Article

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Obstacle avoidance design for a humanoid intelligent robot with ultrasonic sensors

Chen-Yuan Chen, Bih-Yaw Shih, Wei-Chung Chou, Ya-Ju Li and Yi-Hsuan Chen

Abstract

A behavioral strategy designed for a humanoid intelligent robot for the purpose of obstacle avoidance with ultrasonic sensors is proposed and implemented on an autonomous humanoid robot. A mechanical structure with 4 degrees-of-freedom is designed so that a small-size humanoid robot named ARSR is able to avoid obstacles by different types of walking motion. Four ultrasonic sensors are mounted on the ARSR to sense environmental information and detect obstacles. Based on the information obtained from these sensors, a decision tree method is proposed to decide upon one behavior from three possible types of movement: walk forward, turn left and turn right. Meanwhile, three experiments are carried out to show how the robot can autonomously avoid obstacles to effectively arrive at its destination. The result shows that the proposed algorithm outperforms previous obstacle avoidance algorithm by reducing around 25% of time.

Keywords

Decision tree, humanoid intelligence robot, obstacle avoidance, ultrasonic sensor

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1. Introduction

Mobile robots are increasingly being developed for planetary exploration, mining, forestry, hazardous site clean-up, logistics, surveillance, fire rescue missions and soldier assistance military applications (Schempf, 2009; Wang and Liu, 2008).

Eventually, a type of intelligent robot is required, able to avoid obstacles to reach its goal. Usually, an intelligent bipedal robot is ideal for these situations and can provide short-range remote eyes and ears for a variety of potential missions (Li et al., 2009; Manoonpong and Worgotter, 2009) in spatially confined areas and evade obstacles more than other kinds of robots.

Their mobility provides flexible deployment, such as by being placed in advance, being deployed by human beings or even by larger robots and can be easily transported (Braunl and Graf, 2000; Feng et al., 2010; Zhao et al., 2009). Meanwhile, the low cost allows large numbers of robots to be used in one mission. Furthermore, each robot can work independently and is adaptable to changing environments. One crucial problem of the small size robot is the difficulty of locomotion and assemblies of parts including sensor, computing processor as well as power subsystems in a limited space due to their small available space (Joh et al., 2010; Ozturk and Nagarnaik, 2010; Vazquez-Martin et al., 2009). Moreover, the robot must be as mobile as possible to avoid obstacles efficiently by several design requirements (Burguera et al., 2009; Shieh and Chang, 2009; Udengaard and Iagnemma, 2009). The Lego Mindstorms NXT provides a simple shape with an Intelligent Brick as the brain of the biped robot, servo motors for locomotion and sensors for sensing environmental information. Therefore, any proposed obstacle avoidance algorithm can be implemented and tested with it.

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In this study, a mechanical structure with 4 degrees-of-freedom (d.f.) implemented in a Lego Mindstorms NXT Alpha Rex Model, called ARSR (Chen et al., 2010; Shih et al., 2010). Four ultrasonic sensors are mounted on the ARSR to sense environmental information, detect obstacles and accomplish three types of walking motions, forward, turning left and turning right. Based on the information obtained from the sensors, a decision tree method is proposed to decide upon one behavior from these three types of movements which allow ARSR to avoid obstacles and reach destination effectively.

2. Intelligent robot design

The Lego Mindstorms NXT is made of the compact, modular end-user robotics as the experimental robot which is very simple to configure and program. No prior engineering knowledge was needed to configure these devices to work properly with the plug and play nature of sensors and motors used. The Lego Mindstorms NXT robot operates on six AA batteries. The morphology of this robot is also completely customizable. For the work outlined here, the configuration employed is shown in Figure 1 which a very simple shape was built by using Lego NXT Intelligent Brick as the brain of the biped robot incorporating two servo motors and four ultrasonic sensors. Two servo motors

Figure 1. The intelligent biped robot with four ultrasonic sensors.

