Automatic assistant for coupling an agricultural tractor and a trailer

Ville Matikainen

Aalto University, Dept. of Electrical Engineering and Automation,

Otaniementie 17, 02150 Espoo, Finland (Tel: +358503731022; e-mail: ville.matikainen@aalto.fi).

Juha Backman

Natural Resources Institute Finland, Green Technology, Production and Information Systems,
Vakolantie 55, 03400 Vihti. e-mail: juha.backman@luke.fi

Arto Visala
Aalto University, Dept. of Electrical Engineering and Automation,

Otaniementie 17, 02150 Espoo, Finland (e-mail: arto.visala@aalto.fi).

KEYWORDS autonomous work machines, LIDAR, Smith-predictor, ISOBUS

ABSTRACT

In this research a system assisting the operator of an agricultural tractor in the coupling of a trailer was developed. The system utilized knowledge of the dimensions of the trailer in calculating the towing eyelet location from laser range finder measurements using iterative end-point fit. The tractors speed and curvature are then automatically controlled to align the draw hook with the towing eyelet. Curvature is controlled using pure pursuit algorithm and speed with Smith-predictor and P-controller. In final field tests the system provided 10 successful connections out of 10 attempts. Further research is required to make the system more general and robust to environmental anomalies. Overall performance of the system was satisfactory.

1 INTRODUCTION

An agricultural tractor is by itself quite a useless machine, and productive work is carried out by coupling the tractor with a work machine, called an implement, or a trailer. Coupling an agricultural tractor to a trailer is not a trivial task: the hook is difficult to observe from the cabin and the operator has to work in cumbersome position, operating the steering wheel and pedals while looking backwards to monitor the trailers position. Therefore it is a fine application for an automated solution. The goal of this research was to develop methods enabling semi-automatic connection of the trailer, requiring minimal operator effort. Automation only considered the mechanical connection of the trailer.

There is not much previous research regarding this problem. Ahamed presented an automatic coupling system for a hitched implement using a laser range finder and an agricultural implement fitted with reflectors for localization /1/. Bernhardt et al. presented a patent utilizing a 6-degree-of-freedom rear hitch with a coupling frame and suitable sensors to connect a hitched implement /2/.

This article is based on a previous work by the authors published in IFAC World Congress 2014, Cape Town /3/ Details missing from this paper can be recovered from there.

2 METHODS

In this chapter the approach taken along with the test equipment are presented. After that the methods used are presented in more detail. In our approach the idea was to connect to a standard trailer with no modifications. As a means for locating the trailer a SICK LMS221 laser range finder was fitted to an agricultural tractor.

Once the trailer has been successfully located we naturally need to navigate our tractor towards it. As a starting point it is presumed that the tractor is located at a reasonable position relative to the trailer, defined by a professional farmer as a position that is not 12m farther from the trailer and that the trailer isn't offset more than five meters from the tractors centre line.

Figure 1 Tractor and trailer used in the research

A tractor based on a Valtra T132 was used (**Figure 1**). It was instrumented to enable turning control over ISO 11783 network using standard messages. ISO 11783 is a standard for the communication between a tractor and its implements. It expands the CAN 2.0B –protocol by defining the physical layer as well as layers above OSI level 3. It is harmonized with SAE J1939, a common communication standard in the heavy vehicle industry. /4/ The laser scanner was connected to a Moxa serial-to-ethernet –server which passed the measurements to a HP Elitebook 8460p laptop computer with Intel Core i5-2520M CPU with 4 gigabytes of memory, running Windows 7, acting as the ECU. The ECU application was implemented mostly in Simulink /5/ environment using a software platform previously developed in the Agromassi-project /6/. Graphical user interface was created using PoolEdit /7/ and associated parsers. The system architecture is presented in **Figure 2**.

