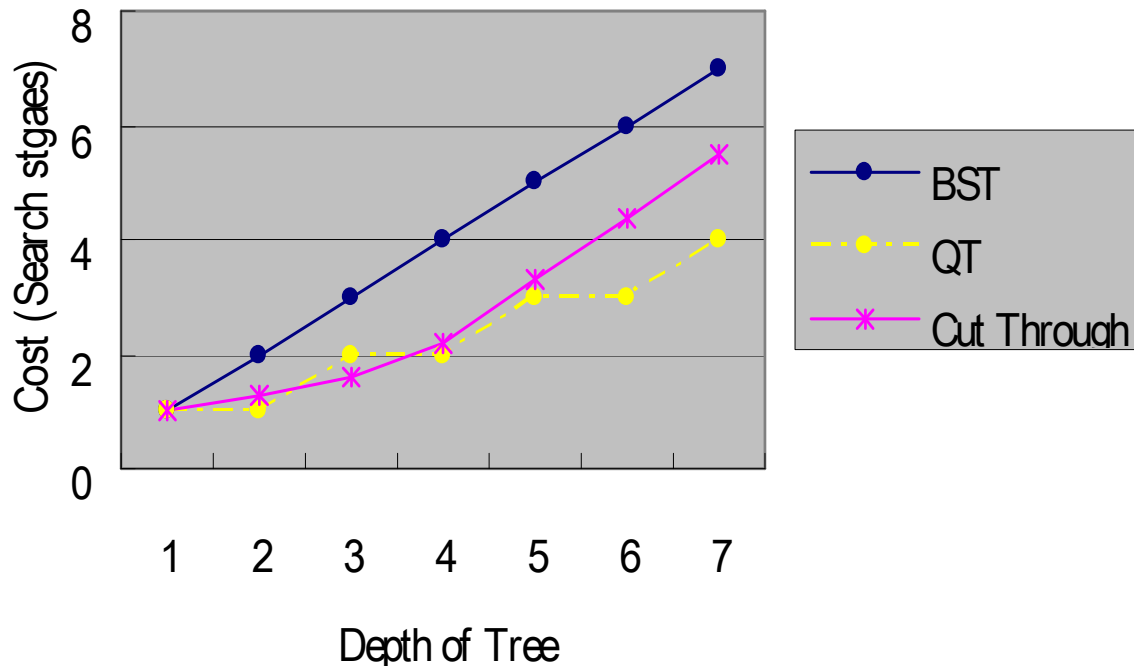
Figure 4. The cost with different tree.

improving the cost of searching tags. The performances are defined as cost evaluated by the searched stages. Especially, quadtree search algorithm is excellent for large number of tree stages.

REFERENCES

Amini F, Vahdani R (2008). Fuzzy optimal control of uncertain dynamic characteristics in tall buildings subjected to seismic excitation. J. Vibrat. Control., 14: 1843-1867.
breaking criterion for an ISW propagating over a ridge. *Environmental Fluid Mechanics*, 10 (5): 577-586, DOI: 10.1007/s10652-010-9172-1.
Cakiroglu M, Bayilmis C, Ozcerit AT (2010). Performance evaluation of scalable encryption algorithm for wireless sensor networks. Sci. Res. Essays., 5(9): 856-861.
Capetanakis JI (1979). Tree algorithms for packet broadcast channels. IEEE Trans. Inf. Theory., 25: 505-515.
Chang CY, Hsu KC, Chiang KH, Huang GE (2008). Modified fuzzy variable structure control method to the crane system with control deadzone problem. J. Vibrat. Control., 14: 953-969.

