Development of Autonomous Traveling for Agricultural Robot Drive Platform by Using a Single Camera

Min Hyuc Ko, Kyoung Chul Kim, Beom Sahng Ryuh, Abhijit Suprem and Nitaigour P Mahalik

Abstract— **In this paper we have presented a study on vision based autonomous driving of a four-wheel-drive platform for agricultural applications. The developed driving platform can be autonomously driven on any path pattern. The key contributions to this paper are development of unique navigation pattern to train the mobile robot to follow any kind of path pattern. We have demonstrated how speed, camera angle, and steering angle per pixel play important role in developing navigation algorithm for a four-wheel drive (4WD) type mobile robot for moderately low speed applications.**

Index Terms— **agricultural robot, Vision based, 4WD, Autonomous driving, Single camera**

I. INTRODUCTION

THIS paper presents work on design of a new prototype agricultural robotic platform to be used for weed monitoring applications. As global competition is pressing farmers on many fronts, mechanized agriculture has become one of the important modern agricultural methods. Conventional mechanized systems may increase productivity but are less adaptive and flexible. As a consequence, there have been initiatives in developing advanced mechanized systems such as robotic platforms in the agriculture [1-3]. Evidently, the scope of robotics is found in agricultural operations (AgOps). The first prototype of harvesting robot for apples was demonstrated in France in 1985 [4-5]. Recently, a research team at Birla Institute of Technology and Science, India, has developed Agribot, a robotic system to be used for agricultural purposes [6]. There are other references which can be found in the literature. As evidenced, there have been initiatives in agricultural robotics research across the world [7]. Table-1 presents some representative of NSF funded projects in the research in the areas of robotics in other fields. While there have been significant and high-end research and development activities in robotics in the application areas of surgery, military, manufacturing, and education, only marginal progress has been made in agricultural robotics.

TABLE I
APPLICATION SPECIFIC NSF FUNDED ROBOTICS RESEARCH PROJECTS

Project title	Areas	Research objective
Autonomous Robotic Rotorcraft for Exploration, Surveillance and Transportation (ARREST)	Military	To develop a complex rotorcraft for exploration, surveillance and transportation utilizing the experiences of the knowledge-enhancement partners.
A Design Methodology for Multi-Fingered Robotic Hands with Second-order Kinematic Constraints	End-of-arm tooling	Systematic design methodology while developing a multi-actuated system for end-of-arm tooling application. The development considers system integration aspects of the design. The desired kinematic task based on a novel formalization of the kinematic synthesis was achieved. This research confers that systematic design approach is vital to design and development.
A Pneumatically Actuated Robot System	Manufacturing	To resolve dynamic challenges in actuators and linkages for higher cycle rates demands. Feasibility of direct-drive pneumatic actuation to accommodate rapid dynamic variations of plant parameters was investigated.
Co-Robots for STEM Education in the 21st Century	Education	To enhance student engagement, increase student motivation in STEM subjects. The project resulted in advancing theory, design, and practice in technology and design-based instruction through the use of a field tested co-robotics curriculum.

Note that agriculture is one of the important U.S. business sectors [8]. There is ample opportunity to innovate, design, develop, and deploy robotic platforms for the agricultural applications because robotic systems perform excellently well in repeated-jobs, round-the-times, all-environments, and as-and-when conditions [9]. Agricultural robotic technology and research activities can be divided into two main areas: task-related and driving or navigation related. In both the areas the research progresses are minimal. For example, there

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is no standardized path available for a robot to navigate properly in agriculture field, although significant autonomous navigation related works and algorithms have already been developed, proposed and tested in other sectors including military, health, and industry [10-12]. In general, the operating environment for agricultural robots can be divided into an open field and a greenhouse. And the tasks of agricultural robots can be classified as harvesting and monitoring. Agricultural robots for a greenhouse have been not yet commercialized due to many technical problems. We have proposed a low-cost solution to navigation problem because in an agricultural setting speed is not considered high. The mobile robotic platform would work slowly and steadily over the hours in much less cyclic fashion. Therefore, the mobile robot driving mechanism for run-time navigation should not execute computationally expensive complex expert system algorithm to determine the next-state path entity [13-14]. The paper presents basic study in developing autonomous driving and travelling algorithm for mobile robot intended for agricultural weed monitoring applications. The four-wheel-drive (4WD) platform that was originally controlled by a remote controller is now capable of driving autonomously.