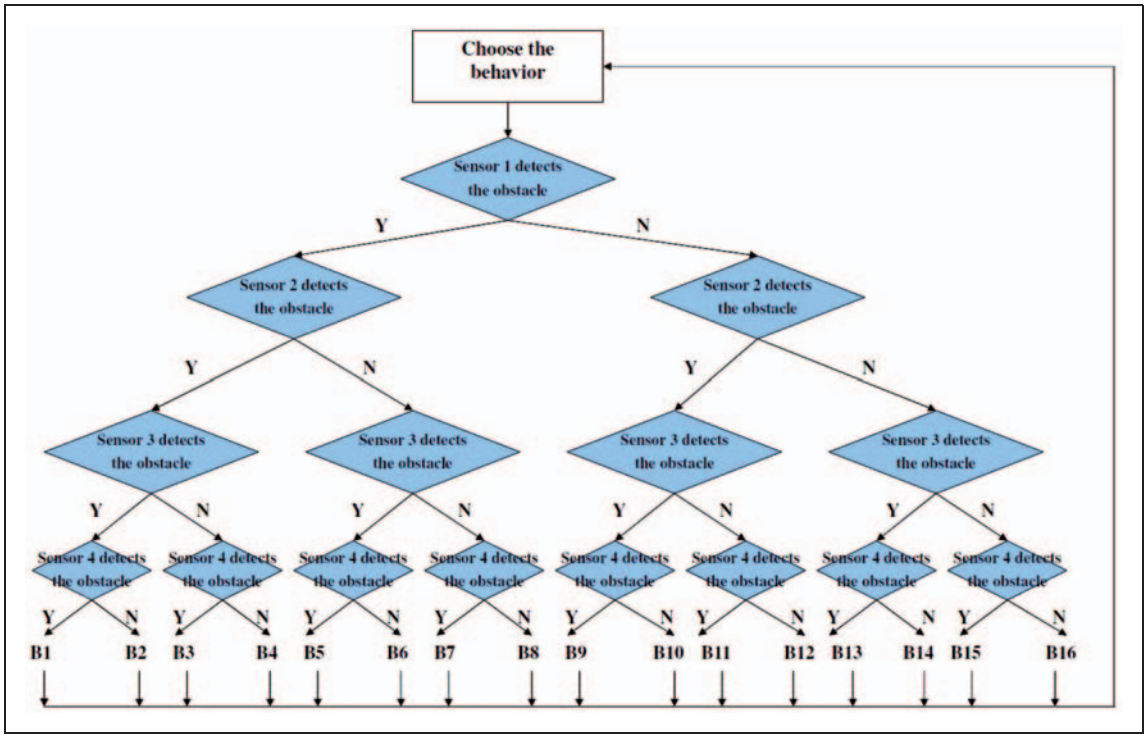
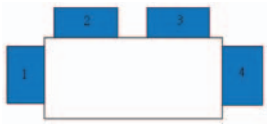
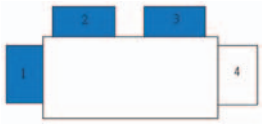
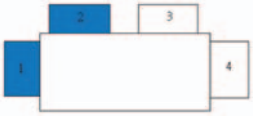
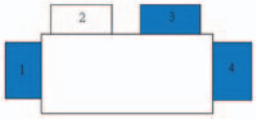
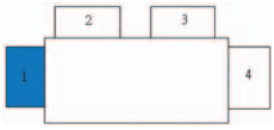


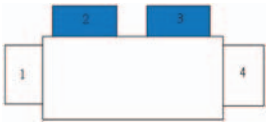
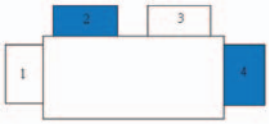
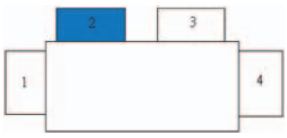
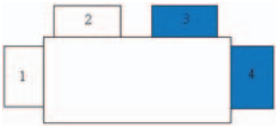
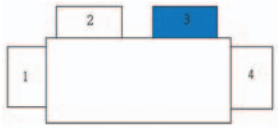
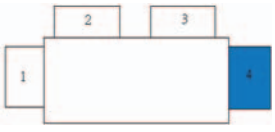
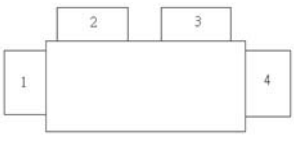
Figure 2. Decision tree of obstacle avoidance strategy for the intelligent bipedal robot.