Chen CW (2006). Stability Conditions of Fuzzy Systems and Its Application to Structural and Mechanical Systems. Adv. Eng. Software, 37: 624-629.
Chen CW (2009a). Modeling and control for nonlinear structural systems via a NN-based approach. Exp. Syst. Appl., 36: 4765-4772.
Chen CW (2009b). The stability of an oceanic structure with T-S fuzzy models. Math. Comput. Simul., 80: 402-426.
Chen CW (2010a). Modeling and fuzzy PDC control and its application to an oscillatory TLP structure. Mathematical Problems in Engineering- An Open Access Journal DOI: 10.1155/2010/120403.
Chen CW (2010b). Application of fuzzy-model-based control to nonlinear structural systems with time delay: an LMI method. J. Vibrat. Control., 16: 1651-1672.
Chen CW (2010c). Fuzzy control of interconnected structural systems using the fuzzy Lyapunov method. Journal of Vibration and Control, DOI: 10.1177/1077546310379625.
Chen CW (2011d). Stability analysis and robustness design of nonlinear systems: an NN-based approach. Appl. Soft Comput., 11(2): 2735-2742.
Chen CW (2011e). Modeling, control and stability analysis for time-delay TLP systems using the fuzzy Lyapunov method. Neural Comput. Appl., 20(4): 527-534.
Chen CW (2011g). A critical review of parallel distributed computing and the Lyapunov criterion for multiple time-delay fuzzy systems. Int. J. Phys. Sci., 6(19): HYPERLINK "tel:4492-4501" \t "_blank, pp. 4492-4501.
Chen CW (2011h). Internet services and interface design for marketing: a preliminary study of Cliven products. International Journal of the Physical Sciences 6(15): HYPERLINK "tel: 3585-3596" \t "_blank, pp. 3585-3596.
Chen CW (2011i). Fuzzy control of interconnected structural systems using the fuzzy Lyapunov method. Journal of Vibration and Control 17(11): 1693-1702.
Chen CW (2012a). Applications of LDI-based criterion to a nonlinear
Chen CW (2012b). Applications of the fuzzy Lyapunov LMI criterion to a chaotic structural system. J. Vibration and Cont., doi:10.1016/j.eswa.2011.09.085.
Chen CW (2012c). Delay independent criterion for multiple time-delay systems and its application in building structure control systems. J.

Vibration and Cont., DOI: 10.1177/1077546309350477.

Chen CW, Chang ML and Tseng CP (2012b). Critical human factor evaluation of knowledge sharing intention in Taiwanese enterprises. Human Factors and Ergonomics in Manufacturing & Service Industries. DOI: 10.1177/1077546310371349.

Chen CW, Chang ML, Tseng CP (2012a). The human factors of knowledge sharing intention among Taiwanese enterprises: a model of hypotheses. Human Factors and Ergonomics in Manufacturing & Service Industries, DOI: 10.1002/hfm.20286.

Chen CW, Chen CY (2010b). Are educational background and gender moderator variables for leadership, satisfaction and organizational commitment. Afr. J. Bus. Manage., 4: 248-261.

Chen CW, Chen CY, Yang HC, Chen TH (2007a). Analysis of Experimental Data on Internal Waves with Statistical Method. Eng. Comput. Int. J. Comput. Aided Eng. Software., 24: 116-150.

Chen CW, Chen PC (2010b). GA-based adaptive neural network controllers for nonlinear systems. Int. J. Innov. Comput. Inf. Control., 6: 1793-1803.

Chen CW, Chen PC and Chiang WL (2011h). Stabilization of adaptive neural network controllers for nonlinear structural systems using a singular perturbation approach. J. Vibration and Cont., 17(8): 1241-1252.

Chen CW, Chen PC, Chiang WL (2010i). Stabilization of adaptive neural network controllers for nonlinear structural systems using a singular perturbation approach. Journal of Vibration and Control, DOI: 10.1177/1077546309352827.

Chen CW, Chen TH, Lin YF (2011e). The statistical analysis for consumers' intensions of purchasing cosmetics. African Journal of Business Management 5(20): HYPERLINK "tel:8271-8276" \t "_blank, pp. 8271-8276.

Chen CW, Chiang WL, Hsiao FH (2004). Stability Analysis of T-S Fuzzy Models for Nonlinear Multiple Time-Delay Interconnected Systems. Math. Comput. Simul., 66(6): 523-537.

Chen CW, Chiang WL, Hsiao FH (2005a). Stability Analysis of T-S Fuzzy Models for Nonlinear Multiple Time-Delay Interconnected Systems. Math. Comput. Simul., 66: 523-537.

Chen CW, Chiang WL, Tsai CH (2006a). Fuzzy Lyapunov Method for Stability Conditions of Nonlinear Systems. International J. Artif. Intell. Tools., 15: 163-171.

Chen CW, Lee KL, Tseng CP (2012c). The relationship between personality traits and sales force automation usage: a preliminary study. Human Factors and Ergonomics in Manufacturing & Service Industries. DOI: 10.1177/1077546310381101.

Chen CW, Lin CL, Tsai CH (2007c). A Novel Delay-Dependent Criteria for Time-Delay T-S Fuzzy Systems Using Fuzzy Lyapunov Method. International J. Artif. Intell. Tools 16: 545-552.

Chen CW, Shen CW, Chen CY, Jeng MJ (2010c). Stability analysis of an oceanic structure using the Lyapunov method. Eng. Comput., 27: 186-204.

Chen CW, Tseng CP, Lee KL, Yang HC (2011d). Conceptual framework and research method for personality traits and sales force automation usage, Scientific Research and Essays 6(17): HYPERLINK "tel:3784-3793" \t "_blank pp. 3784-3793.

