Track Loader Kinematics

Håkan Fredriksson Ulf Andersson Kalevi Hyyppä

Department of Computer Science and Electrical Engineering
Luleå University of Technology
SE-97187 Luleå, Sweden
E-mail: {hakan.fredriksson / ulf.andersson / kalevi.hyyppa}@ltu.se

Abstract: We study the problem to teleoperate a Caterpillar 973c track loader. The track loader and a system for teleoperation are described. A tested and working kinematic model used for dead reckoning is also presented. Track speed sensors combined with a rate gyro are used as input to the model. The model shows good results when tested and compared to a GPS navigation system.

Fig. 1. A teleoperated Caterpillar 973c track loader.

1. INTRODUCTION

Autonomous and teleoperated vehicles benefits from using a kinematic motion model for navigation purposes. Teleoperation may be used in areas where the navigation system required for autonomous operations does not work. During teleoperation in such areas, a rough estimation of the pose (position and orientation) of the vehicle can be achieved using a dead reckoning system based on inputs from onboard sensors.

When the vehicle is moved to an area where autonomous driving is possible the estimated pose of the vehicle from the dead reckoning system can be used as an approximate staring pose in the navigation system. This will speed up the initialisation of the navigation system.

2. TRACK LOADER

The Caterpillar 973c, seen in Fig. 1, has a special steel mill arrangement for working with hot (700°C) slag. The arrangement includes, for instance, a special bucket and extra guarding for the machine and the operator. The operating weight of the track loader is app. 27 tonne and the total length is more that 7m.

The Caterpillar 973c has hydrostatic drive with electronic control. The speed and forward/reverse motion of the vehicle are changed using a single control lever. Pedal steering is used to control the speed of each track independently. Counter rotation of the tracks can be achieved by pressing one of the pedals more than halfway down. The boom and the bucket are controlled using a pilot operated joystick.

2.1 Computer control

Additional equipment have been mounted on the track loader to enable teleoperation and autonomous driving. Teleoperation of the track loader is done from a remote location using the operator panel seen in Fig. 2. The operator panel is connected to a computer that, via a wireless local area network (WLAN), communicates with the system on the track loader. As the communication infrastructure for our software we use GIMnet as described in Saarinen et al. [2007].

Fig. 2. The remote control station consisting of a computer that is connected to an operator panel with joysticks, lamps, and buttons for manoeuvring of the track loader. The station also includes a video monitor.

The track loader has been equipped with a computer, WLAN access, and electronics enabling both manual and computer control. The functions of the original lever and the pedals that control the forward and reverse motion of the tracks are replaced by computer controlled electronics. Proportional hydraulic valves, combined with computer controlled electronics, are mounted to control the boom and the bucket.

When teleoperated, the track loader is controlled with the two joysticks seen in Fig. 2. The right hand joystick controls the boom and the bucket. The left hand joystick sets the drive speed and the turning velocity of the track loader. We use only open loop control of the track speeds so the resulting speeds are highly dependent of the current load on the track loader. The operator panel is also equipped with a number of push buttons to control, for instance, motor start and stop. A number of indicator lamps are used to indicate the status of the track loader.

The individual track speeds are measured by reading the original mounted pulse sensors. A one-axle rate gyro (KVH DSP3000) is mounted to measure the turning velocity of track loader. For reference purpose a GPS navigation system (Novatel GPS ProPak-G2plus) is added. The antenna of the GPS system is mounted on top of the vehicle roof, close to the middle of the track loader undercarriage, both sidewise and lengthwise. Information from all sensors are logged and stored in the on-board mounted PC.

3. KINEMATICS

As other types of skid-steered vehicles, a track loader suffers severe slip when turning. This slip is very hard to measure or estimate accurately since it is depending on both the ground underneath the tracks and the centre of mass of the vehicle. Both these variables may change quite a lot in the environment where the track loader is working. If the bucket is full or empty effects the centre of mass. Different surface materials, bumps and holes, also effect the slip. Therefore, it is of great importance to use dead reckoning sensors that can handle both highly varying friction between the tracks and the ground as well as varying centre of mass of the track loader.

In Martínez et al. [2005] and Mandow et al. [2007] the authors address the kinematics for both tracked and wheeled skid-steered vehicles. The pose estimation is improved by calculating the Instant Centre of Rotation for the vehicle (with fixed centre of mass) for different types of ground materials. However, this approach is not suitable in our application since the centre of mass changes when the bucket is full or empty, and also the ground material, bumps, holes and incline effects the model. We need a kinematic model that is tolerant to all these external environmental disturbances.

3.1 Model

The kinematic model is based on a standard differential drive model

$$\dot{x} = \sin(\theta) * v$$
$$\dot{y} = \cos(\theta) * v$$
$$\dot{\theta} = \omega \tag{1}$$

where v is the driving velocity of the vehicle, x and y are the position coordinates of the vehicle, θ represent the heading, and ω is the turning velocity.