Table 1. Behavioral situations and their corresponding movements

Behavior situation	Sensor situation	Decided movement
B1		Turn left
B2		Turn right
B3		Turn right
B4		Turn right
B5		Turn left
B6		Turn left
B7		Move Forward
B8		Turn right

(continued)

Table 1. Continued

Behavior situation	Sensor situation	Decided movement
B9		Turn left
B10		Turn right
B11		Turn right
B12		Turn right
B13		Turn left
B14		Turn left
B15		Turn left
B16		Continue forward

are used in robot's two legs for locomotion and the four ultrasonic sensors are used as eyes for robot acquire environmental distance information. The Intelligent Brick controls ultrasonic sensors and servo motors which commands two servo motors for controlling walking and turning directions. It also receives information from four ultrasonic sensors for control program making decisions (Jolly et al., 2007) about the ARSR's next movement: forward, left or right. The distance information acquire from four ultrasonic sensors is used to provide a control program with branch-like decision-making ability.

3. System implementation

Based on the information from four ultrasonic sensors, a branch-like decision-making algorithm for obstacle avoidance is proposed and implemented on a Lego Mindstorms NXT Intelligent Brick with the bipedal robot. Compared with other popular bipedal robots as shown in Table 2, the Lego Mindstorms NXT has the advantage of low cost, user friendly programming tool and flexible with embedded sensors.

In the decision tree of obstacle avoidance, the ARSR continues moving forward until it approaches an obstacle. When it meets an obstacle, it stops, at which point the program goes into decision-making mode. A decision tree method (Seraji and Howard, 2002) based on four ultrasonic sensors is proposed as shown in Figure 2. The behavioral output of the decision tree is the robot's three basic motions including go forward, turn left and turn right. Sixteen behavioral situations and their corresponding movements are described in Table 1. The obstacle avoidance strategy will check the relative behavior from the decision tree before the ARSR moves. After the ARSR navigates around an obstacle and is in a safe situation it will continue moving forward (situation B16). The algorithm will continue performing these decision processes until there are no more obstacles.

4. Experimental results

Field tests are conducted to verify the feasibility of the proposed obstacle avoidance decision tree method. The experimental environment was set in an enclosed area and one real experimental process is shown in Figure 3. Three experimental trajectory of the intelligent bipedal robot is shown in Figure 4. In the study, the number of forward steps, turning times and how long the whole process takes are utilized to evaluate the performance of the algorithm. The results of the three experiments' data including forward steps, turning times and how long the whole process takes are compared with the results of a prior obstacle avoidance algorithm as shown in Figures 5 to 7.

When the first experiment begins, the ARSR starts forward locomotion until it meets an obstacle. Then, it stops and follows decision process to decide next behavior.

Since the left side distance is closer than the right side distance, the ARSR makes a right turn to avoid the obstacle. It continues moving forward to walk around the obstacle. After walking around the obstacle the ARSR encounters another obstacle.

When another obstacle is met, the robot again stops and acquires the distance information from the four ultrasonic sensors. At present, the left side distance is longer than the right side distance, and the ARSR makes a left turn to avoid the obstacle. Then the ARSR continues to move forward, until it re-meets an obstacle. Then, the ARSR chooses a right turn because the right side distance is longer. After passing the obstacle, the ARSR resumes forward locomotion. When the ARSR reaches its destination, it stops.

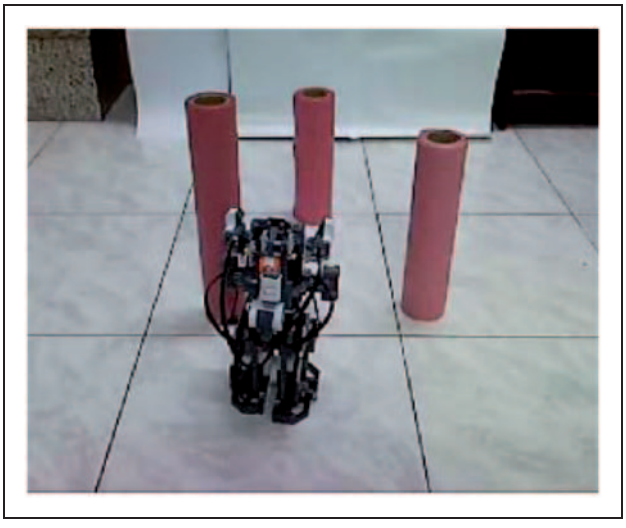


Figure 3. The experimental environment of the study.