Chen CW, Wang HL, Liu FR, Chen TH (2010f). Application of project cash management and control for infrastructure. J. Marine Sci. Technol., 18: 644-651.

Chen CW, Wang MHL, Lin JW (2009g). Managing target the cash balance in construction firms using a fuzzy regression approach. International J. Uncertainty Fuzziness Knowl. Based Syst., 17(5): 667-684.

Chen CW, Wang, Morris HL, Lin JW (2009e). Managing target the cash balance in construction firms using a fuzzy regression approach. International J. Uncertainty Fuzziness Knowl. Based Syst., 17: 667-684.

Chen CW, Yang, Peter HC, Chen CY, Chang AKH, Chen TH (2008b). Evaluation of inference adequacy in cumulative logistic regression models: an empirical validation of ISW-ridge relationships. China Ocean Eng., 22: 43-56.

Chen CW, Yeh K, Chiang WL, Chen CY, Wu DJ (2007f). Modeling, H^{∞} Control and Stability Analysis for Structural Systems Using Takagi Sugeno Fuzzy Model. J. Vibrat. Control 13: 1519-1534.

Chen CW, Yeh K, Liu KFR, Lin ML (2012d). Applications of fuzzy control to nonlinear time-delay systems using the linear matrix inequality fuzzy Lyapunov method. J. Vibration Cont., DOI: 10.1177/1077546311410765.

Chen CW, Yeh K, Liu FR (2009d). Adaptive fuzzy sliding mode control for seismically excited bridges with lead rubber bearing isolation. Int. J. Uncertainty, Fuzziness Knowl. Based Syst., 17: 705-727.

Chen CY (2007). An experimental study of stratified mixing caused by internal solitary waves in a two-layered fluid system over variable seabed topography. Ocean Eng., 34(14-15): 1995-2008.

Chen CY (2009c). Amplitude decay and energy dissipation due to the interaction of internal solitary waves with a triangular obstacle in a two-layer fluid system: the blockage parameter. J. Marine Sci. Technol., 14(4): 499-512.

Chen CY (2010d). Using discriminant analysis to determine the

Chen CY (2011a). A critical review of internal wave dynamics. Part 2 – Laboratory experiments and theoretical physics. J. Vibrat. Control., DOI: 10.1177/1077546310397561.

Chen CY (2011b). A critical review of internal wave dynamics. Part 1 – Remote sensing and in-situ observations. J. Vibrat. Control., DOI: 10.1177/1077546310395971.

Chen CY (2011c). Statistical and dynamical analyses of propagation mechanisms of solitary internal waves in a two-layer stratification. J. Marine Sci. Technol.,, 16(1): 100-114, DOI 10.1007/s00773-010-0112-z.

Chen CY (2011f). A critical review and improvement method on biped robot. Int. J. Innov. Comput. Inf. Control., 7(9): 5245-5254.

Chen CY, Chen CW, Tseng IF (2007e). Localisd mixing due to an interfacial solitary wave breaking on seabed topography in different ridge heights. J. Offshore Mech. Arctic Eng., 129: 245-250.

Chen CY, Hsu JRC, Chen CW, Cheng MH (2006b). Numerical model of an internal solitary wave evolution on impermeable variable seabed in a stratified two-layer fluid system. China Ocean Eng., 20: 303-313.

Chen CY, Hsu RC, Chen CW (2005b). Fuzzy Logic Derivation of Neural Network Models with Time Delays in Subsystems. International J. Artif. Intell. Tools., 14: 967-974.

Chen CY, Hsu, John RC, Chen CW (2007). Wave propagation at the interface of a two-layer fluid system in the laboratory. J. Marine Sci. Technol., 15: 8-16.

Chen CY, Hsu, John RC, Chen CW (2007b). Generation of internal solitary wave by gravity collapse. J. Marine Sc. Technol., 15: 1-7.

Chen CY, Hsu, John RC, Cheng MH (2007g). Laboratory observations on internal solitary wave evolution on steep and inverse uniform slopes. *Ocean Eng.*, 34 (1): 157-170.

Chen CY, Hsu, John RC, Cheng MH (2007h). An investigation on internal solitary waves in a two-layer fluid: propagation and reflection from steep slopes. *Ocean Eng.*, 34 (1): 171-184.

Chen CY, Hsu, John RC, Cheng MH, Chen CW (2008c). Experiments on mixing and dissipation in internal solitary waves over two triangular obstacles. Environ. Fluid Mech., 8: 199-214.

