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Visual Navigation Control System for Home Robots

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Abstract: This study addressed the design of a home robot based on the visual navigation control system. In order to accomplish basic home services, the robot is designed to have the functions of environmental map construction, autonomous navigation, collision-free control and human-robot interaction. For environmental sensing and object tracking, a series of image features recognition procedures are used to establish the database of objective images. By integrating image information of objectives and ground lines, the robot can determine the relative localities of specific objectives and then perform environmental map construction and robot localization. Moreover, the user can also control the robot remotely to navigate and construct the environmental map through the interaction website. The experimental results demonstrate the environmental adaptability of the robot based on the proposed visual navigation control system.

Key words: Home robot, navigation control system, collision-free control, localization, human-robot interaction

INTRODUCTION

The fundamental problems, while an autonomous robot navigates in home environment, consist of "Where is the robot?", "Where is the robot going?" and "How does the robot do?" In order to solve such problems, one can design the robot based on the scheme of perception, localization, cognition and motion control. For example, the robot firstly detects the real environmental objects, obtains raw data of sensing and then extracts useful information. Next, the robot recognizes and determines its position according to the knowledge base of the environment model, the local map and the global map. As follows, the robot realizes the mission commands, executes relative motion controls and acts the desired behaviors and/or tasks. Finally, repeat these processes as long as needed until the mission is accomplished.

However, the scheme mentioned above consists of various complicated techniques. Take environment detection for example, a complete detection needs to integrate multi-sensing data and based on various respective processes. But in real researches of distance estimation, some scholars only adopt laser range finder to search the obstacles or objectives around the robot and the others just utility one of ultrasonic, infrared, visual or other sensing methods (Idris *et al*., 2009; Jarjes *et al*., 2010; Mehrjerdi *et al*., 2010; Yuan *et al*., 2010; Yufeng *et al*., 2011; Shieh *et al*., 2011). Especially, since the computation efficiency of processing systems is highly improved, there are more and more researches focus on visual techniques (Islam *et al*., 2011; Kamaljit *et al*., 2011; Liao and Lee, 2010; Lu *et al*., 2006; Mala and Geetha, 2008; Nouri *et al*., 2011; Tsai *et al*., 2007; Ryde and Hu, 2005; Krose *et al*., 2004) to solve the objective estimation in uncertain environment.

In general, the location of a mobile robot will be decided according to its relative position and/or absolute position. The odometry and inertial navigation are commonly used to determine the robot relative positions from a reference start by highly updating. However, since the odometry has an unbounded accumulation of errors, frequent correction made from other sensors becomes necessary.

Relatively, for absolute positioning, the robot usually needs to detect and recognize the features in environment while it navigates. As similar as human experiences of finding places, if the robot could memorize and recognize the environment features such as landmarks, it will be able to locate itself and figure the environment. Many researchers are devoted to such topics which some focus on feature-based problems and some make efforts in map-based problems.

Liao and Lee (2010) addresses the artificial landmark model in 3D structure of multicolored planar pattern and a robust tracking algorithm for the navigation of indoor mobile robots. Besides, there were extensive works over the past fifteen years in the field of vision-based lane and road detection for autonomous vehicles (Liao and Lee, 2010; Ryde and Hu, 2005; Krose *et al*., 2004). Krose *et al*. (2004) present how the omnidirectional vision system is applied for basic mobile robot navigation. The proposed PCA based image

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processing and *k*-d tree data searching methods benefit localization and environment learning of home robots.

Recently, probability-based methods are widely used to solve robot localization problems. The famous one is Monte Carlo Localization (MCL) algorithm. From the applications proposed by Ma *et al*. (2005), Wolf *et al*. (2005) and Liang *et al*. (2010), one can see that MCL uses many samples during global localization when they are needed, whereas the sample set size is small during tracking, when the position of the robot is approximately known. Liang *et al*. (2010) propose a vision-based localization method which is a combination of Monte Carlo Localization (MCL) (Al-Nasser and Al-Talib, 2010; Nath and Bhattacharjee, 2011) and extended Kalman filter (EKF) (Asseu *et al*., 2010; Hernane *et al*., 2010; Vashani *et al*., 2010) enhancement. The results demonstrate the scheme reduces perceptual errors and increases precision and stability.