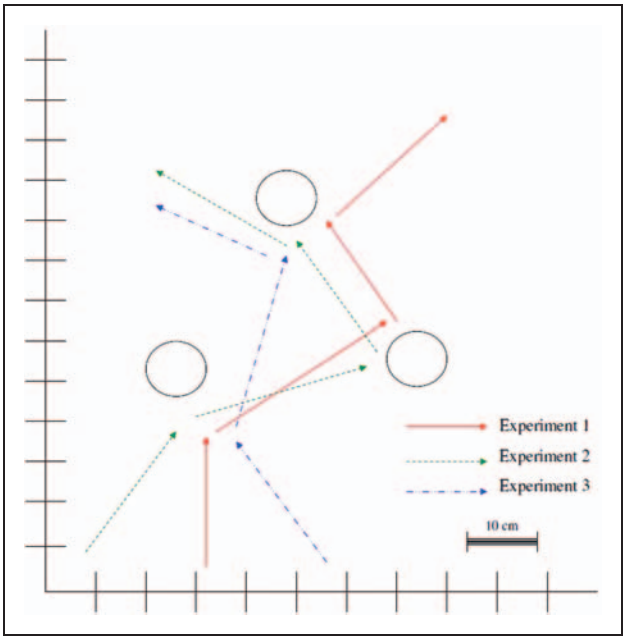


Figure 4. Three experimental trajectory of the intelligent bipedal robot.

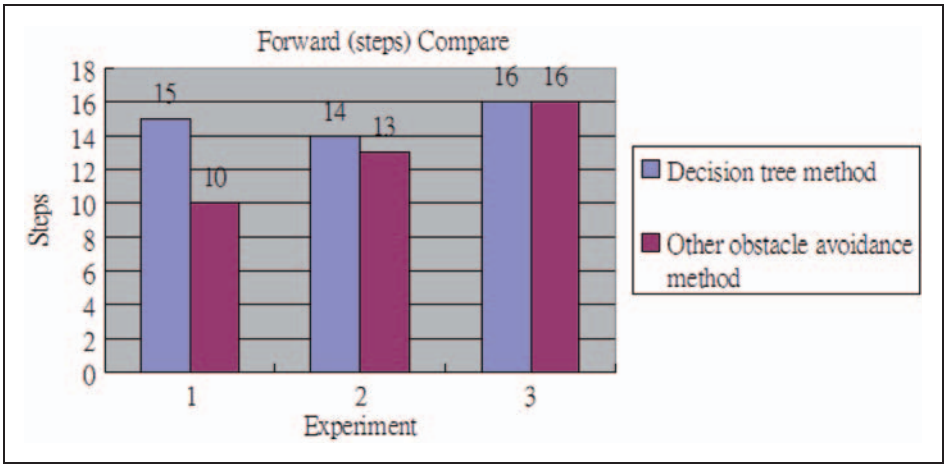


Figure 5. The number of forward steps of three experiments.

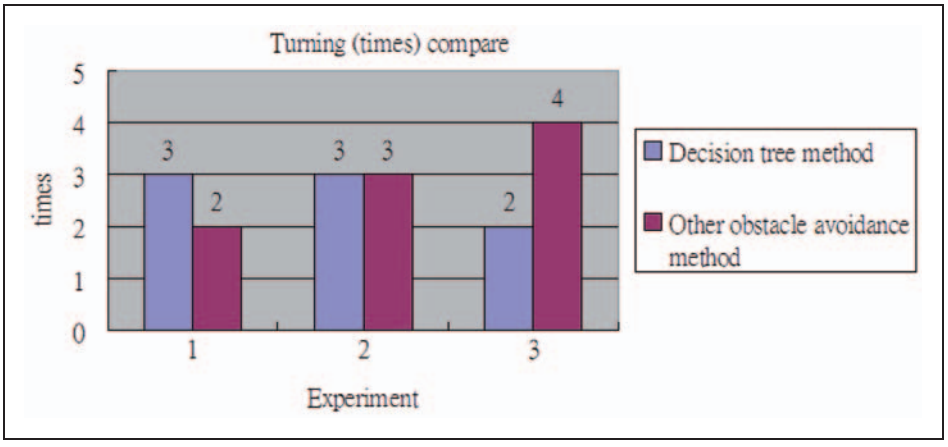


Figure 6. The number of turning times of three experiments.