Chen CY, Huang PH (2011). Review of an autonomous humanoid robot and its mechanical control. J. Vibrat. Control., DOI: 10.1177/1077546310395974.

Chen CY, Lee WI, Kuo HM, Chen CW, Chen KH (2010d). The study of a forecasting sales model for fresh food. Exp. Syst. Appl., 37: 7696-7702.

Chen CY, Lin CL, Tseng, I. F., Chen CW (2007d). Dynamic behavior of an internal solitary wave oscillating over variable bathymetry. Kuwait J. Sci. Eng., 34: 153-166.

Chen CY, Lin JW, Lee, W. I., Chen CW (2010a). Fuzzy control for an oceanic structure: A case study in time-delay TLP system. J. Vibrat. Control., 16: 147-160.

Chen CY, Liu KC, Liu YW, Huang WC (2010h). A case study of reinforced concrete short column under earthquake using experimental and theoretical investigations. Struct. Eng. Mech., 36: 197-206.

Chen CY, Shen CW, Chen CW, Liu KFR, Jeng MJ (2009a). A Stability Criterion for Time-Delay Tension Leg Platform Systems Subjected to External Force. China Ocean Eng., 23: 49-57.

Chen CY, Shih BY, Chen ZS, Chen TH (2011e). The exploration of internet marketing strategy by search engine optimization: A critical review and comparison. African Journal of Business Management,

5(12): 4644-4649.

Chen CY, Shih BY, Chou WC (2011a). The development of autonomous low cost biped mobile surveillance robot by intelligent bricks. Journal of Vibration and Control, DOI: 10.1177/1077546310371349.

Chen CY, Shih BY, Chou WC (2011b). Obstacle avoidance design for a humanoid intelligent robot with ultrasonic sensors. Journal of Vibration and Control, DOI: 10.1177/1077546310381101.

Chen CY, Shyue SW, Chang CJ (2010g). Association rule mining for evaluation of regional environments: Case study of Dapeng Bay, Taiwan. Int. J. Innov. Comput. Inf. Control 6: 3425-3436.

Chen CY, Tseng IF, Yang HC, Chen CW, Chen TH (2006c). Profile Evolution and Energy Dissipation for Internal Soliton Transmitting over Different Submarine Ridges. China Ocean Eng., 20: 585-594.

Chen CY, Yang HC, Chen CW, Chen TH (2008a). Diagnosing and revising logistic regression models: effect on internal solitary wave propagation. Eng. Comput. Int. J. Comput. Aided Eng. Software., 25: 121-139.

Chen CY, Yang YF, Chen CW, Chen LT, Chen TH (2010e). Linking the balanced scorecard (BSC) to business management performance: A preliminary concept of fit theory for navigation science and management. Int. J. Phys. Sci., 5: 1296-1305.

Chen PC, Chen CW, Chiang WL (2008d). GA-Based Fuzzy Sliding Mode Controller for Nonlinear Systems. Mathematical Problems in Engineering- An Open Access Journal DOI: 10.1155/2008/325859.

Chen PC, Chen CW, Chiang WL (2009b). GA-based modified adaptive fuzzy sliding mode controller for nonlinear systems. Exp. Syst. Appl., **36**: 5872-5879.

Chen PC, Chen CW, Chiang WL (2011d). Linear matrix inequality conditions of nonlinear systems by genetic algorithm-based H_∞ adaptive fuzzy sliding mode controller. J. Vibrat. Control 17(2): 163-173.

Chen PC, Chen CW, Chiang WL (2011g). Linear matrix inequality conditions of nonlinear systems by genetic algorithm-based adaptive fuzzy sliding mode controller. J. Vibration and Cont., 17(2): 163-173.

Chen PC, Chen CW, Chiang WL, Yeh K (2009f). A novel stability condition and its application to GA-based fuzzy control for nonlinear systems with uncertainty. J. Marine Sci. Technol., 17: 293-299.

Chen PC, Chen CW, Chiang WL (2011f). GA-based decoupled adaptive FSMC for nonlinear systems by a singular perturbation scheme. Neural Computing and Applications 20(4): 517-526.

Chen PC, Chen CW, Chiang WL, Lo DC (2011c). GA-based decoupled adaptive FSMC for nonlinear systems by a singular perturbation scheme. Neural Comput. Appl., 20(**4**): 517-526.

Chen TH, Chen CW (2010). Application of data mining to the spatial heterogeneity of foreclosed mortgages. Exp. Syst. Appl., 37: 993-997.

Chen TH, Chen CY, Yang CH, Chen CW (2008e). A Mathematical Tool for Inference in Logistic Regression with Small-Sized Data Sets – A Practical Application on ISW-Ridge Relationships. Mathematical Problems in Engineering- An Open Access Journal DOI: 10.1155/2008/186372.