II. KINEMATIC ANALYSIS OF THE 4WD

A. *Four-Wheel Driving (4WD) Scenario*

Initially we studied the kinematics analysis under front-wheel drive (FWD) and rear-wheel drive (RWD) condition. This laid a foundation to formulate the four-wheel driving (4WD) scenario. Fig.1 illustrates the relation between a radius of rotation and a steering angle in 4WD (refer equations 1-13). In order to enhance the steering performance in a small area, the rear wheels can turn in the opposite direction of the front wheels. The design considered the following: the steering angle of the rear left wheel is equal to one of the front left wheel and also the steering angle of the rear right wheel is equal to one of the front right wheel.

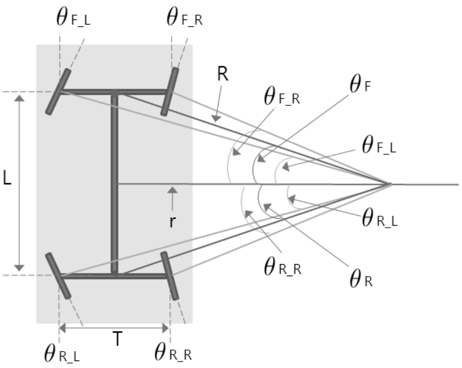


Fig.1. Relation between a radius of rotation and a steering angle in four-wheel steering

The piloted greenhouse of the 4WD platform is shown in Fig.2(a) and (b). Fig.2(c) shows a uniform path pattern. As can be seen the central aisle paved with water pipes between two crop rows. To reduce an additional investment we used the pipes as the driving path in real-world experiment. The robot is able to smoothly transit from one aisle to another based on our developed 4WD algorithm. One can note that in real situation the length of each crop rows are not same for which the drive algorithm does not only takes account of straight and curved path rather a combination of various path patterns. We have developed a path pattern that takes account various navigation strategies, as shown in Fig.(d). Fig.2(d) is the path pattern using which we trained the mobile robot. Note that this path patter contains straight line, curved path, left turn, right turn, etc. So it covers all the possible path scenarios. We also modified the curvatures (not shown) of the path pattern.

$$\sin\theta_F = L/2R \tag{1}$$

$$\theta_F = \sin^{-1}(L/2R) \tag{2}$$

$$\theta_F = \theta_R \tag{3}$$

$$\cos\theta_F = r \tag{4}$$

$$r = R\cos(\sin^{-1}(L/2R)) \tag{5}$$

$$\tan\theta_{F\_R} = \frac{L/2}{(r-T/2)} \tag{6}$$

$$\tan\theta_{F\_L} = \frac{L/2}{(r+T/2)} \tag{7}$$

$$\tan\theta_{F\_R} = \frac{L/2}{R\cos(\sin^{-1}(L/2R)-T/2)} \tag{8}$$

$$\theta_{F\_R} = \tan^{-1}\left(\frac{L/2}{R\cos(\sin^{-1}(L/2R)-T/2)}\right) \tag{9}$$

$$\tan\theta_{F\_L} = \frac{L/2}{R\cos(\sin^{-1}(L/2R)+T/2)} \tag{10}$$

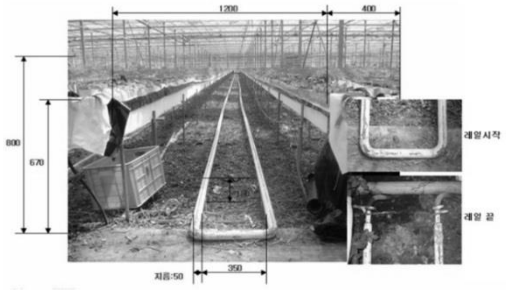
$$\theta_{F\_L} = \tan^{-1}\left(\frac{L/2}{R\cos(\sin^{-1}(L/2R)+T/2)}\right) \tag{11}$$

$$\theta_{F\_R} = \theta_{R\_R}, \tag{12}$$

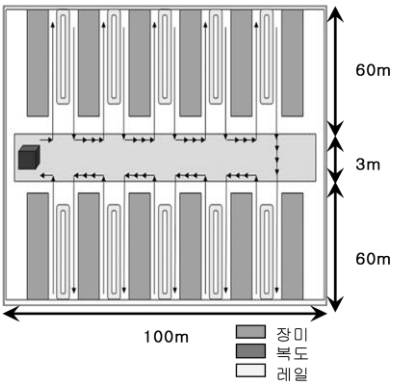
$$\theta_{F\_L} = \theta_{R\_L} \tag{13}$$

