Development of a Control System for a Multipurpose Road Repairing Machine

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Abstract

In this paper an automatic control system for a multipurpose road pavement repairing machine (ROADMOTO) is introduced. ROADMOTO machine is equipped with asphalt milling drum and two asphalt spreaders. The old wearing course of the road is heated and milled. Asphalt spreader in the middle of the machine is used for spreading the crushed old pavement. Asphalt spreader in the back of the machine is used for spreading the new asphalt mass on top of the old layer. Until now most functions of the machine have been manually controlled. The goal is to achieve cost saving and better work quality by using automation. Before the actual repairing work a GPR (Ground penetrating radar), a profilometer or laser scanning techniques are used for collecting information about the road. Designing of repairing tasks is based on the collected data. During a design phase a repair design file is created. ROADMOTO machine is equipped with a GPS positioning unit and the repair design file can be used for automatic control of road repairing operations. The control system also offers a manual control mode as well as automatic height and slope control modes. This ensures flexibility, because the user can choose control mode that best suits for the situation. The control system uses CAN bus as sensor and valve interface and hydraulic actuators are closed loop controlled to achieve high control accuracy. The concept from the data collection and design to the automatic machine control is presented as well as the developed prototype system and results from the first tests.

Keywords: Automation, pavement repairing machines, hydraulic control systems

1. Introduction

It has been estimated that as much as 85% of Europe's road construction projects today include different repairing and rehabilitation operations. Automation is one of the modern means for improving process efficiency and product quality in road construction as well as in road maintenance. The benefits of automation will be produced through the entire construction process. Automated and model based process means exploitation of developed design-, control- and positioning systems in different phases of road construction process.

The process of data flow in road repairing and rehabilitation construction from the automation point of view consists of 1) initial data collection and problem diagnosis, 2) repairing and rehabilitation design, 3) site operations including machine control operations, and 4) quality control actions.

The initial data collection consists of survey methods providing the basic information for rehabilitation design are as follows: a) GPR (ground penetrating radar) for thickness surveys and detecting reasons for damages, b) FWD (falling weight deflectometer) for stiffness measurements of structural layers and subgrade, and c) profilometer or laser scanning techniques to collect data from the road surface. These techniques need accurate positioning systems in order to produce data for precise 3-D road models. The rehabilitation design and machine control models can be processed with special cad tools made for that purpose.

In this paper a control system for a multipurpose road repairing machine (ROADMOTO) is presented (Figure 1). ROADMOTO machine is equipped with asphalt milling drum and two asphalt spreaders. The old wearing course of the road is heated and milled. Asphalt spreader in the middle of the machine is used for spreading the crushed old pavement. Asphalt spreader in the back of the machine is used for spreading the new asphalt layer on top of the old layer. So two layers of asphalt are done at the same time and old crushed asphalt is used on the bottom layer.

The idea of the machine is to use old heated and crushed pavement as much as possible for correcting the worst defects of the road and to minimize the use of new pavement. Typically new mass for correcting the road geometry is needed about 20 kg/m². It is estimated that with automation this can be reduced 50% - 100% and overall cost saving is about 15%. In this case cut and fill operations are done according to a road repairing model.

ROADMOTO machine is also equipped with a mixing drum and it can be used also as an asphalt remixer machine. In this case old crushed pavement is mixed with the new asphalt mass in the mixing drum. The spreader in the middle of the machine is not used in the remixer work.

Figure 1. Multipurpose road repairing machine (ROADMOTO).

2. Surveying and Modeling

Surveying and modelling phases (Figure 2) are important when designing repairing model for road site and applying automation for the repairing of the pavement.