Chen TH, Yang HC, Chen CY, Chen CW (2009c). Application of Logistic Regression Model: Propagation Effect on Internal Soliton. J. Chung Cheng Instit. Technol., 37: 1-10.

Cheng MH, Hsu John RC, Chen CY (2011). Laboratory experiments on waveform inversion of an internal solitary wave over a slope-shelf. Environ. Fluid Mech., 11 (4): 353–384.

Chiang WL, Chiou DJ, Tang JP, Hsu WK, Liu TY (2010). Detecting the sensitivity of structural damage based on the Hilbert-Huang transform approach. Eng. Comput., 27: 799-818.

Chiou DJ, Hsu WK, Chen CW, Hsieh CM, Tang JP, Chiang WL (2011). Applications of Hilbert-Huang transform to structural damage detection. Structural Engineering and Mechanics 39(1): 1-20.

Chu TH, Lin ML, Chen CW (2011). Developing a tour guiding information system for tourism service using mobile GIS and GPS techniques. Advances in Information Sciences and Service Sciences 3(6): 49-58.

Hsiao FH, Chen CW, Liang YW, Xu SD, Chiang WL (2005e). T-S Fuzzy Controllers for Nonlinear Interconnected Systems with Multiple Time Delays. IEEE Trans. Circuits Syst. Regular Papers., 52: 1883-1893.

Hsiao FH, Chen CW, Wu YH, Chiang WL (2005a). Fuzzy Controllers for Nonlinear Interconnected TMD Systems with External Force. J.

Chinese Instit. Eng., 28: 175-181.

Hsiao FH, Chiang WL, Chen CW (2005d). Fuzzy Control for Nonlinear Systems via Neural-Network-Based Approach. Int. J. Comput. Methods Eng. Sci., Mech., 6: 145- 152.

Hsiao FH, Chiang WL, Chen CW, Xu SD, Wu SL (2005c). Application and Robustness Design of Fuzzy Controller for Resonant and Chaotic Systems with External Disturbance. Int. J. Uncertainty, Fuzziness Knowl. Based Syst., 13: 281-295.

Hsiao FH, Hwang JD, Chen CW, Tsai ZR (2005b). Robust Stabilization of Nonlinear Multiple Time-Delay Large-scale Systems via Decentralized Fuzzy Control. IEEE Trans. Fuzzy Syst., 13: 152- 163.

Hsieh TY, Wang MHL, Chen CW (2006). A New Viewpoint of S-Curve Regression Model and its Application to Construction Management. Int. J. Artif. Intell., Tools 15: 131-142.

Hsu WK, Huang PC, Chen CW, Chang CC, Hung DM, Chiang WL (2010). A flood risk assessment model for Taiwan. Natural Hazards, DOI 10.1007/s11069-011-9732-9.

Hsu WK, Huang PC, Chang CC, Chen CW, Hung DM, Chiang WL (2011). An integrated flood risk assessment model for property insurance industry in Taiwan. Natural Hazards 58(3): 1295-1309.

Hush D, Wood C (1998). Analysis of tree algorithms for RFID arbitration. IEEE Int. Symp. Information Theory (ISIT)., p.107.

Kucuksille EU, Yigit T, Gunes A (2010). A system for the detection and reporting of wireless modem signals. Sci. Res. Essays., 5(11): 1346-1350.

Kuo HM, Chen CW (2011). Application of quality function deployment to improve the quality of Internet shopping website interface design. International Journal of Innovative Computing, Information and Control 7(1): 253-268.

Kuo HM, Chen CW (2011a). Application of quality function deployment to improve the quality of Internet shopping website interface design. Int. J. Innov. Comput. Inf. Control., 7(1): 253-268.

Kuo HM, Chen CW (2011b). A novel viewpoint of information and interface design for auction website. Human Factors and Ergonomics in Manufacturing & Service Industries, DOI: 10.1002/hfm.20274.

Kuo HM, Chen CW (2012a). A novel viewpoint of information and interface design for auction website. Human Factors and Ergonomics in Manufacturing & Service Industries, DOI: 10.1002/hfm.20274.

Kuo HM, Chen CW (2012b). A study of B2C supporting interface design system for the elderly. Human Factors and Ergonomics in Manufacturing & Service Industries, DOI: 10.1002/hfm.20297.

Kuo HM, Chen CW, Chen CW (2010). A behavioral model of the elderly Internet consumer: a case study. Int. J. Innov. Comput. Inf. Control., 6(8): 3507-3518.