(a)

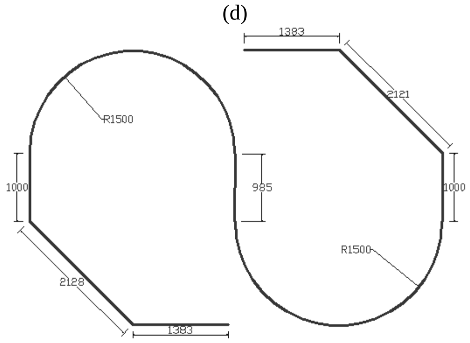
(b)



(c)



(d)

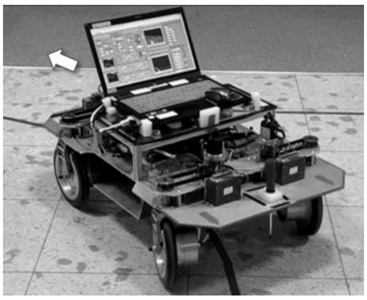


(e)

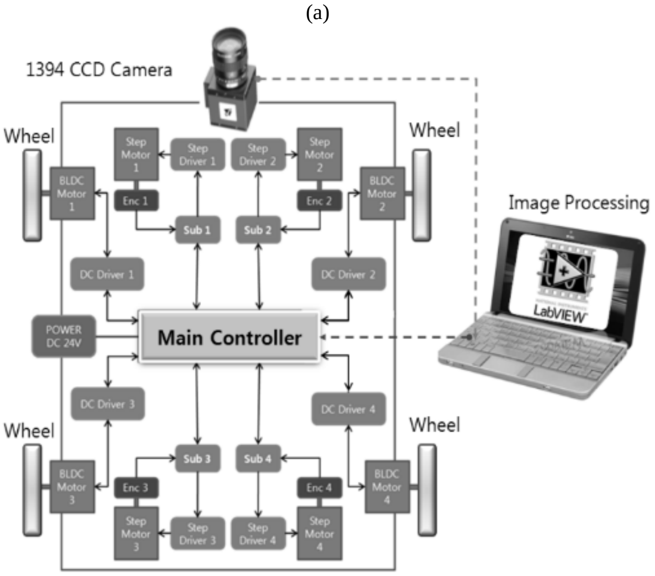
Fig.2.(a) Equations for automation (b) Row crops in a greenhouse showing water pipes for mobile robot’s rail (A piloted greenhouse for rose horticulture), (c) Schematic of a uniform path pattern, (d) Detail view, (e) A path pattern where the robot was trained.

III. VISION-BASED CONTROL SYSTEM

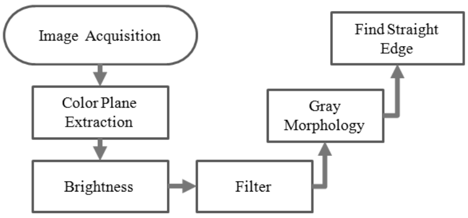
The hardware configuration for control of 4WD platform used in this study is presented in Fig.3(a). In this work centralized control is implemented. All the electronic and electrical devices including the PC are connected to the main controller. The vision system is needed to perform the kinematic experiments. The image data are acquired from the 1394 CCD camera and transmitted to the PC via control board (Atmega128 controller). The PC has LabView software that handles the image processing algorithm. For communication RS232 standard was used (Fig.3(b)). In this paper, we assumed that there are no obstacles because the platform runs over the pipes. There are eight step motors that control four of the wheels.



(a)



(b)



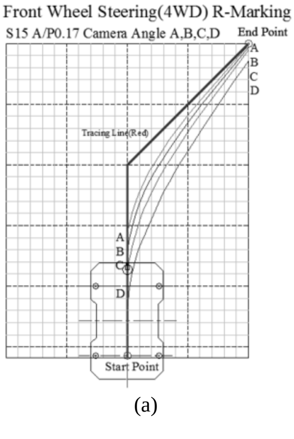
(c)

Fig.3.(a) Mechanical structure for a vision-based autonomous control of the 4WD platform for agricultural robots, (b) The vision control system, (c) The vision algorithm.