In order to locate the robot in environment by detecting landmarks, it needs to recognize them as follows by the knowledge of landmark locations. The vanishing lines and vanishing points of corridors in the environment are useful for determining the relative orientation and position of a mobile robot. Tardos *et al*. (2002) and Yang and Tsai (1999), discuss how to adopt the features in the environment such as the boundaries of ceiling and corridors as guidance for robot navigation.

In this study, the proposed home robot is based on a visual navigation system. By detecting and recognizing environmental features, the robot could locate itself in the known map. Besides, the fuzzy controller aims to provide collision-free controls according to the determination of the vanishing lines and points. The proposed scheme is also able to be implemented for tracking specified objects within unknown environment.

THE SYSTEM CONFIGURATION

The proposed system is implemented in the home robot as shown in Fig. 1. It is two-wheel driven by two DC servo motors. A touch monitor and two LED array display modules are mounted on its head for human-robot interaction. Its head also consists of a force sensor as the emergency stop button, a microphone for acoustic detection and conversation and a web camera for visual perception. It includes the computation units and controllers inside the middle part of the robot. There are eight ultrasonic sensors and four IR detectors assigned around the lumber region of the robot for obstacle estimation. The driver, batteries, wheels and DC servo motors are placed within the bottom level for motion actuation.

The ultrasonic, infrared ray, acoustic and visual sensors are adopted to detect and determine the features in environment. These sensory results are provided for

