Development and evaluation of an autonomous robot for inter-row operations

Hamid Jafarbiglu[1], Hossein Mousazadeh[2]*, Alireza Keyhani[3]

1. M.Sc. student, Agricultural Machinery Engineering Department, University of Tehran, Iran.

2. Assistant Prof., Agricultural Machinery Engineering Department, University of Tehran, Iran.

3. Prof., Agricultural Machinery Engineering Department, University of Tehran, Iran.

*Corresponding author: Agricultural Machinery Engineering Department, University College of Agriculture and Natural Resources, Karaj, Iran.
Email: hmousazade@ut.ac.ir

Abstract

Simultaneous to industrial automation, automating agricultural tasks would be affordable for efficiency improvement. To obtain an applicable fully automatic vehicle in the straight rows and headland turning, an autonomous system was developed and evaluated in three different modes. The study was implemented on actual sized, renewable energy based off-road vehicle (SAPHT). Experimental evaluations were conducted based on machine vision and teleoperation modes with various speeds. The vehicle also was driven manually for comparison. RMSE analysis in the straight path illustrated the prominence of vision based guidance (10.09 cm). While in the curved test track, teleoperational navigation gives good results (12.84 cm). However for an accurate navigation, combination of two evaluated methods would be recommended: between crop rows that line is detectable, vision system could handle accurately, while in headland, teleoperational control would navigate precisely.

Keywords: Navigation; Teleoperation; Machine vision; Autonomous; Inter-row operation.

1-Introduction

Field robotics and vehicle automation aims at efficiency improvement, environmental protection and labor save (Pinto, Reid, Zhang, & Noguchi, 2000). There are many farm tasks susceptible to automation, and multiple ways of automating functions in a vehicle. Some of the functions that would be incorporated into vehicles include; automated navigation, automatic implement control, mapping and monitoring, automatic safety alerts and routine messaging to send updated information to the farm station. Among them, automated navigation is the most sophisticated one allowing drivers to concentrate on other managerial activities while the vehicle is accurately guided without driver effort. The navigation would be defined as auto guidance or auto steering.

Tillet (1991) classified guidance systems as mechanical, optical, radio navigation (teleoperation), ultrasonic or leader cables system (Tillett, 1991). In teleoperation, the vehicle is still controlled by the operator (either to guide the vehicle or to actuate any of its attachments), but from outside the cabin, so little intelligence is required. Cui et al. (2003) defined the teleoperation as a means to operate a robot using human intelligence (Cui, Tosunoglu, Roberts, Moore, & Repperger, 2003).

One of the well-known methods for local perception and consequently vehicle navigation is machine vision, especially for unstructured environments. This method offers significant advantages over other sensors. High-rate images provide rich information about the scene ahead of an intelligent vehicle. In addition, it provides instantaneous updates on what is occurring in the vicinity of the vehicle. The greatest challenges are the computational loads of the processing algorithms needed and coping with outdoor illumination patterns. In agriculture, this method takes guidance from the crop row itself. There are, however, many complications as the condition of the crop changes through the growing cycle. Initially the plants appear as rows of small dots among scattered random dots which are weeds. The rows can be incomplete, i.e. there can be missing plants and plants can be at different stages of growth (size) along the field. Later they fuse to form a clear solid line. However, the lines have thickened and threaten to block the laneways. Great tolerance in the vision algorithm is thus required to fulfill all the seasonal requirements (Billingsley & Schoenfisch, 1997),(Åstrand & Baerveldt, 2005).