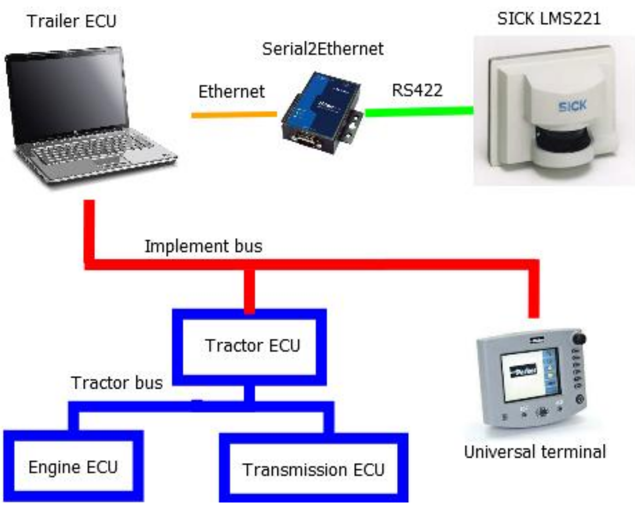

Figure 2 Architecture of the trailer coupling system

2.1 Locating the trailer

First the 181 distance measurements are read from the laser scanner. To eliminate outliers, measurements are filtered by taking five temporally sequential measurements (1), removing the smallest and the largest and taking average of the remaining three(2).

$$S = \langle d_k \ldots d_{k-4} \rangle \tag{1}$$

$$d_{fk} = \frac{1}{3}\sum(S - \min(S) - \max(S)), \tag{2}$$

where d_k is the measured value at step k, S is set of five measurements and d_{fk} the filtered value. The measurements where then converted from polar coordinates to Cartesian coordinates. Then the measurements were split into line segments using iterative end-point fit –algorithm to get a smoother view of the environment. /8/ /9/ Suitable threshold value i_{tol} was tuned by analysing the irregularities of the trailers front wall.
As there were problems with iterative end-point fit and distant points, the measurements were filtered again in Cartesian coordinates for the spring season tests. The algorithm was quite simple and the details are presented in /3/
From the line segments obtained above, segments within a suitable margin w_{tol} of the measured trailer width were sought. Once the trailer wall was found, the position of the towing eyelet, (x_{target}, y_{target}), was calculated from the known tow bar length l_{bar} using vector product (4).

$$x_{tc} = \frac{x_{tl} + x_{tr}}{2} \quad (3)$$

$$y_{tc} = \frac{y_{tl} + y_{tr}}{2}$$

$$x_{target} = x_{tc} + x_{offset} + l_{bar} \cdot \frac{y_{tr} - y_{tl}}{d_{lr}} \quad (4)$$

$$y_{target} = y_{tc} + d_{s2h} + l_{bar} \cdot \frac{x_{tl} - x_{tr}}{d_{lr}},$$

where x_{tc}, y_{tc}, x_{tl}, y_{tl}, x_{tr} and y_{tr} are the x- and y-coordinates of the centre, left corner and right corner of the trailer's front wall, respectively, d_{s2h} the horizontal distance between the laser scanner and the draw hook and x_{offset} a calibration variable for the horizontal direction.

2.2 Pure pursuit in path tracking

Pure pursuit is a geometric method for path tracking of non-holonomic vehicles. The reference curvature for reaching the goal point is given by

$$\gamma = \frac{2x}{l^2}, \quad (5)$$

where γ is the reference curvature, x the horizontal distance to the goal point and l the distance to the goal point. /10/ A modification was made to limit the maximum absolute value of curvature when close to the goal point. The point of origin for the algorithm is in the middle of the rear wheels, which is somewhat different from the target point calculated in the previous chapter. The error caused by this was deemed insignificant. To smoothen the controls, the value given by the algorithm was passed through a second order digital low-pass filter before giving the curvature reference to the tractor.

2.3 PI-controller in path tracking

As an alternative approach to pure pursuit a simple PI-controller was also tested for steering. The error fed to the controller was simply the x-coordinate of the towing eyelet position in tractors coordinate frame. (**Figure 3**)

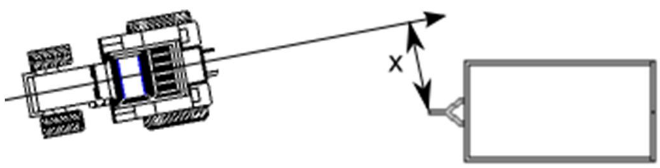

Figure 3 PI-controller based steering

2.4 Speed control

To enable position control of the tractor we needed a dynamic model of the tractors longitudinal motion. The transfer function from tractors cruise control set-point to distance traversed by tractor was assumed to be a first-order lag integrating process with time delay (FOLIPD). To identify the dynamics a set of predefined speed trajectories was executed from which the dynamic parameters were identified using MATLABs System Identification Toolbox /11/.
The identified dynamics were used to tune a special formulation of Smith-predictor designed for integrating processes with disturbances. Smith-predictor is a controller structure used to compensate for pure delay in a system. /12/

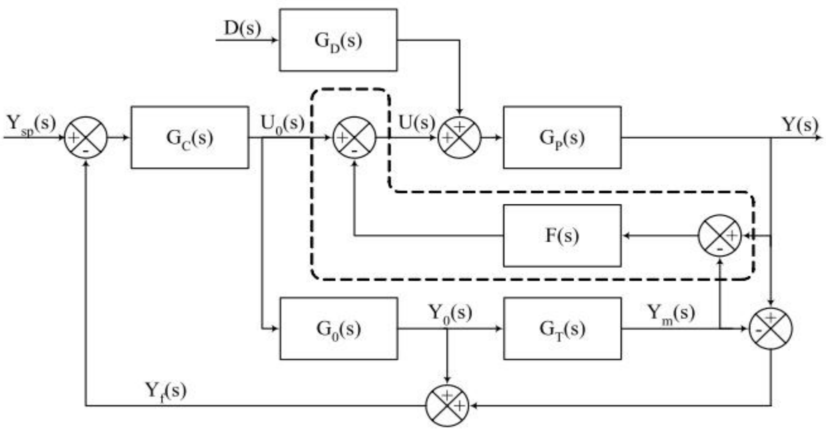

Figure 4 The Smith-predictor structure used in this research /12/

In the diagram (**Figure 4**) $G_C(s)$ is the controller, which in this research was a P-controller(6)

$$G_C(s) = K_C, \tag{6}$$

where K_C is the controller proportional gain. The unmeasured disturbance D(s) and its associated transfer function $G_D(s)$ is attributed to the non-ideal features of the tractor's cruise control, dynamics of the tires etc. $G_P(s)$ is the actual process, here the longitudinal dynamic behaviour of the tractor (7)

$$G_P(s) = \frac{K_P}{1 + sT_P} e^{-\theta_P s}, \tag{7}$$

where K_P is the system gain, T_P is the dynamic delay and θ_P the dead time delay. G_0 is the delay-free model of the system (8) and G_T (9) is the pure delay of the system. F(s) is a factor for compensating the disturbance (10).

$$G_0(s) = \frac{K_P}{1 + sT_P} \tag{8}$$

$$G_T(s) = e^{-\theta_P s} \tag{9}$$

$$F(s) = \frac{1}{2\theta_P K_P} \tag{10}$$

As the system was used in a computer controlled system, the controller was discretized using zero-order hold.

2.5 Operational logic

To bind the aforementioned functionalities together and manage the behavior of the tractor, a Simulink Stateflow /13/ chart was created. Most states in the state machine have a corresponding view on universal terminal(UT) interface, which is a device used to display data and get input from the operator /14/.
When the system is started and set into automatic mode via UT, it first searches the environment for trailers matching the given trailer wall length. Once found, it presents the coordinates of the towing eyelet and instructs the operator to engage automatic control. The tractor then reverses to a predefined approach position, at which the UT instructs the operator to lower the draw hook and then engage the cruise control again. Finally it informs the operator of a successful connection.

2.6 Test setup

Functionality of the system was tested in a tarmac backyard which was covered with ice and snow during the first tests. The trailer used was a traditional multi-purpose agricultural trailer with a corrugated plate front wall.

3 RESULTS

The parameters of the system are presented in /3/. Three different test sets of 10 runs each are presented in **Table 1**: winter test with steering control using P-controller, winter test with pure pursuit steering control and spring season test with pure pursuit steering control and additional filtering of the laser measurements. It presents the number of successful connections, and also the number of “large failures”, ie. test runs where the tractor didn’t come within a meters radius of the towing eyelet. It also presents the lateral and longitudinal errors of the failed runs with corresponding deviations.

Table 1 Results of the three test sets

Test	Success rate	Rate of large failure	Lateral error	Longitudinal error
Winter1, PI-controller	3/10	6/10	10,3cm (+4,7;-6,3)	3cm (+1;-1)
Winter2, Pure pursuit	2/10	4/10	3cm (+1;0)	-2,8cm (+6,7;-44)
Spring	10/10	-	-	-

4 DISCUSSION

Overall the system performed surprisingly well, considering the various non-ideal properties like delays, deformation of tires, and the irregularity of the trailer wall. Especially the accuracy of repetition was impressive.
As line segments of similar length can be detected in the environment as well, segments directly behind the tractor could be considered the most possible ones matching the trailer and weighed above the others.
The need for a calibration constant in the x-coordinate of the towing eyelet position can be attributed to two possible factors: the orientation of the laser scanner was not calibrated exactly and neither was the curvature control of the tractor calibrated, so there might be some angle error in it.
While the use of two different trailers in the tests makes comparison between the test sets problematic, it also acts as a proof of generality, ie. the algorithm is not tuned for simply one trailer.
The location of the laser scanner would have to be redesigned in an actual commercial application.

5 CONCLUSIONS

In this research a method to assist a driver in coupling a trailer to an agricultural tractor was developed. To the authors' best knowledge, this was the first method for this exact case.
The presented navigation method gave a systematic response from chosen starting area. The localization of the trailer from LMS 221 range measurements worked well in a static environment. As a whole the system met the research goal, being a system that makes the process of coupling a trailer to a tractor simpler.

6 ACKNOWLEDGEMENTS

This research was conducted in project Agromassi which is part of FIMECC-program EFFIMA. FIMECC is Finnish Metals and Engineering Competence Cluster whose aim is to increase and deepen the cooperation between companies, universities and research institutes in the area of top quality research.

7 REFERENCES

/1/ T. Ahamed, Navigation of an Autonomous Tractor Using Multiple Sensors, Tsukuba: University of Tsukuba, 2006.

/2/ G. Bernhardt, S. Fedotov, R. Rudik and H. Weiss, "Vehicle/implement coupling system". US Patent 6,581,695 B2, 29 January 2002.

/3/ V. Matikainen, J. Backman and A. Visala, "Semi-automatic coupling of an agricultural tractor and a trailer," Cape Town, 2014.

/4/ ISO, *ISO 11783 Part 1: General standard for mobile data communication.,* Geneva: International Organization for Standardization, 2005.

/5/ MathWorks, "Simulink - Simulation and Model-Based Design," Mathworks, 2013. /Online/. Available: http://www.mathworks.se/products/simulink/. /Accessed 15 4 2013/.

/6/ T. Oksanen, A. Kunnas and A. Visala, "Development and Runtime Environment for Embedded Controller supporting ISO 11783 Standard.," in *IFAC World Congress*, Milan, 2011.

/7/ M. Öhman, J. Kalmari and A. Visala, "XML Based Graphical User Interface Editor and Runtime Parser for ISO 11783 Machine Automation Systems," in *IFAC World Congress*, South Korea, 2008.

/8/ U. Ramer, "An iterative procedure for the polygonal approximation of plane curves," *Computer Graphics and Image Processing,* vol. 1, no. 3, pp. 244-256, 1972.

/9/ D. Douglas and T. Peucker, "Algorithms for the reduction of the number of points required to represent a digitized line or its caricature," *The Canadian Cartographer,* vol. 10, no. 2, pp. 112-122, 1973.

/10/ C. Coulter, "Implementation of the Pure Pursuit Path Tracking Algorithm," Carnegie Mellon, Pittsburgh, 1992.

/11/ MathWorks, "System Identification Toolbox - MATLAB," Mathworks, 2013. /Online/. Available: http://www.mathworks.se/products/sysid/. /Accessed 15 4 2013/.

/12/ R. Rice and D. J. Cooper, "Practical Model Predictive Control Structures for Non-Self Regulating (Integrating) Processes," in *ISA Expo*, Houston, TX, 2003.

/13/ MathWorks, "Stateflow," Mathworks, 2013. /Online/. Available: http://www.mathworks.se/products/stateflow/. /Accessed 13 6 2013/.

/14/ ISO, *ISO 11783 Part 6: Virtual terminal,* Geneva: International Organization for Standardization, 2004.

/15/ J. M. Snider, "Automatic Steering Method for Autonomous Automobile Path Tracking," Carnegie Mellon University, Pittsburgh, Pennsylvania, 2009.