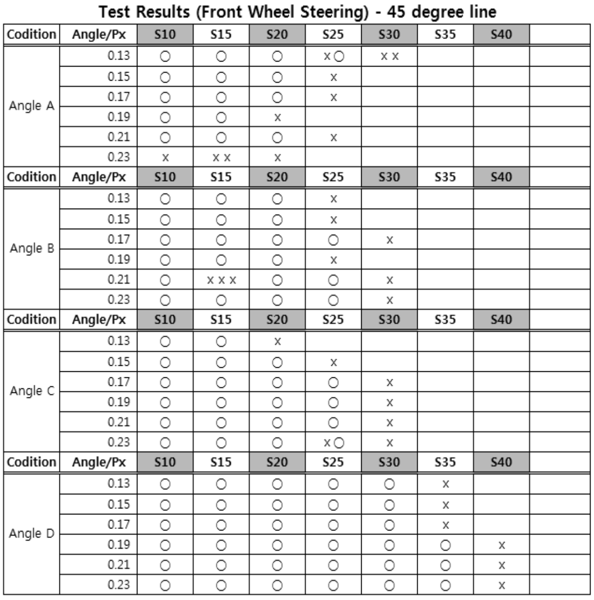
The vision algorithm is schematically shown Fig.3(c). The camera acquires images. It is then converted to grey scale image. The image is transformed through a process called discrimination that recognizes the tracking line and disregards others. The image is finally filtered to produce the tracking line at the end of the row. Note that image processing is needed only during transition from one row to another.

IV. PRELIMINARY TEST OF AUTONOMOUS TRAVELING

First we tested the mobile platform using a simple path pattern as shown in Fig.4(a). We have considered three parameters: camera angel, driving speed and steering angle per pixel. The results of autonomous FWD for this pattern with Speed Value S15 (10.92 m/min), angle per pixel AP0.17, and camera angles (A64°, B50°, C34° and D20°) is shown in Fig.4(a). Fig.4(b) shows the success rate of autonomous driving for the pattern. "○" means successful driving and "×" means failed driving. Greater camera angle can drive successful rather than the relatively smaller camera angle. A greater camera angle provides the drive platform to see farther so the drive platform can turn earlier. Fig.4(c) shows the results of the autonomous experiments based on rear-wheel driving. In rear-wheel steering vehicle’s turning behavior is different. That is the rear wheels turn in a greater steering angle. In case of the camera angle A, there is no successful driving due to missing the tracking line at the 45° point in the CCD camera. Fig.4(d) shows the success rate of autonomous driving for the pattern under rear-wheel steering. As for the trajectory, the typical turning of the front-wheel steering is also presented. There are significant differences concerning the position of the vehicle in FWD and RWD. Due to some kinematic differences, the driving conditions were differed between them which can be notices from Fig.3(e).



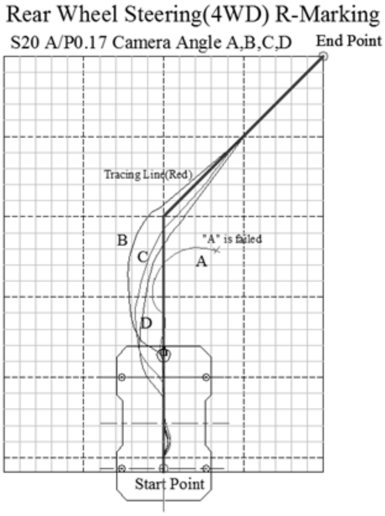
(a)



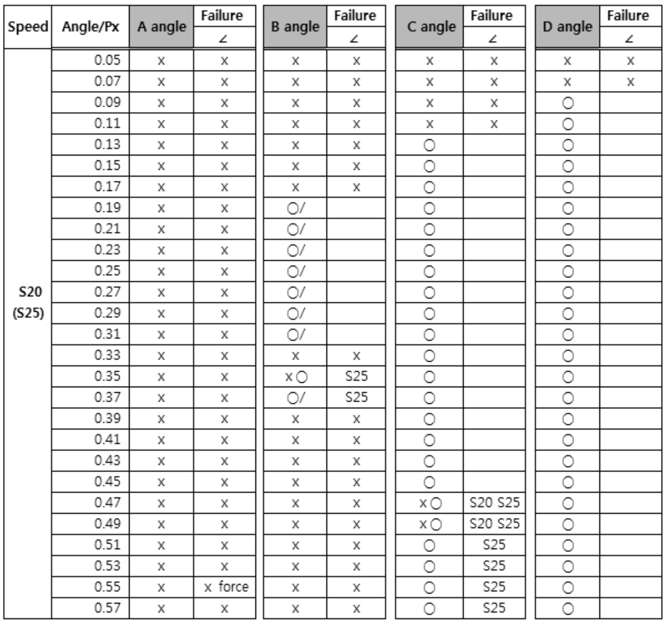
Test Results (Front Wheel Steering) - 45 degree line