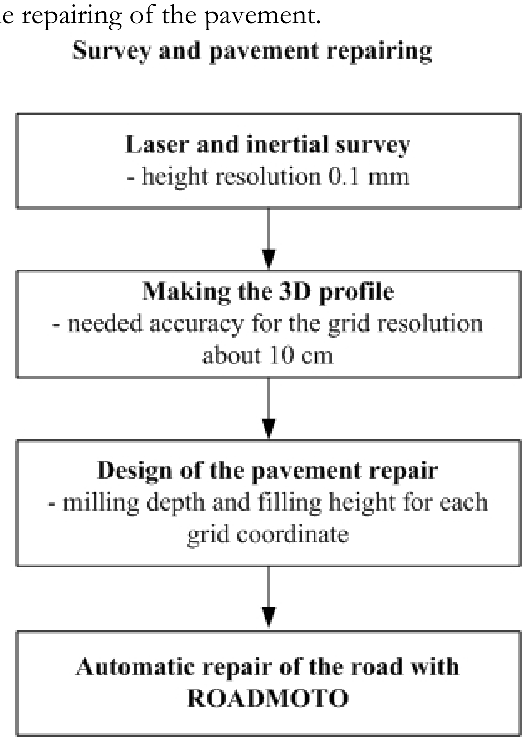

Figure 2. Process to survey and repair the road.

2.1 Survey and 3D model

Surveying of the road is done by special measurement system mounted in a car (Figure 3). Measurement system contains laser, full inertial and GPS devices. System collects all the data from the sensors to the raw data file during the measurement. Next phase is the processing of the collected data. Transversal and longitudinal road profiles are combined in to one 3D surface of the road.

Figure 3. Surveying system.

Accuracy for the 3D model in vertical direction is provided by high resolution laser units (0.1 mm). In horizontal direction grid resolution is possible to choose to be high enough for terrain modelling applications. Ground penetrating radar can be used, if information about road structure e.g. pavement thickness is needed.

2.2 Design for repair

Design for repair is done with terrain modelling application. Design is done with the accuracy level specified. In the designing phase of the repair process it has to be known what kind of repairing work will be done and what the target of repair is. Different kinds of things of the pavement condition has to be surveyed and decided how to fix them. There can be e.g. edge drops, potholes or deep rutting. Various kinds of road damages need special actions when repaired.

The amount of asphalt used is optimized in the designing phase. E.g. there are sections where it is possible to mill more than needed for repairing and there will be sections where the crushed asphalt will be used for filling. GPR data is useful in optimization.

When designing is ready the plan is inserted in to the automated pavement repairing machine ROADMOTO. Repairing file is created and ROADMOTO's control software can read it as input data. Input data file defines the milling depth and filling height for each grid coordinate. The input data file covers whole construction site. If spreader is used in the repairing work, the spreader height level for each grid coordinate is given and it is related to milled surface.

3. Machine Control System

3.1 Main functions

The development work of the control system started with analysing different working situations during operation of the machine. Two main situations are:

-No surveying and modelling is done beforehand. This is typical situation in small roads and work sites.

-Surveying and modelling is done beforehand and a repairing model is available for automatic machine control. Surveying and modelling are typically done only in main roads and large work sites.

The machine control system should be applicable for both of these situations. Because the circumstances vary on a work site considerably, choosing between manual and automatic operation should be as flexible as possible.

The automatic control system is used for controlling the milling drum and the asphalt spreader in the middle of the machine. These are referenced below as the cutter and the spreader. Asphalt spreader in the back of the machine is controlled manually and is not connected to the automation system.

Both the cutter and the spreader are moved by two hydraulic cylinders (Figure 4). The variables that the automation system controls are cutting depth (or height) h_1 and h_2 and slope θ of the cutter (or spreader).

Ultrasonic sensors are used for measuring the actual height h_{1m} and h_{2m} relative to the road surface and inclination sensor is used for measuring actual slope a_m.

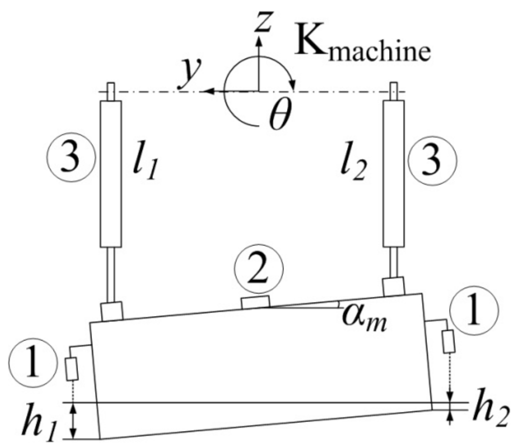

Figure 4. Hydraulic cylinders of the cutter and the spreader

The ROADMOTO machine weights 40 tons, length is 16 m and wheelbase is about 8.5 m. The machine is equipped with rubber tyres in the front and air tyres on the back. Compression of the tyres and the torsion of the frame also affect the position and orientation of the cutter and the spreader.