Kuo HM, Chen CW, Chen CW (2011). A study of merchandise information and interface design on B2C websites. J. Marine Sci. Technol., 19(1): 15-22.

Kuo HM, Chen CW, Chen CW (2011). A study of merchandise information and interface design on B2C websites. J. Marine Sci. Technol., 19(1): 15-25.

Lee SC, Lin PH, Wang JS, Huang CH, Chen CY, Huang PH (2011b). Mass media in Taiwan and the formation of Chien-Ming Wang's baseball superstar image. Int. J. Phys. Sci., 6, 3000-3006.

Lee SC, Wang CC, Huang CC, Wang JS, Huang CH, Chen CY, Huang PH (2011a). The idolization of Chien-Ming Wang and social psychological factors in Taiwan. Int. J. Phys. Sci., 6, 2607-2612.

Lee WI, Chen CW (2012). A forecasting model for fresh food sales in POS database: a comparison between the logistic regression, moving average and BPNN methods. J. Marine Sci. Technol., DOI: 10.1177/1077546310381101.

Lee WI, Chen CW, Chen TH, Chen CY (2010a). The relationship between consumer orientation, service value, medical care service quality and patient satisfaction: The case of a medical center in Southern Taiwan. Afr. J. Bus. Manage., 4: 448-458.

Lee WI, Chen CW, Wu CH (2010b). Relationship between quality of medical treatment and customer satisfaction - a case study in dental clinic association. Int. J. Innov. Comput. Inf. Control .,6: 1805-1822.

Lee WI, Chen CY, Kuo HM, Sui YC (2010c). The development of half-circle fuzzy numbers and application in fuzzy control. J. Vibrat. Control., 16(13): 1977-1987, DOI: 10.1177/1077546309349849.

Lee WI, Chiu YT, Liu CC, Chen CY (2011c). Assessing the effects of consumer involvement and service quality in a self-service setting.

Human Factors and Ergonomics in Manufacturing & Service Industries, DOI: 10.1002/hfm.20253.

Lee, WI (2010). The development of a qualitative dynamic attribute value model for healthcare institutes, Iranian J. Public Health, 39(4): 15-25.

Lin CL, Wang JF, Chen CY, Chen CW, Yen CW (2009b). Improving the generalization performance of RBF neural networks using a linear regression technique. Exp. Syst. Appl. 36: 12049-12053.

Lin JW, Chen CW, Chung SH (2011b). Modeling and assessment of bridge structure for seismic hazard prevention. Natural Hazards, DOI 10.1007/s11069-011-9969-3.

Lin JW, Chen CW, Hsu TC (2012a). Fuzzy statistical refinement for the forecasting of tenders for roadway construction. J. Marine Sci. Technol., 10.1177/1077546310397561.

Lin JW, Chen CW, Peng CY (2012b). Kalman filter decision systems for debris flow hazard assessment. Natural Hazards, DOI 10.1007/s11069-011-9907-4.

Lin ML and Chen CW (2012). Stability analysis of community and ecosystem hierarchies using the Lyapunov method. J. Vibration Cont., DOI: 10.1177/1077546310385737.

Lin ML, Chen CW (2010a). Application of fuzzy models for the monitoring of ecologically sensitive ecosystems in a dynamic semi-arid landscape from satellite imagery. Eng. Comput., 27: 5-19.

Lin ML, Chen CW (2010b). Stability analysis of community and ecosystem hierarchies using the Lyapunov method. Journal of Vibration and Control, DOI: 10.1177/1077546310385737.

Lin ML, Chen CW (2011). Using GIS-based spatial geocomputation from remotely sensed data for drought risk-sensitive assessment. Int. J. Innov. Comput. Inf. Control, 7(2): 657-668.

Lin ML, Chen CW (2011). Using GIS-based spatial geocomputation from remotely sensed data for drought risk-sensitive assessment. International Journal of Innovative Computing, Information and Control 7(2): 657-668.

Lin ML, Chen CW, Wang QB, Cao Y (2009a). Fuzzy model-based assessment and monitoring of desertification using MODIS satellite imagery. Eng. Comput., 26: 745-760.

Liu FR, Hsu CY, Yek K, Chen CW (2011a). Hierarchical analytic network process and its application in environmental impact evaluation. Civil Engineering and Environmental Systems 28(1): 1-18.

Liu K FR, Lu CF, Chen CW, Shen YS (2012a). Applying Bayesian belief networks to health risk assessment. Stochastic Environmental Research & Risk Assessment, DOI 10.1007/s00477-011-0470-z.