Codition	Angle/Px	S10	S15	S20	S25	S30	S35	S40	
Angle A	0.13	○	○	○	x○	x x			
	0.15	○	○	○	x				
	0.17	○	○	○	x				
	0.19	○	○	x					
	0.21	○	○	○	x				
	0.23	x	x x	x					
Codition	**Angle/Px**	**S10**	**S15**	**S20**	**S25**	**S30**	**S35**	**S40**	
Angle B	0.13	○	○	○	x				
	0.15	○	○	○	x				
	0.17	○	○	○	○	x			
	0.19	○	○	○	x				
	0.21	○	x x x	○	○	x			
	0.23	○	○	○	○	x			
Codition	**Angle/Px**	**S10**	**S15**	**S20**	**S25**	**S30**	**S35**	**S40**	
Angle C	0.13	○	○	x					
	0.15	○	○	○	x				
	0.17	○	○	○	○	x			
	0.19	○	○	○	○	x			
	0.21	○	○	○	○	x			
	0.23	○	○	○	x○	x			
Codition	**Angle/Px**	**S10**	**S15**	**S20**	**S25**	**S30**	**S35**	**S40**	
Angle D	0.13	○	○	○	○	○	x		
	0.15	○	○	○	○	○	x		
	0.17	○	○	○	○	○	x		
	0.19	○	○	○	○	○	○	x	
	0.21	○	○	○	○	○	○	x	
	0.23	○	○	○	○	○	○	x	

(b)

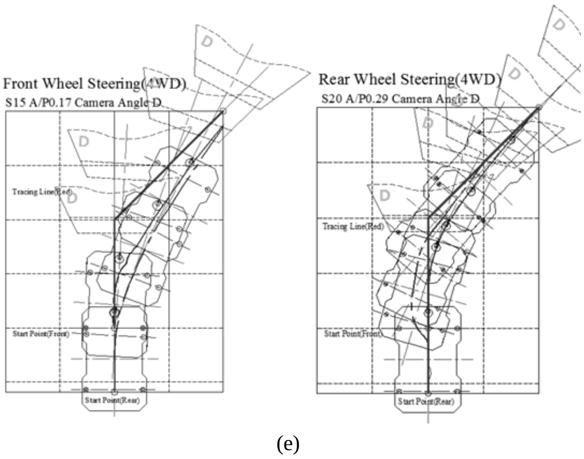


(c)



Speed	Angle/Px	A angle	Failure	B angle	Failure	C angle	Failure	D angle	Failure
			∠		∠		∠		∠
S20 (S25)	0.05	x	x	x	x	x	x	x	x
	0.07	x	x	x	x	x	x	x	x
	0.09	x	x	x	x	x	x	○	
	0.11	x	x	x	x	x	x	○	
	0.13	x	x	x	x	○		○	
	0.15	x	x	x	x	○		○	
	0.17	x	x	x	x	○		○	
	0.19	x	x	○/		○		○	
	0.21	x	x	○/		○		○	
	0.23	x	x	○/		○		○	
	0.25	x	x	○/		○		○	
	0.27	x	x	○/		○		○	
	0.29	x	x	○/		○		○	
	0.31	x	x	○/		○		○	
	0.33	x	x	x	x	○		○	
	0.35	x	x	x○	S25	○		○	
	0.37	x	x	○/	S25	○		○	
	0.39	x	x	x	x	○		○	
	0.41	x	x	x	x	○		○	
	0.43	x	x	x	x	○		○	
	0.45	x	x	x	x	○		○	
	0.47	x	x	x	x	x○	S20 S25	○	
	0.49	x	x	x	x	x○	S20 S25	○	
	0.51	x	x	x	x	○	S25	○	
	0.53	x	x	x	x	○	S25	○	
	0.55	x	x force	x	x	○	S25	○	
	0.57	x	x	x	x	○	S25	○	

(d)



(e)