Operating modes

To allow most flexibility to the user, the control system was designed so that user can set a control mode individually for each of the four cylinders. Different control modes are marked by letters J, U, K and M. Control modes are:

- *J (Joystick mode):* Full manual control using a joystick.
- *U (Ultrasonic mode):* Cutting depth and height control using ultrasonic sensors (Figure 4 number 1).
- *K (Slope control):* Automatic slope control using an inclination sensor (Figure 4 number 2).
- *M (Model control):* Automatic slope control according to the repairing model.

Changing between control modes can be done on-the-fly during operation. Because the user can choose from four different modes for both cylinders, there are 16 possible combinations of control modes. Although the number of combinations is quite high, the control logic is easy to learn and offers flexibility.

3.2 Control method

Controlling the motions of the cutter and the spreader, a Cartesian control method is used (Figure 5). The benefit of the Cartesian control is that different Cartesian values can be controlled independently (height of left end h_1 and height of the right end h_2 and absolute slope a) according to the selected control mode (m_1 and m_2). Joysticks (j_1 and j_2) can override automatic control.

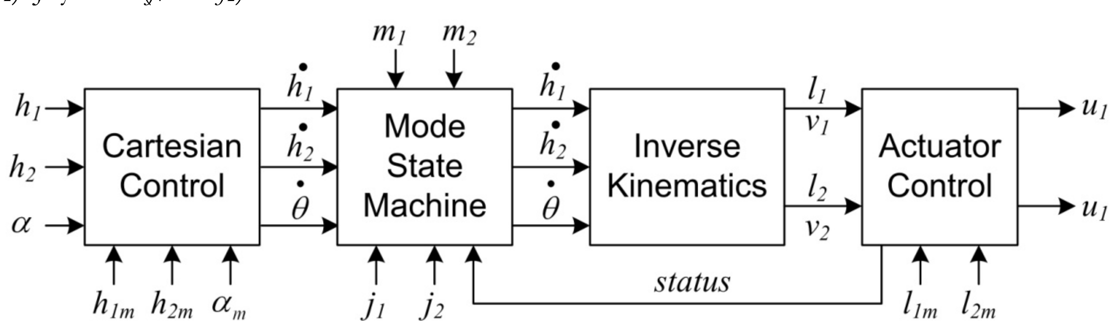

Figure 5. Cartesian control method.

Outputs from the Cartesian control are Cartesian velocities $\dot{h}_1$, $\dot{h}_2$ and $\dot{\theta}$. From these set values for the positions (l_1 and l_2) and velocities (v_1 and v_2) of the cylinders are calculated. Positions of the cylinders are then closed-loop-controlled. *Status* of the actuator control is used as feedback. If delay of cylinders exceeds limits, Cartesian velocities are limited.

In this case the mechanism that is controlled is quite simple. Cartesian control based on solving inverse kinematics gives more advances when controlling more complex mechanism and when manual control is demanding and high accuracy is needed. Some applications are co-ordinated manual control and automatic control based on real time positioning and 3D models of the surface, e.g. road. Some examples are road grader [Kilpeläinen 1999], stabilization cutter [Kilpeläinen 2004] and excavator [Makkonen 2006].

3.3 Hardware and software

The control system architecture is a combination of centralized control and distributed IO. The control system consists of two user interface modules (one in both sides of the machine, Figure 6) and four IO modules, which are connected together using a CAN bus (Controller Area Network). Analogue sensors, such as ultrasonic sensors, are connected to the CAN bus via IO modules. Devices supporting CANOpen protocol (e.g. directional valves and inclination sensors) are connected directly to the CAN bus. Use of CAN bus reduces the amount of wiring considerably.