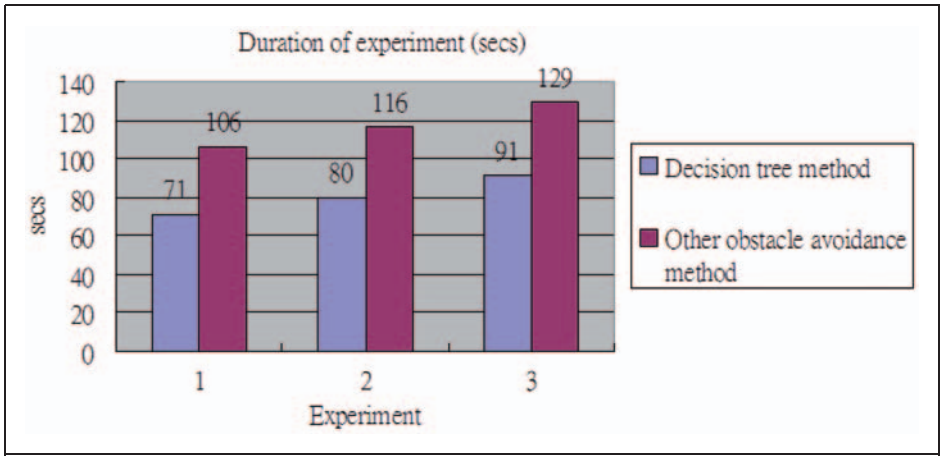


Figure 7. The duration of three experiments.

Table 2. Comparison of three popular bipedal robots

Product	Advantages	Disadvantages	Estimated cost
Kondo KHR-2	• The robot responds immediately to commands i.e., good for real-time operation • High performance servos, and scalable analog inputs • Simpler resin plastic joints	• Cannot turn or change direction while walking • Expensive (robot kit about USD $1400; ultrasonic sensor about USD $68)	Robot kit + four ultrasonic sensors = about USD $1672
16-DOF Robotinno kit	• Capable of throwing objects, punching, etc • Easy-to-use programming • A great way to learn about programming; even beginners can create subroutines with just the click of a mouse	• Not sure how the programming really works • Expensive (robot kit about USD $850; ultrasonic sensor about USD $38)	Robot kit + four ultrasonic sensors = about USD $1002
Lego Mindstorms NXT (Alpha Rex model)	• Easy-to-use programming • An autonomous 32-bit LEGO microprocessor that can be programmed using a PC or a Mac • Bluetooth support. • Much cheaper (robot kit about USD $280; ultrasonic sensor about USD $32)	• Cables are unique, you have to buy them from Lego • Less DOFs	Robot kit + four ultrasonic sensors = about USD $408

5. Conclusions

In this study, a behavioral strategy designed for a humanoid intelligent robot for the purpose of obstacle avoidance with ultrasonic sensors is proposed. The ARSR was specifically designed to verify the usefulness of the proposed method which is able to move around an indoor environment and the hardware used to build the robot is inexpensive, and easy to obtain, as shown in Table 2. An easy reachable humanoid intelligent robot can be built by using Lego Mindstorms NXT with four ultrasonic sensors for testing the proposed mechanism.

Meanwhile, the results of three experiments show that the proposed obstacle avoidance decision tree method outperform the prior obstacle avoidance method. In addition, the efficiency of the proposed algorithm and the ARSR biped walking structure are evaluated. The proposed method needs only 1 minute and 31 seconds to cross over three obstacles and the prior obstacle avoidance method takes more than 2 minutes to cross over three obstacles.

Several sequences of experiments demonstrate that the ARSR performs a robust obstacle avoidance function. To achieve the goal of a robust bipedal robot, the NXT-G program is used to design the control program of the ARSR. The experimental results show the effective performance of the obstacle avoidance functions. Although the results appear promising, the ARSR has some limitations. In particular, the environment does not guarantee optimal performance every time, especially when an obstacle interferes with the ultrasonic sensor's detection ability. Also, the slipperiness of the floor could also hamper the ARSR's walking ability. In other words, when the floor is slippery (Tada and Hosoda, 2007), the ARSR may not walk in a straight line.

There remains a lot of work to be completed. To have real time obstacle avoidance ability (Fahimi et al., 2009), the ARSR needs an on-line communication function (Peyrard, 2008). Hence, future work could be done using wireless data transmission devices (Barnes and Counsell, 2003; Valera et al., 2007) to give the ARSR the ability to have real time obstacle avoidance functions.