Several strategies have been proposed for crop row detection. Eight common line detection algorithms are: stripe analysis, Hough Transform (HT), linear regression, vanishing point-based, stereo-based approach, blob analysis, accumulation of green plants and frequency analysis (Montalvo et al., 2012). Most researchers used algorithms based on the HT as a robust row recognition algorithm. Some used the Improved Hough Transform to detect the margin lines between the end of the farmland and the suspected furrow. However to segment crop rows, segmentation algorithms have been used in another researches (Jiang, Xiao, Zhang, Wang, & Tai, 2013). The HT is widely used for localization of linear objects in images. This transform is quite robust against 'noise' and missing parts (Leemans & Destain, 2006). The disadvantage of HT is that it needs lots of complicated calculation. When processing a large number of images, the time-consuming algorithm is difficult to meet the real-time demand (Wu, Xu, Song, & Cai, 2011). Strand et al. described a new method for robust recognition of plant rows based on the HT. They reported the accuracy of the position estimation relative to the row, proved to be good with a standard deviation between 0.6 and 1.2 cm depending on the plant size (Åstrand & Baerveldt, 2005). Ronghua et al. compared gradient-based Random Hough Transform (RHT) versus HT algorithms in order to detect crop rows. They reported while RHT takes 0.8 s, HT takes 1.7 s and finally it was concluded RHT improves the detection speed effectively (Ji & Qi, 2011). Montalvo et al. proposed a new method, oriented to crop row detection in images from maize fields with high weed pressure. They captured some images in real condition and processed them in three steps: image segmentation, double thresholding based on the Otsu's method, and crop row detection. They compared this method against HT and they found it 8% more effective and one second faster than HT, that takes 1.34 second (Montalvo et al., 2012). Xuewen et al. studied a weed detection method based on position and edge features. They used the pixel histogram method to find centerline of crop rows. In this method the centerline was set as starting point and crop rows edge as ending point. They reported that this algorithm was successful by 95 % approximately (Wu et al., 2011).

Unlike to some autonomous vehicles that perform autonomous navigation around unstructured terrain, agricultural vehicles are typically driven in fields arranged into crop rows, orchard lanes or greenhouse corridors. So, more attentions are required to establish a successful navigation algorithm. As most crops are cultivated in rows, an important step towards autonomous navigation for a field robot is the development of a row-recognition system, which will allow a robot to accurately follow a row of plants (Åstrand & Baerveldt, 2005). Although each system uses different technologies to guide the vehicle, most of the systems use the same guidance parameters: heading angle and offset of the vehicle, to control the vehicle steering. Offset is departure of the vehicle gravity center from the desired path. Heading angle is the angle between the vehicle centerline and the desired path (Tillett, 1991). Up to date almost all studied navigation systems were as autopilot, where the driver had to be present in-the-cab to perform some turns at the headlands, engage some implements, and execute some maneuvers. Considering this, the aim of this project is developing a multi-purpose navigation system to be implemented in an actual sized renewable energy based tractor (SAPHT) without any driver in-the-cab. Experimental evaluation of the developed system based on teleoperation, machine vision and manual mode is other objective of this study.

2-Materials and methods

Automating conventional vehicles needs special requirements. CVT transmission, auto- steering, automatic braking and PTO and three-point-hitch (3PH) actuation are some capabilities of an autonomous vehicle. Considering this, a special platform named as SAPHT (Solar Assist Plug-in Hybrid electric Tractor) is used in this project for development of a navigation systems and evaluation in different modes. The SAPHT is an "I" class tractor for light - duty operations. Two different sources supply the SAPHT with electric energy: (i) onboard PV arrays and (ii) electricity from the grid. Propelling power of the SAPHT is approximately 28 hp. While another power source provides about 22 hp to activate 3PH and standard 540 and 1000 rpm PTO system (Mousazadeh et al., 2011).

2-1-Design of auto-navigation system

To operate the SAPHT in autonomous mode, the steering system enhancement was the first important step. The steering system was reformed to an electrically controlled system for driverless operations. An approximated 800 W DC motor with a gearbox on it actuates steering system. As illustrated in the **Figure 1**, the constructed power board is based on a full H-bridge and uses four Metal-Oxide Semiconductor Field-Effect Transistors (MOSFET type: IXTN79N20 N-channel, Enhancement mode). The electronic board controls direction of rotation according to the received command and provides soft start as well. It consists of low side and high side drivers based on PWM signals.

The front wheel was equipped with a rotational potentiometer to fed-back turning information into the closed-loop steering control. The designed system is very sensitive with a resolution of approximately 0.29 degrees per step.

For teleoperational guidance two transceiver boards were developed based on HM-TRP module by maximum range of 1 km and 433 MHz operating frequency. One of the transceivers was located in a portable user friend box that could send operator commands. The next transceiver was located in the vehicle’s Electronic Control Unit (ECU) box to receive transmitted data. The sent controlling commands by the user were: steering control, forward/backward selection, velocity, PTO activation and 3PH actuation. The steering system can be updated approximately by 20 Hz. However, in teleoperation steering, allowed typical delays in the digital transmission would be less than 100 millisecond (Suomela, 2001).