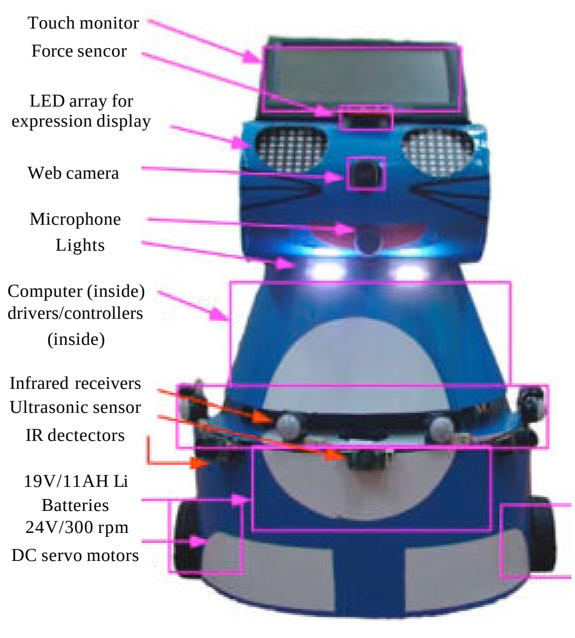

Fig. 1: The appearances of the “Fairy-II” robot

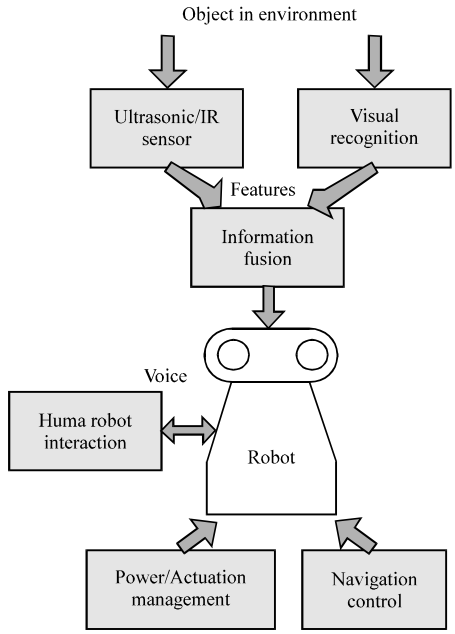

Fig. 2: The system structure of the "Fairy-II" robot

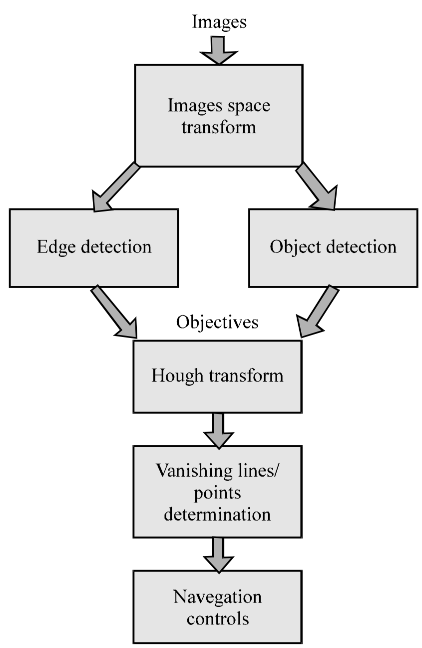

Fig. 3: The procedures of image processing

different control purposes. For example, the ultrasonic and infrared ray sensors are mainly for detecting obstacles and objects around the robot; the microphone receives voice commands for interaction; moreover, the camera captures the image sequences and the relative image processing units determine the features for detecting and recognizing objectives. As shown in Fig. 2, the robot also needs to integrate all sensory results and make appropriate controls and responses for carrying out the desired home tasks.

Figure 3 illustrates the procedures of image processing and visual servo control. The images captured from the camera are processing with image space transform, edge detection and object detection in order. Then, by recognizing the features, the direction and angular velocity of the robot could be determined for mobile controls.

VISION-BASED NAVIGATION CONTROL

In order to navigate in the environment, the robot needs to ensure a collision-free navigation and an autonomous movement on the desired trajectory. Hence, in this study, the proposed vision-based navigation control system consists of two parts: the one is the obstacle avoidance controller and another is the guiding and following controller.

For obstacle avoidance, the robot will detect the objects around it by ultrasonic and IR sensors firstly and then find out a collision-free passageway. Moreover, from the images obtained from the camera, the robot could detect and recognize whether obstacles are existed in the front region. While the system has detected some obstacles in the warning area, the robot will slow down, look for new possible passages and determine the appropriate controls for safe collision-free movement.

Under collision-free controls, the robot will perform fuzzy guiding controls according to the features determined by recognizing the images of passages. From the image of a hallway scene, it is easily seen there are various lines and segments. Since any two parallel lines will converge to a vanishing point in the image coordinate under perspective projection, one can adopt the positions of the vanishing points and the slopes of the vanishing lines as useful features to determine the relative posture and location of the robot.

The image is processing with filtering background, recognizing the blocks of the guiding lines and then determining the slopes and parameters of these lines by Hough transform. It finally results in the vanishing point as the input for fuzzy guiding controls.

Figure 4 illustrates the geometric relationship of vanishing point and lines. As the robot faces to different aspects on the central line of the pathway, the captured images as shown in Fig. 4a show there are different vanishing points (p and pr) converged by the vanishing lines of the same slopes. It is noted that the lateral position of the point p is left to that of the point pr because the robot turns towards right side.

However, under the conditions as the robots are towards to the front but on different lateral positions, the pairs of the vanishing lines with different slopes but converge to the same point. From the Fig. 4b, one also can see that the slope of the left vanishing line is larger than the reference one while the robot moves on the left way with respect to the reference.

Assume the slope of the reference vanishing line is S_{ref}, where the line is assigned by the left one of the vanishing lines as the robot moves on the central line. And the variable S denotes the slope of the left vanishing

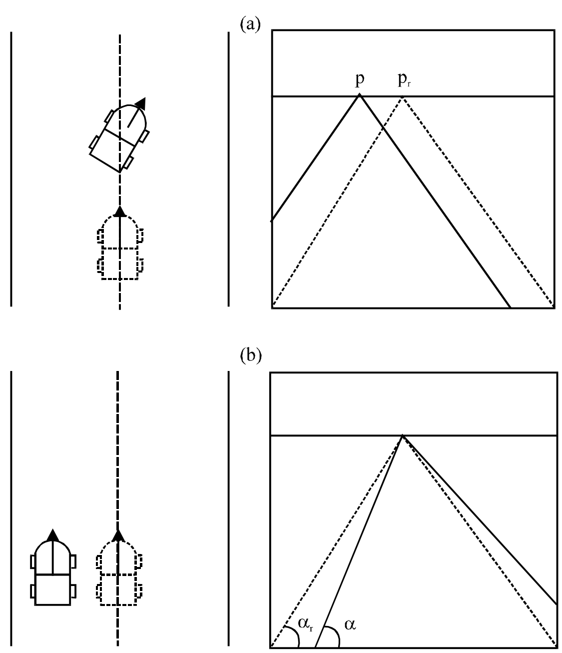

Fig. 4(a-b): Geometric relationship of vanishing point and lines, (a) Parallel and (b) Unequal line while the robot is in any posture. It is easily seen the slope S is equal to tanα as shown in Fig. 4b. The difference between S and S_{ref} will be denoted by ΔS. Similarly, assume the difference between the x-coordinate values of the vanishing point (p) and the image center (p_r) as ΔX. That is, these two differences are defined as:

$$\begin{cases} \Delta S = S - S_{ref} \\ \Delta X = X_{V_p} - X_{center} \end{cases} \quad (1)$$