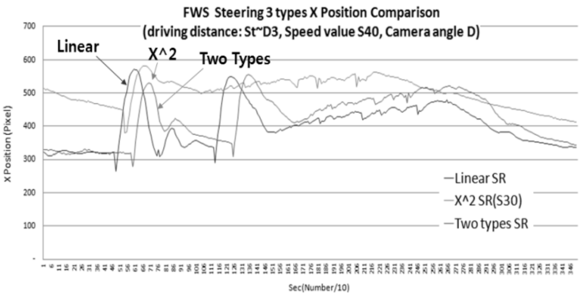
Fig.4 (a) Front wheel steering diagram (b) Front wheel steering results (c) Rear wheel steering diagram (d) Rear wheel steering results (e) Front and rear wheel steering side by side.

V. EXPERIMENTAL RESULTS OF AUTONOMOUS TRAVELING

After the preliminary test, we conducted experiment on the considered pattern shown in Fig.2(d). Fig.5(a) shows the results. The entire patter can be classified into three groups: linear, square, and combination of these two as shown in the figure. Fig.5(a) shows linear, square, and the combined form of driving algorithm under FWS condition. The graph shows the *x* position of the mobile robot at different driving distances with SV S40 and camera angle D. Fig.(b) shows linear, square, and the combined form of driving algorithm under RWS condition. The graph shows the *x* position of the mobile robot at different driving distances with SV S40 and camera angle D. Fig.5(c) shows the comparison between FWS and RWS in terms of steering angle at same speed value and camera angle over the entire length. Fig.(d) shows the comparison between FWS and RWS in terms of steering angle at same speed value and camera angle over the entire length in opposite direction of the considered path pattern. Fig. 5(e) shows the comparison between FWS and RWS under same condition. As can be seen there is not much difference except the time delay in case of RWS.

VI. DISCUSSION

We identified the training parameters in order to develop subroutines for a fully-fledged Global Algorithm. Utilizing three parameters such as camera angles, driving speed and steering angle per pixel, the information that were gathered during learning stage. The constraints accumulated during learning stage were used to develop steering algorithm during the training stage. Note that speed reduction algorithm is important at sudden turns and curves. Twelve sub-routines were developed. The pseudo code for the Global Algorithm is “set SV; if the straight edge angle exceeds constraints, determine the new SV”.