The driving velocity is calculated with

$$v = \frac{v_r + v_l}{2} \tag{2}$$

where the left v_l and right v_r track speeds are measured by the sensors originally mounted on the track loader.

To reduce the influence of slip in the model, we use a gyro to measure the turning velocity ω of the vehicle. We also tested dead reckoning based on information from the individual track speeds according to

$$\omega = \frac{v_r - v_l}{trackgauge} \tag{3}$$

where $trackgauge$ is the distance from the middle of the left track to the middle of the right track.

4. TESTS

To test the kinematic model, we logged the positions of the track loader using the GPS system when the track loader was driven in an eight pattern and in a square pattern. The GPS positions where then compared with the dead reckoning positions. Figure 3 and 4 shows a comparison of driving and turning velocity based on information from the different sensors.

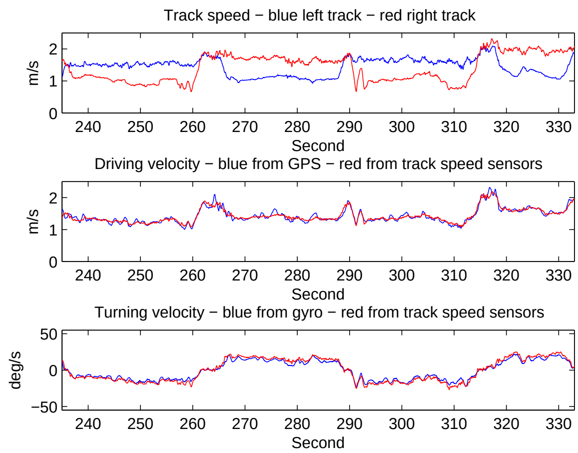

Fig. 3. Velocity data from the eight pattern testrun shown in Fig. 5.

The goal was to develop a kinematic model that can handle different centres of mass due to loaded or non-loaded bucket as well as driving on surfaces with highly varying friction. The kinematic model showed very good results when compared to the GPS positions, see Fig. 5 and 6. Furthermore, the estimated positions and headings showed almost no differences when driving with load in the bucket compared to driving non-loaded.

The tests show that the use of information from a gyro to estimate the turning velocity of the track loader increases the accuracy in the dead reckoning pose. The increase is quite significant compared to when the turning velocity is estimated based on information from the track speed sensors only. The tests also show that the mean value from the left and right track speed sensor signals were good enough to be used as the estimate of the driving speed.

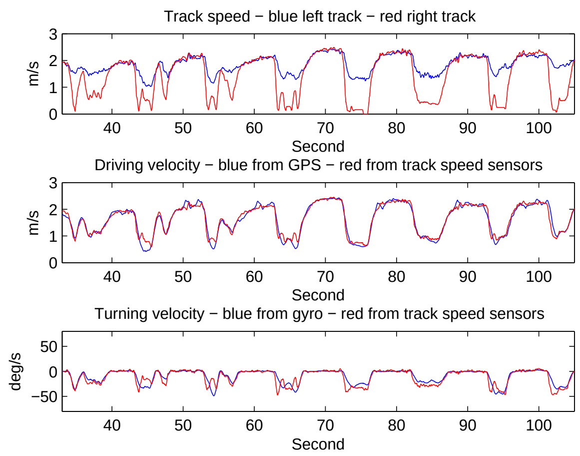

Fig. 4. Velocity data from the square pattern testrun shown in Fig. 6.

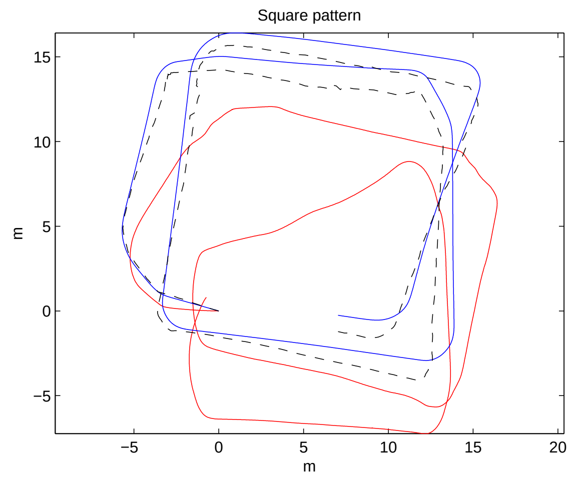

Fig. 6. Performance of the dead reckoning system when driving the track loader in a square pattern. The black dashed line is the GPS path, the blue solid line is the dead reckoning path with gyro, and the red solid line is the dead reckoning path based on information from the track speed sensors only.

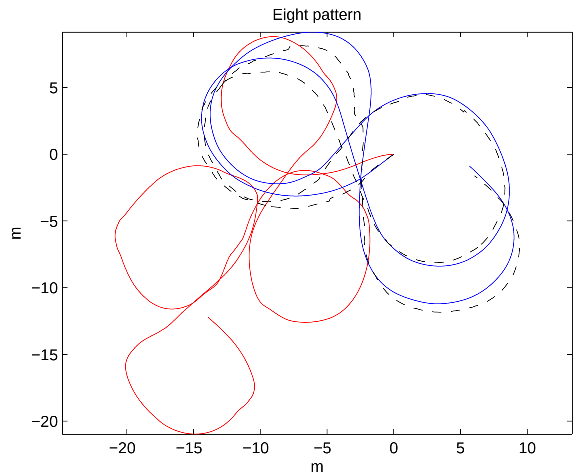

Fig. 5. Performance of the dead reckoning system when driving the track loader in an eight pattern. The black dashed line is the GPS path, the blue solid line is the dead reckoning path with gyro, and the red solid line is the dead reckoning path based on information from the track speed sensors only.

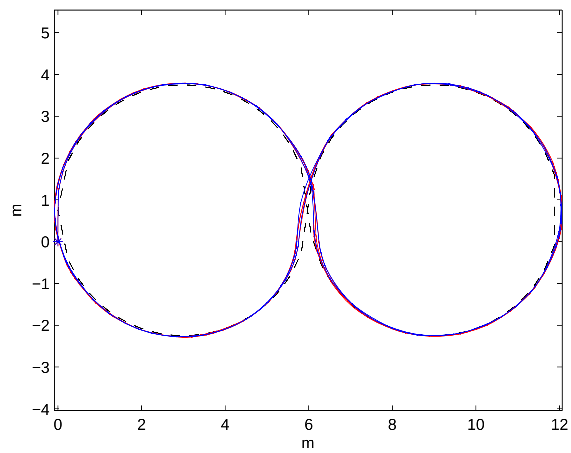

Fig. 7. Dead reckoning path when the track loader was driving autonomously in an eight pattern two times (blue solid line) without load in the bucket, and three times (red solid line) with load in the bucket. The black dashed line show the reference path that the track loader should follow.

A video from an early test of the teleoperation system is available at Fredriksson [2010].

5. ONGOING AND FUTURE WORK

We are currently investigating the possibility to assist the teleoperator with autonomous functionality. Ongoing work includes implementation of a path-following algorithm for the track loader. Early tests of this work can be seen in Fig. 7. The path-following algorithm makes the vehicle follow a predefined path using the dead reckoning pose as the actual pose.

To support the the dead reckoning system and to get a position of the track loader in absolute coordinates, we will use externally mounted laser scanners, see Fig. 8, that will serve as navigation sensors. Due to the extreme operation environment in the area where the track loader is to operate there are limited possibilities to mount sensors on the track loader. Hence, off-board navigation sensors have to be used.

Finally, it would be interesting to do further studies on the accuracy of the dead reckoning system. This could be done by comparing the dead reckoning pose with the pose from a reference navigation system with high accuracy. The GPS used in this paper provided a position with a standard deviation of app. 3m during the tests. A proper reference system would need to provide a position with a standard deviation 0.1m or less.

Fig. 8. Caterpillar 973c track loader and a Sick LMS111 laser scanner.

ACKNOWLEDGEMENTS

We would like to thank Ovako Bar AB in Smedjebacken, Sweden, for making the track loader available for our tests. Thanks also to LKAB in Kiruna, Sweden, for borrowing us the operator panel used in the tests. A special thanks to Bo Dahlgren at Pon-Cat, Sweden, for his assistance in mounting of necessary equipment on the track loader. The work presented was supported by Process IT Innovations.

REFERENCES

H. Fredriksson. Remote controlled caterpillar 973c. http://www.youtube.com/watch?v=DjpRvBn6CBk, July 2010.

Anthony Mandow, Jorge L. Martínez, Jesús Morales, Jose-Luis Blanco, Alfonso García-Cerezo, and Javier Gonzalez. Experimental kinematics for wheeled skid-steer mobile robots. In *IROS*, pages 1222–1227, 2007.

Jorge L. Martínez, Anthony Mandow, Jesús Morales, S. Pedraza, and Alfonso García-Cerezo. Approximating kinematics for tracked mobile robots. *I. J. Robotic Res.*, 24(10):867–878, 2005.

J. Saarinen, A. Maula, R. Nissinen, H. Kukkonen, J. Suomela, and A. Halme. GIMnet Infrastructure for Distributed Control of Generic Intelligent Machines. In *Robotics and Applications and Telematics*, Würzburg, Germany, 2007.