In order to guide a robot with collision-free controls, the most simple way is to avoid obstacles firstly and then to guide the robot towards the center line of the passage as possible. From the above discussions about vanishing point and vanishing lines, one can choose the variables ΔS and ΔX as the inputs of fuzzy guiding controller.

It is noted while the robot is facing towards the right side as shown in Fig. 4a, the vanishing point will appeared in the left part of the image, that is ΔX is NB or NS. Moreover, if the robot is now in the right sideline, the slope of the left vanishing line is smaller than the reference value of S_r (that is ΔS is NB or NS) and then the steering command will be set as "to turn left large or little" to let the robot return to the center region of the passage. It results in:

"ω_L is VS, ω_R is VB" or ω_L is "S, ω_R is B"

Similarly, one can inference the fuzzy rules as tabulated in Table 1.

Table 1: The rule table of the fuzzy collision-free guiding controller

		ΔX									
ω_L, ω_R		NB		NS		ZE		PS		PB	
ΔS	PB	M	M	F	M	F	S	VF	S	VF	VS
	PS	M	F	M	M	F	M	F	S	VF	S
	ZE	S	F	M	F	M	M	F	M	F	S
	NS	S	VF	S	F	M	F	M	M	F	M
	NB	VS	VF	S	VF	S	F	M	F	M	

MPB: Positive big, PS: Positive small, ZE: Zero, NS: Negative small, NB: Negative big, M: Medium speed, F: Fast, S: Slow, VF: Very fast, VS: Very slow

EXPERIMENTAL RESULTS

Navigation is always an important topic in robotic mobile controls. Especially, the complexity of the environment where home robots are patrolling will make the robotic design hard. However, if we have solved similar but simpler cases, we maybe can obtain some useful ideas to solve such complex problems. For example, to consider the actual environments such as the passage shown in Fig. 5a and the laboratory shown in Fig. 5b, one can see that both the sides of a passage can be regarded as lines. That is, if the robot can detect the distances from the sides by processing captured images, moreover, also can estimate the space features of the robot with respect to the environment, we believe the robot can perform simple navigations based on algorithms of wall following or side tracking in the passage without obstacles.

Figure 6 shows the trace of the actual navigation of the experiment. As shown in Fig. 7. It indicates that the robot really can pass the obstacles and successfully reach the destination. Besides, Fig. 8a and b show the actual screens of experiments when the robot stays on two different positions. Figure 8a indicates the robot is at the position 49.68 m with respect to its left wall where the

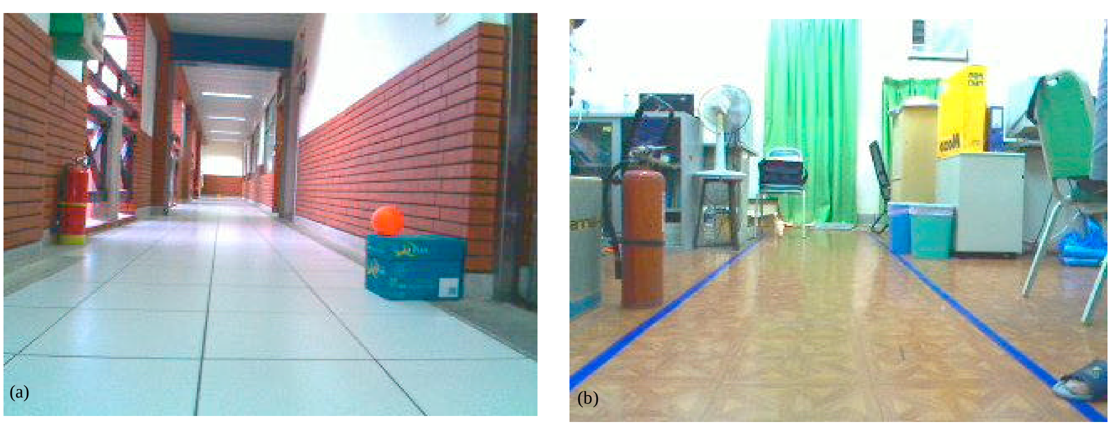

Fig. 5(a-b): The actual environments of experiments, (a) Passage and (b) Laboratory