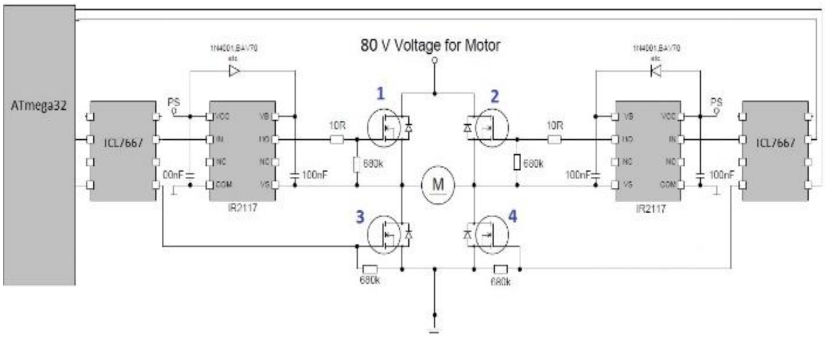

Figure 1. Electronic and power board of developed auto-steering system

2-2-Experimental evaluation

The designed system was evaluated by comparison of navigation results in three different modes: Teleoperation, machine vision and manually guidance. Experimental evaluations were performed in a standard test course that is provided by the American Society of Agricultural and Biological Engineers (ASABE) titled as X587 Dynamic Testing of Satellite-Based Positioning Devices Used in Agriculture (ASABE, 2007). Due to existed limitations, the standard was applied with some changes. Standard X587 provides two straight segments each 90 m long, that linked by a turn of radius 5–10 m, traveling speeds of 0.1, 2.5, and 5 m/s, test durations of under an hour, and four repetitions per combination of speed and direction. Considering dimension of the test campus, two straight lines each by 40 m length that were linked by a turn of 5 m were sketched using white color (**Figure 2**).

For machine vision based navigation, a standard industrial CCD camera (EyeVision EYE-700P) was mounted in front of the SAPHT. Camera setting was: pitch, roll and yaw angles of 30°, 0° and 0° respectively at a height of 1.3 m from the ground as it showed in **Figure 2**. The focal length of the lens was 3.5-8 mm and data were imported to a laptop using standard LAN port. The on-board PC on the SAPHT was a personal laptop with 1 GB installed memory (RAM) and 1.8 GHz processor that operated under windows 7 ultimate 32-bit OS. This test was performed from March to July 2014 under different condition of illuminations. To evaluate accuracy of designed system based on machine vision, and to measure offset drift, the SAPHT was navigated on the sketched lines as hypothetical plant rows. In this mode offset from desire path in four different speeds; 2, 2.5, 3 and 4 km/h, each with three replications were measured as error and evaluated. Increasing speed more than 4 km/h leads to miss the line due to fast changes in the direction, especially in curved tracks. The response frequency of steering system was evaluated by shifting it from 1 Hz to 3 Hz as well in speeds of 3 and 4 km/h. A user interface is developed in visual C# for video streaming and images are processed for real-time data mining. The developed program extracts offset and heading errors from desired path and sends these data to ECU (detailed explanations are provided in the next section).

Evaluation in teleoperation mode was performed in the same test course as well. In this mode, the accuracy was not acceptable for speeds above 2 km/h (e.g. in 4 km/h the vehicle fluctuated by maximum error of one meter approximately). Therefore, the travelling speed was limited to 2 km/h , but in three different positions: 1) two meter far from the corner of the field by approximately two meter in height, 2) from center of the field, and 3) 10 meter far from the center of the field by approximately five meter in height. The SAPHT speed was accurately read by an encoder on the drive wheel. Offset data was extracted in teleoperation mode using another digital CCD color camera. This camera saves video from course information and data was extracted offline. Another application program was developed in Visual C# environment for this data mining that was based on HT.

Evaluation in manual mode (driver in-the cab) was performed as well, for comparison. In the manual mode, the travel speed was set to 2, 4 and 6 km/h, with three replications for each speed.