Control software is implemented in a centralized way, which means that all the control tasks are handled by the user interface module. Both of the user interface modules can work as a CAN master and handle control tasks. The benefit of this is the duplication of control devices, which increases reliability. The user interface module is based on a 16 bit digital signal processor from Freescale. That offers 60 MIPS performance for control tasks.

Figure 6. User interface module.

User interface module consists of joystick for manual control and switches for changing operational modes and set values (e.g. height can be set in 1 mm steps). Current settings are presented in a graphical user interface.

3.4 Model based control mode

In the model based control mode the ROADMOTO machine is equipped with PC computer and RTK (Real Time Kinematic) GPS receiver. PC computer handles positioning and reads set values from the repairing model according to the position of machine. These values are transferred to the machine control system via CAN bus. If the user has selected model control mode (M mode), height of cutter (or spreader) are controlled automatically according to the values from repairing model.

4. Prototype Test

The system was taken in use in June 2008. During summer 2008 the system has been in use for about two months. In October 2008 a test was arranged in order to test the whole concept from the surveying and modelling to the automatic machine control.

4.1 Test site

Test site is typical road in south Finland (Figure 7). Annual average daily traffic in the test site is approximately 2000 vehicles. There were no problems during the survey or making the 3D profile due to low traffic.

Condition of the test site was good and the main reason for repairing was the rutting. Some sections had edge drops, but only 20 – 30 cm from the edge was damaged.

Repairing work with ROADMOTO was done during daytime. All the ROADMOTO sensors were mounted and raw data was collected during the test. Both full 3D profiling and automatically controlled repair work were successful. The test site considered total 26 000 m² of repairing work.

Figure 7. Test site.

4.2 Testing of the control system

During the tests different operating modes of the system were tested. Typical situation was that ROADMOTO machine was driven along the left lane of the road. In this case ultrasonic control was used on the right side of the machine (centre of the road) and manual control was used on the left side (road border). Ultrasonic control is not applicable if the surface of the road is very uneven, which is typical for road border.

In figure 8 the functioning of the control system is shown when model control (M mode) is used on the right side of the machine. During the 20 second time period in the figure the machine moves forward about 2 m. In the upper graph set value for height h_2 and measured value h_{2m} are shown. In lower graph set value l_2 and measured value l_{2m} of the position of the cylinder are shown.

The closed-loop-control is done over CAN bus. Simple P-controller and feed forward of the velocity set value is used [$u = K_p \cdot e + K_v \cdot v$]. Sampling time T_s was 20 ms. Accuracy of the position control of the cylinders is about ± 1 mm.

Relative accuracy of the height control is about ±5 mm. The drawback of the test was that absolute accuracy of the height control could not be verified properly. Height control is based on ultrasonic sensors. Temperature changes affect to the output of the ultrasonic sensors, because the velocity of sound changes 0.18% / ºC. To compensate this integrated temperature compensation is used in ultrasonic sensors. In the case of heated asphalt air near the surface can be very hot (about 150 ºC). Ultrasonic sensors still work quite well, but the big temperature difference in the air increases noise of the measurement. Also the zero position of the height, that is set during calibration of the system, changes. To overcome this problem development work is still needed.

4.3 Quality measurements

After the repairing work quality measurement was done. One way to measure quality of the road is Internatiol Roughness Index (IRI) [Sayers 1986].

IRI was measured before and after the repairing job (Figure 9). In the Figure 9 is one section where ROADMOTO was doing automated repairing. IRI level 0.8 is good and it is not easy to go under that value just doing repairing of the pavement. High original value between the distances from 600 to 700 was smoothed in the repairing work to be 0.8 mm/m.

5. Conclusions

The ROADMOTO machine equipped with the control system presented in this paper has been in use since June 2008. The repairing process of the road pavement consists of surveying, design of repairing, site operations including machine control and quality control tasks. The developed control system can exploit the design data, a road repairing model, in automatic machine control. