Agronomy Research **13**(1), 167–172, 2015

Laser scanner based collision prevention system for autonomous agricultural tractor

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Abstract. In manned agricultural vehicles, the automated systems assist the driver by reducing the workload. This is achieved e.g. by using an automatic guidance system to steer the tractor along the desired path. However, increasing automation tends to cause a reduction of awareness, so risks to collide obstacles in the field are higher. In this study, an autonomous tractor was equipped with front side laserscanner (LIDAR) to sense the environment in front. The laserscanner scans the environment at 50 Hz rate. The theoretical maximum range of the sensor is 25 m, but it was found in the tests, that in agricultural field conditions, the feasible range is not more than 7 m, due to the sunlight disturbance. Agricultural vehicles weigh tons, so the deceleration is limited and the limited range causes challenges to detect the obstacle and decelerate without colliding it. The developed algorithm is able to detect solid objects, like electricity poles in the trajectory. The deceleration algorithm is based on the known dynamics and actuator delays of the tractor locomotion system, by taking into account the maximum deceleration rate. In field tests, the system was evaluated in grass fields. In the first test, the system was tested with real electricity poles with no implement. In the second test, the system was tested with a mower and by using artificial obstacles placed into the grass. The system was able to detect the obstacles with high accuracy and stop precisely, but in the corners of the field the system caused false positives when the sensor was sensing beyond the edges of the field plot.

Key words: tractors, vehicles, robotics, environment sensing, autonomous emergency brake, accidents, control systems.

INTRODUCTION

Several kinds of obstacles may exist in agricultural fields and agricultural vehicles, like tractors, have to avoid hitting them. Some of the obstacles are permanent, like electricity poles or large rocks, while the others are temporary, like other vehicles and containers to store inputs and outputs.

Traditionally tractors and other vehicles have been in the full control of the driver and visual perception of the neighbourhood has been conducted continuously. However, nowadays automatic steering / guidance systems have emerged and the driver may not pay so much attention for the environment any more. Therefore the risk to hit the obstacles arises. Increased automation and fewer tasks for the human operator may cause a lack of attention, in any industry.

Modern passenger cars are equipped with radars or other sensors which are monitoring the area ahead. These systems are able to take emergency braking actions, in case the driver has lost concentration or something unexpected appears, to prevent rear-end collisions. Kaempchen et al. (2009) call the system as Autonomous Emergency Brake (AEB) and considers various possible trajectories in dynamic environment.

These systems are not yet installed on tractors, but they could be used for the same reasons. Agricultural tractors with heavy loads are used in on-road traffic and due to increased speed and mass the same requirements may be considered as for trucks, to prevent rear-end collisions on dynamic objects. However, in agricultural vehicles the on-road rear-end collision are not considered as usual as off-road collisions on static objects.

Various approaches to obstacle detection in agricultural context have been proposed. Yang & Noguchi (2012) used omnidirectional stereovision to detect humans, with machine vision methods. The motivation was a robot tractor where the safety needs to be secured. Backman et al. (2013) presented a collision avoidance system for a tractor with the automatic steering system; the laser scanner based object detection was integrated closely on the guidance algorithm which enabled manoeuvring around the obstacle.

In this paper, the developed collision prevention system for an autonomous system is presented. The objective was to study how to take the dynamic vehicle velocity model into account in the deceleration control system, in order to perform the (emergency) deceleration at last possible minute.

MATERIALS AND METHODS

Tractor

The autonomous tractor used in this study is equipped with 123 kW diesel engine and hydrostatic transmission with four wheel equal size. The weight of the tractor is about 6,000 kg without implements and each wheel is steerable. The tractor is equipped with four wheels and the overall width is 2.3 m. The maximum speed was limited electronically to 3 m s^{-1}, even though the transmission would give much more. The acceleration and deceleration were controlled electronically, in both directions the maximum rate was set to 1.0 m s^{-2}, to reduce pressure stress for the hydrostatic system. (Oksanen, 2012a; Oksanen, 2012b)

Sensor

The environment was monitored with a 2D laser scanner, LIDAR, made by SICK. LMS100 model is designed for indoor use, but it was considered sufficient for this experimental system. The sensor sensed the environment with 50 Hz frequency and 0.5 degree resolution. The communication protocol is based on TCP/IP over Ethernet.

In the tests, the sensor was installed at first in front of the tractor and later on the front mounted mower. The scanner was installed on horizontal orientation. The installation of the laser scanner on the mower is presented in Fig. 1.

The scanner was specified to measure a maximum range of 25 m, but in outdoor with bright sunlight the maximum range was found to be limited to approximately 7 m. Therefore, the obstacles beyond 7 m cannot be detected reliably, even if in some conditions they are clear. The laser scanner senses the distance by sending an infrared light pulse to the environment and it measures the time-of-flight of reflection. In bright sunlight, the power of transmitted light is not sufficient to measure long ranges. However, the maximum range found was adequate for the maximum driving speed of m s^{-1}.

Figure 1. Installation of the laser scanner on the mower. The laser scanner is the blue component in the center.

Object detection

The algorithm was monitoring the area in front of the tractor. The region of interest is a rectangle or a bent rectangle. The width of rectangle equals to tractor or implement width and the length was 10 m ahead. The curvature or bent rectangle was equivalent to the current curvature of the vehicle. An illustration of the region of interest is presented in Fig. 2.

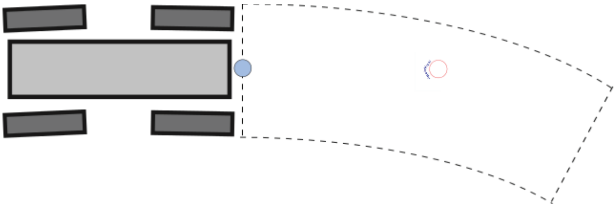

Figure 2. Illustration of the object detection region of interest. Red circle represents an obstacle and blue dots around are measurements the laser scanner get reflection from.

Deceleration control

As the tractor velocity control contains a control delay of magnitude 400 ms, this was taken into account in a predictive way. Also, the maximum deceleration rate of the vehicle needs to be known. From these factors, a model based control design was derived, to make a decision whether deceleration should be started, based on the object vicinity.

The faster the tractor is moving, the more distance and time is required to stop. When commanding the speed to zero, it takes 400 ms without any action and then the velocity starts to decrease at maximum rate of 1 m s^{-2}, which is the limitation of the tractor. From these figures it is possible to calculate the time required making a full stop and, furthermore, the distance the tractor has travelled after the stop was started. This is a function from the initial speed before full deceleration to the distance required to stop.

For deceleration control, an inverse function of that is required. For the parameters of this particular vehicle, the function is presented in Fig. 3. The obstacle detector system gives a distance from the nearest part of the vehicle to the obstacle in meters, or infinity when no obstacles exist in the region of interest. This distance is used as input to the function and the output gives the speed threshold when the deceleration must be done at maximum rate in order to prevent collision. For the distance, an offset is added as a tuning variable, to leave a safety zone between the obstacle and the vehicle.

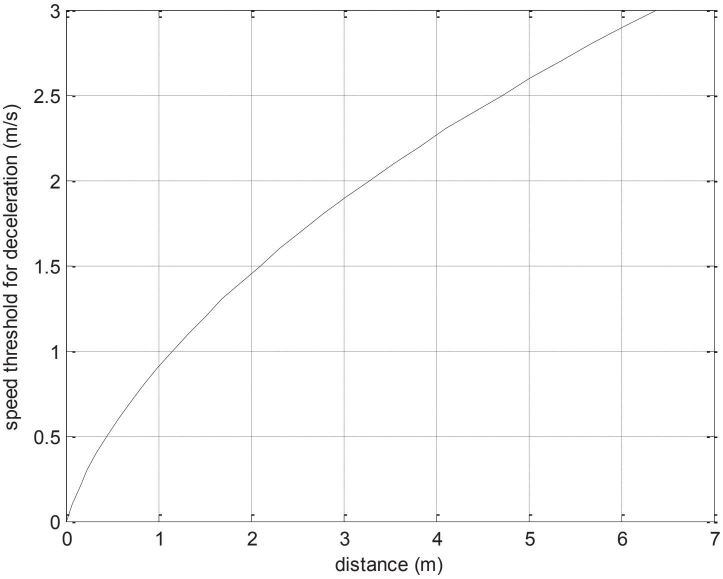

Figure 3. The function for deceleration control threshold. Below the curve is the safe zone, no deceleration action is necessary.

RESULTS AND DISCUSSION

The system was evaluated by approaching the obstacle from a single direction repeatedly, and by varying the speed every time. The obstacle was an artificial round pole, made of dark foam. The diameter corresponds to the typical I-type wooden electricity pole. The situation is illustrated with Fig. 4. During the test the weather was cloudy, so the detection range of the laser scanner was not an issue. The safety offset for distance was set to 2.0 m.

Figure 4. Test setup, an artificial obstacle representing an electricity pole.

Each run was carried out by driving cruise control enabled towards to the obstacle and the system was decelerating automatically. An example of the deceleration test is presented in Fig. 5. The tractor approached the obstacle with cruise control enabled at 2.6 m s^{-1} (bold line). At time step 3.5 s, the obstacle detector (solid line) started to limit the commanded speed (dashed line) and the command starts to follow this limit curve. The tractor stopped at time step 7.3 s and the distance to the object was 2.01 m in the end.

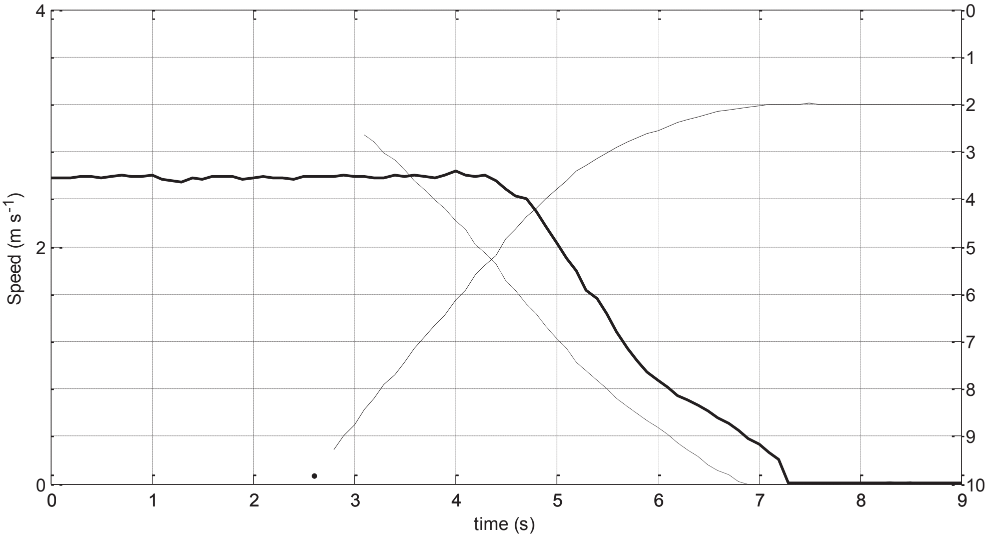

Figure 5. A sample deceleration. Bold line is the measured velocity, dashed line is the commanded deceleration and the solid line represents the measured distance to the obstacle.

The test was repeated 11 times, with varying speeds. The results are presented in Table 1. It can be seen that the tractor is able to decelerate automatically and stop within maximum error being 4 cm.

Table 1. Tests and results

Initial speed (m s^{-1})	Final distance to object (m)
0.9	1.97
0.9	1.96
1.8	2.04
2.7	2.01
2.7	2.00
2.7	1.98
2.6	2.01
3.0	2.00
2.8	2.02
3.0	2.03
2.8	2.04

CONCLUSIONS

A system with the automatic detection of solid obstacles in the field was developed and it was integrated into the tractors control system, to prevent collision by automatic deceleration. The deceleration is controlled by using a model based control of the tractor dynamics and control delay.

In the tests, the robot tractor was able to use full deceleration and it stopped to the safety margin from various speeds within accuracy level of two-inches.

The sensor used was intended for indoor use and the maximum range was found to be limited to 7 m in case of bright sunlight. Despite this was sufficient for the maximum driving speed of this tractor, even in bright sunlight, it cannot be used for higher speeds. Therefore, the sensor is not suitable for driving speed beyond 3 m/s. However, other sensor models of the same manufacturer should be used or other sensor types to overcome the sunlight problem.

ACKNOWLEDGEMENTS. This research was funded by ERA-NET ICT-AGRI project GrassBots. The research was supported by MTT Agrifood Research Finland, especially the author wants to thank Mr. Raimo Linkolehto and Dr. Juha Backman for the assistance and test environment during the research.

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