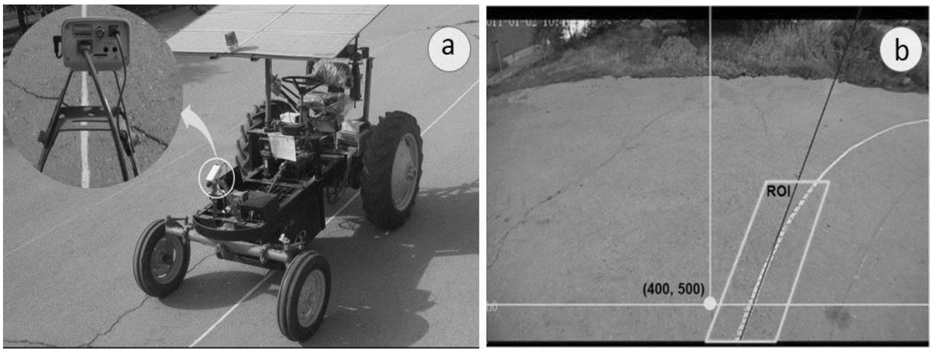

Figure 2. The SAPHT in the test course (a), line detection interface developed in C# (b).

2-3-Machine vision based navigation algorithm

Since in machine vision mode the navigation is performing online using machine intelligence, the image would be processed on-the-go. So a robust and dynamic program is required for accurate and agile navigation. As mentioned earlier, an application program was developed in Visual C# environment for this purpose. First of all this program streams video using RTSP (Real Time Streaming Protocol) and plays it on the developed graphical user interface (GUI) with frame rate of 25 fps. Then each frame is digitalized and converted to 24-bit RGB color space, where pixels are belong to natural numbers set [0, 255]. As illustrated in the **Figure 3**, for first five images the algorithm seeks line in whole of the image (800 * 600 Pixels) as Region Of Interest (ROI). To accelerate the algorithm, after five frames the ROI box becomes dynamic. The width of this trapezoidal box is equal to 100 pixels; 50 pixels right and 50 pixels left the line (**Figure 2**). Depend on outdoor illumination the background was divers, so for each frame average of ROI was redefined as a threshold. Then pixels higher than threshold value were determined as points on the white line (red points in the Figure (2-b). The main stage of this algorithm was line fitting to determined points (blue line in the Figure (2-b)). This task was performed using RHT that is not sensitive for outliers.

The HT is a mathematical transformation that enhances the alignment of points very efficiently due to its low sensitivity to outliers (Doerr, 2010). The transformation takes place between the image space represented by the pixels (x, y) of the image processed and the parameter space (ρ, θ) in which linear features are detectable. The transformation is carried out by applying Equation (1) to every determined pixel in the image. When the transformed points lie in a straight line, all of the sinusoids in the parameter space will cross at one point defined by (ρL, θL). The inverse transformation (2) represents the best fitted line in the image space (Más, Zhang, & Hansen, 2010).

$$\rho = x\,.\sin\theta + y\cos\theta \qquad -90^\circ < \theta < 90^\circ \tag{1}$$

$$y = \frac{\rho_L}{\sin\theta_L} - \frac{\cos\theta_L}{\sin\theta_L}.x \tag{2}$$

Two main features of the line; slope and intercept was extracted for calculation of offset and heading errors. The slope of straight line was 90° and acceptable slope range was between 40° and 140°. Also the absolute value of slopes in two consecutive frames would not be more than a special threshold. The offset error was calculated as the departure from the desired path. Without applying slope impact on the offset error the vehicle fluctuates in the high speeds on a sinusoidal path. So according to the given flowchart, final error was derived after applying slope effect on it. The effect of slope was applied by ratio of 4 that was determined experimentally. Considering vehicle speed, two consecutive errors would not be more than a predefined threshold. Finally for correction of steering wheels, error value flows to the

ECU via RS232 interface using a USB to RS232 converter. At each iteration, some data include time, offset error, heading and steering signals were saved in an excel file. Although, the algorithm can be updated by frequency of 10 Hz, sending data to ECU decreases the speed and finally the steer was refreshed by frequency of 3 Hz approximately.

To compare accuracy of each experimental test, offset and heading errors are calculated in straight and turning paths separately. The test variables were different navigation modes, different speeds and steering system frequency. ANOVA analyses were performed using the well-known statistical software SPSS V17. 5.

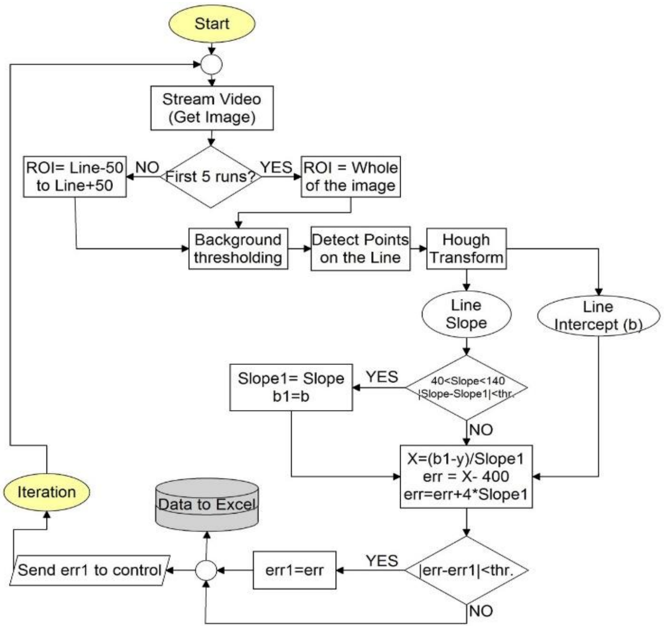

Figure 3. Flowchart of navigation algorithm in machine vision

3-Results and discussion

Evaluation tests were carried out in various modes and speeds between 2 and 4 km/h. To compare error of navigation system in straight path and also in the curved test track, all data were separated in two line and turning data categories that respectively refers to straight path and curved test track. Then, all data were classified in Microsoft excel before analysis. **Table 1** shows a summary of test planning and RMSE of extracted data obtained from combination of all replications. According to this table in machine vision mode, the RMSE of straight line (LIN) was obviously smaller than the RMSE of total path (TOT) that includes straight and curved path (10.09 cm versus 37.31 cm). In comparison to teleoperation, navigation in vision mode had a better performance in straight paths, while in total path, the teleoperation resulted better. These results also show that the performance of vision mode in straight path was better than teleoperation mode both in full path and straight path.

Table 1. Test planning and RMSE (cm) of evaluated experiments

	Manual		Vision guidance		Teleoperation					
					P1		P2		P3	
Speed (km/h)	TOT	LIN	TOT	LIN	TOT	LIN	TOT	LIN	TOT	LIN
2	3.02	2.15	37.31	10.09	20.70	13.88	18.58	12.84	25.66	28.07
2.5	-	-	42.50	13.51	-	-	-	-	-	-
3	-	-	45.21	9.87	-	-	-	-	-	-
4	4.58	2.94	37.78	11.60	-	-	-	-	-	-
6	14.53	3.55	-	-	-	-	-	-	-	-

The SPSS software was used for comparison of the obtained RMSE's and assessment of significance of differences. Analyzing the manual mode was performed in SPSS software by Duncan method at the 0.05 level and with speeds of 2, 4 and 6 km/h. The results indicated that differences between replications were not significant but there were significant differences between various speeds in both full path as well as straight path. For full path the differences between speeds of 2 km/h and 4km/h was nonsignificant while speeds of 2km/h and 4km/h had significant difference with 6 km/h. The Least Significant Difference (LSD) method had same results for full path. However in straight paths while there was no significant difference between various speeds by Duncan method, the difference between 2km/h and 6 km/h was significant by LSD method.

In the machine vision mode, tests were started by speed of 2 km/h and steering frequency of 1 Hz. The test was continued by speed of 2.5 km/h at the same frequency. Since offset error increased quickly, consequently tests were continued by increasing the steering frequency to 3 Hz, in speed of 3 km/h. The last stage is performed by speed of 4 km/h and in steering frequency of 3 Hz.

Statistical analyses in vision mode illustrated significant differences due to steering frequency. It's concluded that the frequency has an important effect on system performance. According to Duncan test in full path there was no significant difference between various speeds while differences in straight paths were significant. **Figure 4** shows summary of results for vision mode. In this figure letter 'V' refers to vision mode and subscripted numbers indicates speed of vehicle. The underline divides the symbols in two subsets. As illustrated in the **Figure 4-a,** V3 gives best result. This means that high frequency in low speed leads to accurate navigation. The V2.5 with travel speed of more than V2 and in the same frequency had worst result. As shown, differences between V2 and V4 and also V4 and V2.5 were not significant. This result could be interpreted as the importance of steering system frequency in vision based navigation. Due to impact of steering frequency, the V4 with highest travel speed had no significant difference with V2 that had the lowest speed.

To compare machine vision mode versus manually driving, an analysis is performed between V2, V4, M2 and M4 ('M' refers to Manual mode and subscripted numbers show the travel speed). The results illustrated that the differences between machine vision mode and Manual mode was significant at 0.01 levels with predominance of manual mode (**Figure 4-b**).

Teleoperation mode was evaluated from three different positions (P1, P2 and P3). A shown in the **Figure 4-c**, in straight path there was significant difference at 0.01 levels between P3 and two other positions. As P2 refers to center of the course so it is concluded that this difference was resulted from the distance between operator and vehicle. When operator stands in a far distance from the vehicle, due to optical illusions a biased error is occurred from desired path. However, analysis in full path and based on Duncan test, illustrates that three positions had significant difference at 0.01 levels.

Finally three different modes were compared in a constant speed of 2 km/h (**Figure 4-d**). Results of analysis indicated that differences between three modes were significant in full path at 0.05 levels. In full path performance of Teleoperation mode were better than vision mode but worse than Manual mode. While in straight path the performance of vision mode was better but the difference was not significant. The Manual mode had significant difference with vision mode and Teleoperation mode in both full path as well as straight path. **Figure 5** shows test trajectory and results of evaluations in different modes. In the figure the desired test trajectory is shown by green color and best replication of

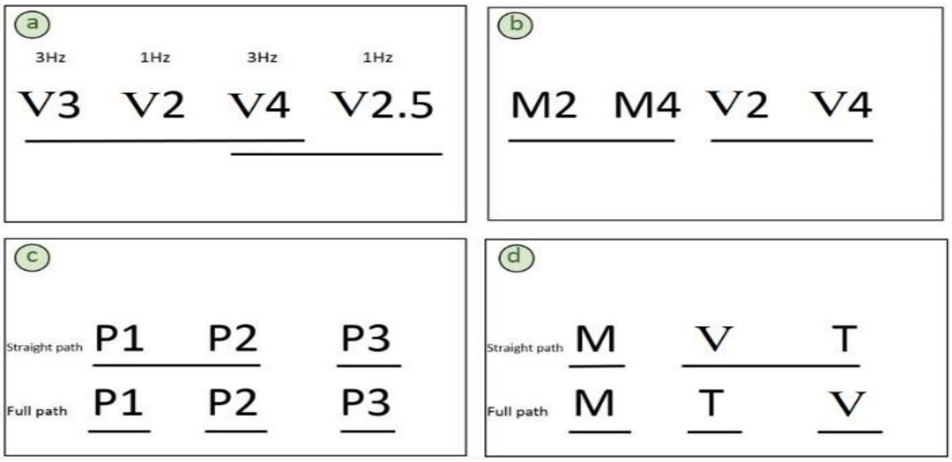

Figure 4. Mean comparison of RMSE in different modes. a) Machine vision in various speeds and steer frequency b) manual and machine vision c) various positions in teleoperation d) manual, machine vision and teleoperation mode in speed of 2 km/h.

traveled routes in speed of 2 km/h are illustrated by different colors and symbols. According to this figure in straight path vision navigation follows the line accurately but encounters gross error in turning curved track.

As illustrated in the Figure (5), and according to the results of RMSE comparison, Teleoperation mode gives good results in turning curves in comparison to vision. However in straight paths that are more susceptible for agricultural fields the accuracy of vision based navigation is favorable. Overall, comparing two evaluated methods for navigation between field rows, the machine vision has remarkable predominance. However, application a combination of two evaluated modes would be affordable for a successful navigation between plant rows. Between rows that crop line is detectable, vision system could handle accurately, while in turning path that there is no guidance sign, teleoperational control would give good results, especially if the control is performed from a GUI in the farm office.