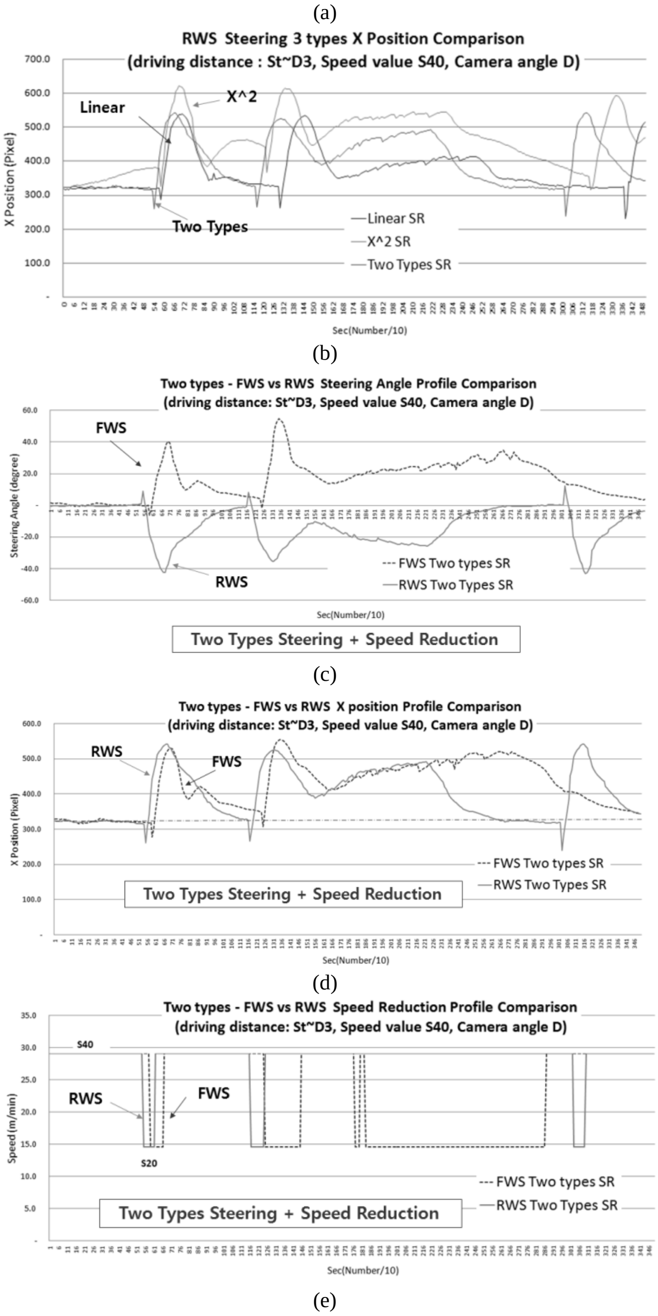


Fig.5. (a) Linear, square, and the combined form for FWD, (b) That of RWD, (c) Comparison between F and R, (d) Comparison between F and RWS w.r.t. steering angle, (e) Difference in time delay under F and R.

Note that the kinematic characteristics of the front and rear steering angle due to per pixel cannot be the same. Thus, in the case of the steering wheel AP0.17, rear-wheel steering, the results were compared with driving with AP0.2. In the case of a rear-wheel driving, the platform tracks the line with dissimilar distances. Therefore the driving convergence during runtime needs to be addressed.

VII. CONCLUSION

In this paper, we have demonstrated FWD and RWD of a 4WD mobile robotic platform intended for weed monitoring application. Initially, we defined a path pattern for testing and learning of the driving constraints. The robotic platform was experimented a greenhouse. The vision-based autonomous driving algorithm was developed and validated. The image processing was achieved using a single camera. In this paper, autonomous driving platform among the many factors that affect the driving characteristics was comprehensively studied. The important parameters to be considered for 4WD system are camera mounting angle, driving speed, and steering angle per pixel. Cornering and straight line driving principles were studied. In a narrow space like greenhouse, the rear-wheel steering with excellent driving characteristics can be the future work.

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REFERENCES

[1] Kim, Mi - Ok, yijeonghan, Yoo, Wan – Suk (2009). Four-wheel steering Autonomous Study on optimal speed of the robot, Bureau of Automotive Engineers, No. 17, No. 4,, pp.86-92
[2] Yangchangwan (2011). Plant production robot platform for application-driven development of four-wheel steering, pp. 36-45
[3] Lee Yong Tae (2011). Plant production robots-wheel independent steering drive platform for the application of research, Journal of Korea Society of Precision Engineering 28 Chapter 8 pp. 942-950.
[4] Reza N. Jazar (2008). Vehicle Dynamics: Theory and Applications, Steering Dynamics, pp. 379-451
[5] T. Gillespie (1992). Fundamentals of vehicle Dynamics" Tmecca
[6] A. Gollakota, M. Srinivas (2011) Agribot: A multipurpose agricultural robot, *INDICON*, vol.1, no.4, pp. 16-18
[7] M. Kim, O. Yijeonghan, W. Yoo (2009). Four-wheel steering on the optimal speed of Autonomous Mobile Robot Research, Korea Society of Automotive Engineers, No. 17, No. 4, pp.86-92
[8] T. Matsuda, T. Clark, H. Lee (1997). Electronic commerce for agricultural transactions: role of intermediaries and accurate pricing, *Proceedings of the Thirtieth Hawaii International Conference on System Sciences*, vol.4, pp.13-20
[9] Gwoninso (2011). Autonomous Technology, Vol.51, No.3, 2011
[10] Sook, Kim, Tae - Wan, yichanggu (2002). Vision of Autonomous Mobile Robot Using Line Recognition and Study on the Determination of the direction of travel, Summer 2002, Proceedings of the Korean Institute of Electrical Engineers, 10-12,
[11] Songhyeonseung, autonomous driving distance measurement for the minutiae matching algorithm based on the research, pp. 1-4, 2002
[12] Than Aung, Mike Conlow, LabVIEW machine vision for line dectection EGR315: Instrumentation, Springer 2010
[13] Guilherme V. Raffo, Guilherme K. Gomes, Julio E. Normery-Rico, Christian R. Kelber, Leandro B. Becker, A predictive controller for autonomous vehicle path tracking, IEEE Trans. on intelligent transportation systems, vol. 10, No.1, 2009
[14] J. Borenstein, L. Feng, UMBmark-A method for measuring, comparing, and correcting dead-reckoning errors in mobiel robots, Technical report UM-MEAM-94-22, University of Michigan, 1994