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Retraction notice

The following article has been included in a multiple retraction:

Chen CY, Chen T-H, Chen Y-H, Yu S-E and Chung P-Y (2013) Information technology system modeling an integrated C-TAM-TPB model to the validation of ocean tidal analyses *Journal of Vibration and Control* Epub ahead of print 7 May 2013. doi: 10.1177/1077546312472924

In 2013 the Editor of *Journal of Vibration and Control* and SAGE became aware of a peer review ring involving assumed and fabricated identities that appeared to centre around Peter Chen at National Pingtung University of Education, Taiwan (NPUE). SAGE and the Editor then began a complex investigation into the case during the rest of 2013 and 2014. Following an unsatisfactory response from Peter Chen, NPUE was notified.

NPUE were serious in addressing the Journal and SAGE's concerns. NPUE confirmed that the institution was investigating Peter Chen. SAGE subsequently uncovered a citation ring involving the above mentioned author and others.

We regret that individual authors have compromised the academic record by perverting the peer review process and apologise to readers. On uncovering problems with peer review and citation SAGE immediately put steps in place to avoid similar vulnerability of the Journal to exploitation in the future. More information may be found at
www.sagepub.co.uk/JVC_Statement_2014.

The Journal and SAGE understand from NPUE that Peter Chen has resigned his post at NPUE.

The following articles are retracted because after thorough investigation evidence points towards them having at least one author or being reviewed by at least one reviewer who has been implicated in the peer review ring and/or citation ring. All authors have had an opportunity to respond to the allegations and proposed actions.

OnlineFirst articles (these articles will not be published in an issue)

Chen CY, Chen T-H, Chen Y-H, Yu S-E and Chung P-Y (2013) Information technology system modeling an integrated C-TAM-TPB model to the validation of ocean tidal analyses *Journal of Vibration and Control* Epub ahead of print 7 May 2013. doi: 10.1177/1077546312472924

Chang R-F, Chen CY, Su F-P and Lin H-C (2013) A two-step approach for broadband digital signal processing technique *Journal of Vibration and Control* Epub ahead of print 26 April 2013. doi: 10.1177/1077546312472925

Chen TH, Chang CJ, Yu SE, Chung PY and Liu C-K (2013) Nonlinear information analysis and system management technique: the influence of design experience and control complexity *Journal of Vibration and Control* Epub ahead of print 12 April 2013. doi: 10.1177/1077546312473321

Chen CY, Shih BY, Chen YH, Yu SE and Liu YC (2013) The exploration of a 3T flow model using vibrating NXT: II. Model validation *Journal of Vibration and Control* Epub ahead of print 10 April 2013. doi: 10.1177/1077546312470481

Chen CY, Shih BY, Chen YH, Yu SE and Liu YC (2013) The exploration of 3T flow model using vibrating NXT: I. model formulation *Journal of Vibration and Control* Epub ahead of print 6 February 2013. doi: 10.1177/1077546312467360

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Articles published in an issue

Chen C-W (2014) Applications of neural-network-based fuzzy logic control to a nonlinear time-delay chaotic system *Journal of Vibration and Control* 20 (4): 589–605. Epub ahead of print 5 November 2012. doi: 10.1177/1077546312461370

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Retraction notice

In 2013 the Editor of *Journal of Vibration and Control* and SAGE became aware of a peer review ring involving assumed and fabricated identities that appeared to centre around Peter Chen at National Pingtung University of Education, Taiwan (NPUE). SAGE and the Editor then began a complex investigation into the case during the rest of 2013 and 2014. Following an unsatisfactory response from Peter Chen, NPUE was notified.

NPUE were serious in addressing the Journal and SAGE's concerns. NPUE confirmed that the institution was investigating Peter Chen. SAGE subsequently uncovered a citation ring involving the above mentioned author and others.

We regret that individual authors have compromised the academic record by perverting the peer review process and apologise to readers. On uncovering problems with peer review and citation SAGE immediately put steps in place to avoid similar vulnerability of the Journal to exploitation in the future. More information may be found at www.sagepub.co.uk/JVC_Statement_2014.

The Journal and SAGE understand from NPUE that Peter Chen has resigned his post at NPUE.

The following articles are retracted because after thorough investigation evidence points towards them having at least one author or being reviewed by at least one reviewer who has been implicated in the peer review ring and/or citation ring. All authors have had an opportunity to respond to the allegations and proposed actions.

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