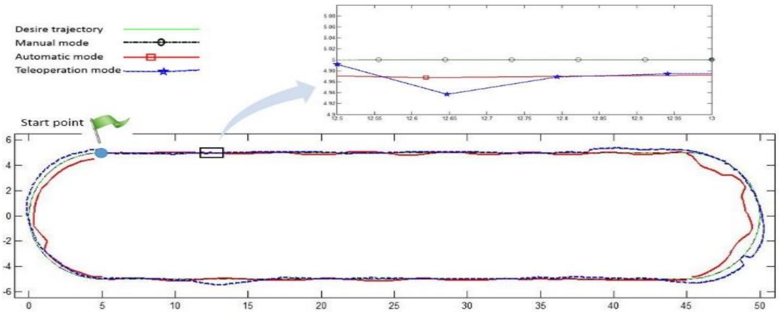

Figure 5. Test trajectory and results of evaluations in different modes

4-Conclusion

Field robotics and vehicle automation aims at efficiency improvement, environmental protection and labor save. Automatic navigation is one of the sophisticated tasks that were under consideration over the last century. To obtain a full automatic vehicle that can be applicable in the straight rows and headland turning, an autonomous system was developed and evaluated in three different modes (machine vision, teleoperation and manually). The study was implemented on actual sized platform, titled as Solar Assist Plug-in Hybrid electric Tractor (SAPHT). Experimental evaluations were conducted with various speeds, different steering frequency and several positions for teleoperation mode. Offset and heading errors were analyzed using Randomized Hough Transform theorem. Test results were evaluated using SPSS software in straight path as well as curved test track. RMSE analysis in the straight path illustrated the prominence of vision based guidance (10.09 cm). While in the turning curves; teleoperational navigation showed good results (12.84 cm). Test results indicated that increasing movement velocity increased offset error and steering frequency had important impact on the navigation accuracy. However, for an accurate navigation, combination of the two evaluated methods would be recommended i.e. between field rows that crop line is detectable, vision system could handle accurately, while in turning path that there is no guidance sign, teleoperational control would perform properly, especially if the control is performed from a GUI in the farm office.

5-Acknowledgement

The financial support provided by the University of Tehran under grant number 73130963/1/01, Iran, is duly acknowledged.

REFERENCES

1. ASABE. (2007). X587 Dynamic Testing of Satellite-Based Positioning Devices used in Agriculture *St. Joseph, ASABE*.
2. Åstrand, B., & Baerveldt, A.-J. (2005). A vision based row-following system for agricultural field machinery. *Mechatronics, 15*(2), 251-269. doi: 10.1016/j.mechatronics.2004.05.005
3. Billingsley, J., & Schoenfisch, M. (1997). The successful development of a vision guidance system for agriculture. *Computers and Electronics in Agriculture, 16*(2), 147-163.