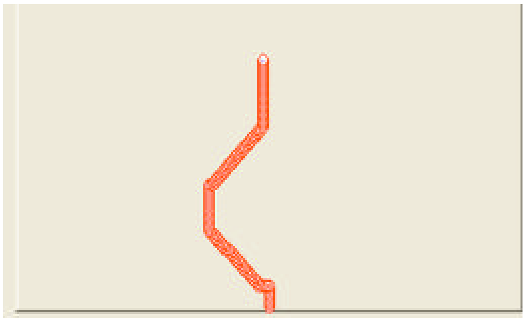

Fig. 6: The actual navigation results

distance between the robot and a fire extinguisher is estimated by the vision-based navigation controller as 2.89 m because that the pixels of the fire extinguisher's image are 14×15. It also can determine that the robot is at (50, 211) with 0 degrees of angle of orientation from the robotic posture estimation.

Figure 8b indicates the robot is at the position 77 m with respect to its right wall where the distance between the robot and a fire extinguisher is estimated as 1.47 m because that the pixels of the fire extinguisher's image are 24×90. It also can determine that the robot is at (106, 144) with 188 degrees of angle of orientation from the robotic posture estimation.

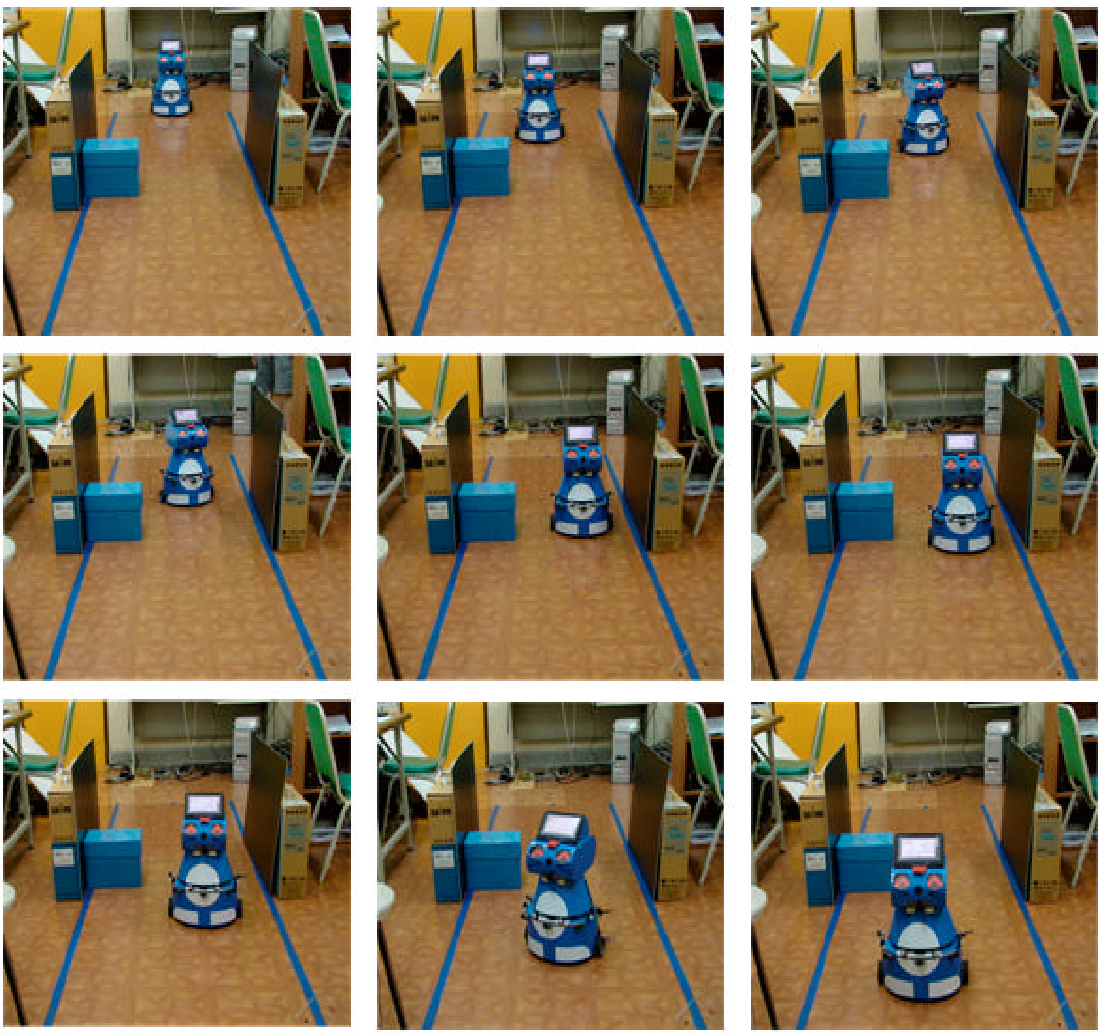

Fig. 7: The successive images when the robot navigates collision-free in the passage

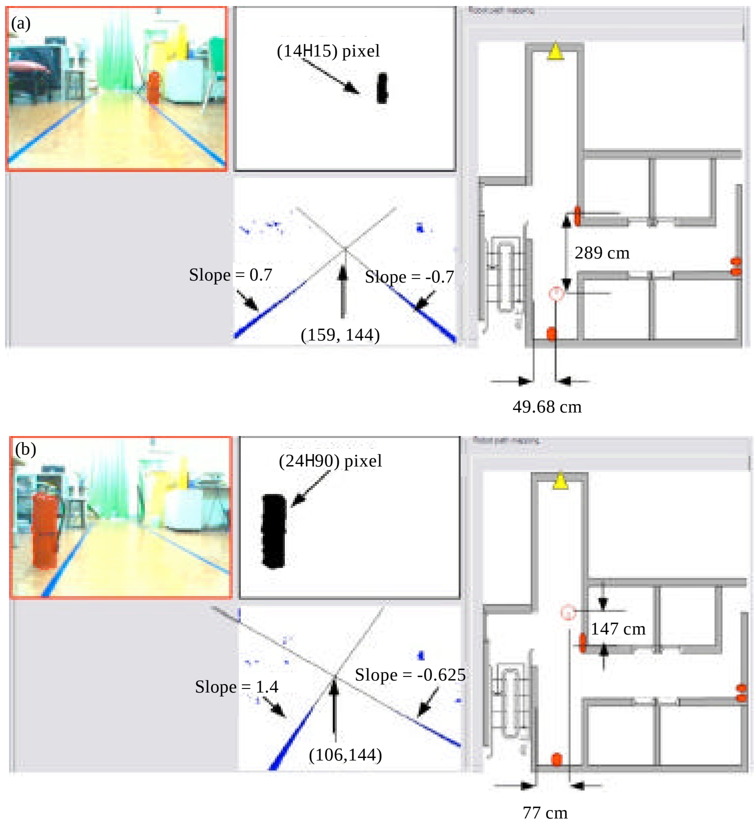

Fig. 8(a-b): The position estimation results, (a) The robotic monitor interface when the robot faces to the triangle mark and (b) The robotic monitor interface when the robot is approaching to the fire extinguisher

CONCLUSIONS

In this study, an interactive home robot is implemented in indoor environment. A visual navigation system is proposed to deal with guidance and collision-free controls based on the robotic posture estimation system and the navigation controller. By integrating image information of objectives and ground lines, the robot can determine the relative localities of specific objectives and then perform environmental map construction and robot localization. The experimental results reveal the feasibility of the proposed scheme.

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REFERENCES

Al-Nasser, A.D. and M. Al-Talib, 2010. The ranked sample-mean Monte Carlo method for unidimensional integral estimation. Asian J. Math. Stat., 3: 130-138.

Asseu, O., S. Ouattara, K.E. Ali, Z. Yeo and M. Koffi, 2010. An extended Kalman filter approach for flux-sensorless control of a linearized and decoupled induction motor drive. Trends Applied Sci. Res., 5: 91-106.

Hernane, Y., S. Hernane and M. Benyettou, 2010. PFPSO: An optimised filtering approach based on sampling. J. Applied Sci., 10: 494-499.

Idris, M.Y.I., E.M. Tamil, Z. Razak, N.M. Noor and L.W. Kin, 2009. Smart parking system using image processing techniques in wireless sensor network environment. Inform. Technol. J., 8: 114-127.