Liu TY, Chiang WL, Chen CW (2011b). Identification and monitoring of bridge health from ambient vibration data. J. Vibration Cont., 17(4): 589-603.

Liu TY, Chiang WL, Chen CW (2012b). Structural system identification for vibration bridges using the Hilbert-Huang transform. Journal of Vibration and Control.

Liu TY, Chiang WL, Chen CW, Hsu WK, Lu LC, Chu TJ (2011). Identification and monitoring of bridge health from ambient vibration data. J. Vibrat. Control., 17(4): 589-603.

Lu LT, Chiang WL, Tang JP, Liu MY, Chen CW (2003). Active Control for a Benchmark Building Under Wind Excitations. J.Wind Eng. Ind. Aerodyn., 91(4): 469-493.

Mark de B., Marc van K, Mark O, Otfried S (2000). Computational Geometry: Algorithms and Applications, 2nd Ed, Springer, Berlin.

Shamshirb S, Kalantari S, Bakhshandeh Z (2010). Designing a smart multi-agent system based on fuzzy logic to improve the gas consumption pattern. Sci. Res. Essays., 5(6): 592-605.

Shen CW, Cheng MJ, Chen CW, Tsai FM, Cheng YC (2011). A fuzzy AHP-based fault diagnosis for semiconductor lithography process. Int. J. Innov. Comput. Inf. Control., 7(2): 805-816.

Shen CW, Cheng MJ, Chen CW, Tsai FM, Cheng YC (2011). A fuzzy AHP-based fault diagnosis for semiconductor lithography process. International Journal of Innovative Computing, Information and Control 7(2): 805-816.

Shih BY, Chang CJ, Chen AW, Chen CY (2010c). Enhanced MAC Channel Selection to Improve Performance of IEEE 802.15.4. Int. J. Innov. Comput. Inf. Control, 6: 5511-5526.

Shih BY, Chen CY, Chang H, Ma JM (2011b). Dynamics and control for robot manipulators using a greedy algorithm approach. Journal of Vibration and Control, DOI: 10.1177/1077546311407649.

Shih BY, Chen CY, Chou WC (2011a). Obstacle avoidance using a path correction method for autonomous control of a biped intelligent robot. J. Vibration Cont., DOI: 10.1177/1077546310372004.

Shih BY, Chen CY, Li CE (2010d). The exploration of mobile mandarin learning system by the application of TRIZ theory. Computer Applications in Engineering Education DOI : 10.1002/cae.20478.

Shih BY, Chen CY, Shih CH, Tseng JY (2010a). The development of enhancing mechanisms for improving the performance of IEEE 802.15.4. Int. J. Phys. Sci., 5: 884-897.

Shih BY, Lee WI, Chen CY (2011d). A hybrid artificial intelligence sales-forecasting system in the convenience store industry. Human Factors and Ergonomics in Manufacturing & Service Industries, DOI: 10.1002/hfm.20272.

Shih BY, Shih CH, Li CC, Chen TH, Chen YH, Chen CY (2011d). Elementary school student's acceptance of Lego NXT: The technology acceptance model, a preliminary investigation. Int. J. Phys. Sci., 6 (22): HYPERLINK

Shih CH, Wakabayashi N, Yamamura S, Chen CY (2011c). A context model with a time-dependent multi-layer exception handling policy. Int. J. Innov. Comput. Inf. Control., 7(5A): 2225-2234.

Shih CH, Yamamura S, Chen CY (2010b). Analysis of control structure for turning maneuvers. Mathematical Problems in Engineering 2010, DOI:10.1155/2010/481438.

Su TJ, Cheng JC, Huang MY, Lin TH, Chen CW (2012). Applications of cellular neural networks to noise cancellation in gray images based on adaptive particle swarm optimization. Circuits, Systems, and Signal Processing, DOI 10.1007/s00034-011-9269-x.

Tang JP, Chiou DJ, Chen CW, Chiang WL, Hsu WK, Chen CY, Liu TY (2011). A case study of damage detection in benchmark buildings using a Hilbert-Huang Transform-based method. J. Vibrat. Control., 17(4): 623-636.

Tang JP, Chiou DJ, Chen CW, Chiang, WL, Hsu, W K, Liu TY (2011). A case study of damage detection in benchmark buildings using a Hilbert-Huang Transform-based method. J. Vibration and Cont.,17(4): 623-636.

Trabia MB, Renno JM, Moustafa KAF (2008). Generalized design of an anti-swing fuzzy logic controller for an overhead crane with hoist. J. Vibrat. Control., 14: 319-346.

Tsai CH, Chen CW (2010). An earthquake disaster management mechanism based on risk assessment information for the tourism industry-A case study from the island of Taiwan. Tourism Manage., 31(4): 470-481.