4. Cui, J., Tosunoglu, S., Roberts, R., Moore, C., & Repperger, D. W. (2003). *A review of teleoperation system control*. Paper presented at the Proceedings of the 2006 Florida conference recent advances in robotics (FCRAR), Florida Atlantic University, FL.
5. Doerr, Z. (2010). *Evaluating the ability to detect foreign objects in crops using laser range scanners mounted on agricultural vehicles*: University of Ottawa.
6. Ji, R., & Qi, L. (2011). Crop-row detection algorithm based on Random Hough Transformation. *Mathematical and Computer Modelling, 54*(3), 1016-1020.
7. Jiang, H., Xiao, Y., Zhang, Y., Wang, X., & Tai, H. (2013). Curve path detection of unstructured roads for the outdoor robot navigation. *Mathematical and Computer Modelling, 58*(3-4), 536-544. doi: 10.1016/j.mcm.2011.10.068
8. Leemans, V., & Destain, M. F. (2006). Application of the Hough Transform for Seed Row Localisation using Machine Vision. *Biosystems Engineering, 94*(3), 325-336. doi: 10.1016/j.biosystemseng.2006.03.014
9. Más, F. R., Zhang, Q., & Hansen, A. C. (2010). *Mechatronics and Intelligent Systems for Off-road Vehicles*: Springer.
10. Montalvo, M., Pajares, G., Guerrero, J. M., Romeo, J., Guijarro, M., Ribeiro, A., . . . Cruz, J. M. (2012). Automatic detection of crop rows in maize fields with high weeds pressure. *Expert Systems with Applications, 39*(15), 11889-11897. doi: 10.1016/j.eswa.2012.02.117
11. Mousazadeh, H., Keyhani, A., Javadi, A., Mobli, H., Abrinia, K., & Sharifi, A. (2011). Life-cycle assessment of a Solar Assist Plug-in Hybrid electric Tractor (SAPHT) in comparison with a conventional tractor. *Energy Conversion and Management, 52*(3), 1700-1710. doi: http://dx.doi.org/10.1016/j.enconman.2010.10.033
12. Pinto, F. A. C., Reid, J. F., Zhang, Q., & Noguchi, N. (2000). Vehicle Guidance Parameter Determination from Crop Row Images using Principal Component Analysis. *Journal of Agricultural Engineering Research, 75*(3), 257-264. doi: 10.1006/jaer.1999.0501
13. Suomela, J. (2001). *Tele-presence aided teleoperation of semiautonomous work vehicles.* (Licentiate of Technology), Helsinki University of Technology
14. Tillett, N. (1991). Automatic guidance sensors for agricultural field machines: a review. *Journal of Agricultural Engineering Research, 50*, 167-187.
15. Wu, X., Xu, W., Song, Y., & Cai, M. (2011). A Detection Method of Weed in Wheat Field on Machine Vision. *Procedia Engineering, 15*, 1998-2003. doi: 10.1016/j.proeng.2011.08.373

نهمین کنگره ملی مهندسی ماشین‌های کشاورزی
(مکانیک بیوسیستم) و مکانیزاسیون
پردیس کشاورزی و منابع‌طبیعی دانشگاه تهران
۲ و ۳ اردیبهشت ۱۳۹۴ -کرج

توسعه و ارزیابی روبات خودکار برای عملیات بین ردیف های کشت

چکیده

همزمان با پیشرفت صنعتی، نیاز به پیشرفت در زمینه کشاورزی نیز برای افزایش بازدهی به شدت احساس می شود. در حال حاضر پیشرفت های زیادی در زمینه ماشین ها و روبات های کشاورزی به منظور کاهش استفاده از نیروی کار، جلوگیری از قرار گیری نیروی کار در شرایط سخت و خطرناک مزرعه، افزایش دقت در مراحل مختلف کشاورزی و همچنین کاهش استفاده از سموم و علف کش ها، روی داده است. در این تحقیق به منظور دستیابی به روباتی تمام خودکار که قادر به انجام عملیات مختلف کشاورزی در میان ردیف های کشت باشد یک سامانه ناوبری کاربردی طراحی و ساخته شد. این سامانه بر روی سافت که یک تراکتور هیبرید الکتریکی – خورشیدی است نصب گردید. با نصب این سامانه، سافت توانست در سه حالت کنترل دستی، کنترل از راه دور و کنترل خودکار در سرعت های مختلف حرکت نماید. به منظور ارزیابی سافت در حالت های کنترلی مختلف، این تراکتور در یک زمین خط کشی شده استاندارد به عنوان ردیف های فرضی کشت مورد آزمایش قرار گرفت. تجزیه و تحلیل آماری برتری روش کنترل خودکار را با RMSE 10 سانتی متر در مسیر های مستقیم نشان می دهد. در حالی که در مسیر های منحنی و دور های سر زمین عملکرد کنترل از راه دور با RMSE 12 سانتی متر بهتر است. در هر حال برای دستیابی به یک سامانه ناوبری دقیق تلفیق دو حالت کنترل از راه دور در پیچ های انتهای زمین و حالت خودکار در میان ردیف های کشت، قابل توصیه است.

کلمات کلیدی: ناوبری، کنترل از راه دور، ماشین بینایی، هدایت خودکار، عملیات میان ردیف کشت.