Islam, S., E. Izekor and J.O. Garner, 2011. Effect of chilling stress on the chlorophyll fluorescence, peroxidase activity and other physiological activities in *Ipomoea batatas* L. genotypes. Am. J. Plant Physiol., 6: 72-82.

Jarjes, A.A., K. Wang and G.J. Mohammed, 2010. GVF snake-based method for accurate pupil contour detection. Inform. Technol. J., 9: 1653-1658.

Kamaljit, K., K. Amarjeet and S.T. Pal, 2011. Analysis of ingredients, functionality, formulation optimization and shelf life evaluation of high fiber bread. Am. J. Food Technol., 6: 306-313.

Krose, B., R. Bunschoten, S.T. Hagen, B. Terwijn and N. Vlassis, 2004. Household robots look and learn: environment modeling and localization from an omnidirectional vision system. IEEE Rob. Autom. Mag., 11: 45-52.

Liang, Z., X. Ma, F. Fang and S. Zhu, 2010. Improved Monte Carlo localization algorithm in a hybrid robot and camera network. Inform. Technol. J., 9: 1585-1597.

Liao, H.C. and P.C. Lee, 2010. A novel vision-based location authentication approach in a ubiquitous camera environment. Inform. Technol. J., 9: 1571-1584.

Lu, M.C., W.Y. Wang and C.Y. Chu, 2006. Image-based distance and area measuring systems. IEEE Sensors J., 6: 495-503.

Ma, X., X. Dai and S. Wen, 2005. Vision-based extended Monte Carlo localization for mobile robot. IEEE Int. Conf. Mechatron. Autom., 4: 1831-1836.

Mala, T. and T.V. Geetha, 2008. Story summary visualizer using L systems. J. Artificial Intell., 1: 53-60.

Mehrjerdi, H., M. Saad, J. Ghommam and A. Zerigui, 2010. Optimized neuro-fuzzy coordination for multiple four wheeled mobile robots. Inform. Technol. J., 9: 1557-1570.

Nath, D.C. and A. Bhattacharjee, 2011. A Bayesian Approach for Autoregressive Models in Longitudinal Data Analysis: An Application to Type 2 Diabetes Drug Comparison Asian J. Applied Sci., 4: 640-648.

Nouri, M., I. Nowrouzian, A. Vajhi, S.H. Marjanmehr and D. Faskhoudi, 2011. Morphometric radiographic findings of the digital region in culling lame cows. Asian J. Anim. Sci., 5: 256-267.

Ryde, J. and H. Hu, 2005. Fast circular landmark detection for cooperative localisation and mapping. Proceedings of the IEEE International Conference on Robotics and Automation, April 18-22, 2005, Barcelona, Spain, pp: 2745-2750.

Shieh, M.Y., J.S. Chiou and C.J. Hu, 2011. Design of a shopping assistance agent system. Inform. Technol. J., 10: 1186-1193.

Tardos, J.D. J. Neira, P.M. Newman and J.J. Leonard, 2002. Robust mapping and localization in indoor environments using sonar data. Int. J. Rob. Res., 21: 311-330.

Tsai, P.S., L.S. Wang and F.R. Chang, 2007. Nighttime vehicle distance measuring systems. IEEE Trans. Circuits Syst., 54: 81-85.

Vashani, S., M. Azadi and S. Hajjam, 2010. Comparative evaluation of different post processing methods for numerical prediction of temperature forecasts over Iran. Res. J. Environ. Sciences, 4: 305-316.

Wolf, J., W. Burgard and H. Burkhardt, 2005. Robust vision-based localization by combining an image retrieval system with Monte Carlo localization. IEEE Trans. Robotics, 21: 208-216.

Yang, Z.F. and W.H. Tsai, 1999. Viewing corridors as right parallelepipeds for vision-based vehicle localization. IEEE Trans. Ind. Electron. 46: 653-661.

Yuan, X., C.X. Zhao and Z.M. Tang, 2010. Lider scan-matching for mobile robot localization. Inform. Technol. J., 9: 27-33.

Yufeng, S., Z. Chunjie and L. Zheng, 2011. Fuzzy sliding-mode control for the swing arm used in a Fourier transform spectrometer. Inform. Technol. J., 10: 736-747.