Tsai CH, Chen CW (2011). The establishment of a rapid natural disaster risk assessment model for the tourism industry. Tourism Manage., 32(1): 158-171.

Tsai CH, Chen CW (2011a). The establishment of a rapid natural disaster risk assessment model for the tourism industry.Tourism Management 32(1): 158-171.

Tsai CH, Chen CW (2011b). Development of a mechanism for typhoon and flood risk assessment and disaster management in the hotel industry - a case study of the Hualien area. Scandinavian Journal of Hospitality and Tourism 11(3): 324-341.

Tsai CH, Chen CW, Chiang WL, Lin ML (2008). Application of Geographic Information System to the Allocation of Disaster Shelters via Fuzzy Models. Eng. Comput. Int. J. Comput. Aided Eng. Software., 25: 86-100.

Tseng CP, Chang ML, Chen CW (2012a). The human factors of knowledge sharing intention among Taiwanese enterprises: a preliminary study. Human Factors and Ergonomics in Manufacturing & Service Industries, DOI 10.1002/hfm.20284.

Tseng CP, Chen CW (2012). Natural disaster management mechanisms for probabilistic earthquake loss. Natural Hazards,DOI 10.1007/s11069-011-9889-2.

Tseng CP, Chen CW, Liu FR (2011). Risk control allocation model for pressure vessels and piping project. Journal of Vibration and Control, DOI: 10.1177/1077546311403182.

Tseng CP, Chen CW, Liu FR (2012b). Risk control allocation model for pressure vessels and piping project. Journal of Vibration and Control, DOI: 10.1177/1077546311403182.

Tseng CP, Chen CW, Tu YP (2012c). A new viewpoint on risk control decision models for natural disasters. Natural Hazards, DOI 10.1007/s11069-011-9861-1.

Tseng IF, Chen CY, Kuo HM (2009). Nonlinear internal wave run-up on impermeable steep slopes. J. Offshore Mech. Arctic Eng. ASME., 131 (4): doi:10.1115/1.3168528.

Tu JW, Qu WL, Chen J (2008). An experimental study on semi-active seismic response control of a large-span building on top of ship lift towers. J. Vibrat. Control., 14: 1055-1074.

Uddin J, Reaz MBI, Hasan MA (2010). UHF RFID antenna architectures and applications. Sci. Res. Essays., 5(10): 1033-1051.

Wang TP (2006). Enhanced binary search with cut-through operation for anti-collision in RFID systems. IEEE commun. lett., 10(4): 236-238.

Yang CH, Chen TH, Chen CW, Chen CY, Liu CT (2008b). Accuracy evaluation of a diagnostic test by detecting outliers and influential observations. China Ocean Eng., 22: 421-429.

Yang HC, Chen CY, Chen CW, Chen TH (2008a). Estimation on internal wave reflection in a two-layer fluid system by cumulative logistic regression model. J. Marine Sci. Technol., 16: 44-51.

Yeh K, Chen CW (2010). Stability analysis of interconnected fuzzy systems using the fuzzy Lyapunov method. Mathematical Problems in Engineering- An Open Access J., p. 10 Doi: 10.1155/2010/734340.

Yeh K, Chen CW, Lo DC, Liu KFR (2012). Neural-network fuzzy control for chaotic tuned mass damper systems with time delays. Journal of Vibration and Control, DOI: 10.1177/1077546311407538.

Yeh K, Chen CW, Lo DC (2011). Neural-network fuzzy control for chaotic tuned mass damper systems with time delays. Journal of Vibration and Control, DOI: 10.1177/1077546311407538.

Yeh K, Chen CY, Chen CW (2008). Robustness Design of Time-Delay Fuzzy Systems Using Fuzzy Lyapunov Method. Appl. Math. Comput., 205: 568-577.

Yildirim S, Erkaya S, Eski I, Uzmay I (2009). Noise and vibration analysis of car engines using proposed neural network. J. Vibrat. Control, 15: 133-156.

Yu SE, Li MY Leon, Huarng KH, Chen TH, Chen CY (2011b). Model construction of option pricing based on fuzzy theory. J. Marine Sci. Technol., 19 (5): 460-469.

Yu SES, Huarng KH, Li MYL, and Chen CY. (2011). A novel option pricing model via fuzzy binomial decision tree. Int. J. Innov. Comput. Inf. Control., 7: 709-718.

Zhao FG, Chen J, Guo L, Li X (2009). Neuro-fuzzy based condition prediction of bearing health. J. Vibrat. Control., 15: 1079-1091.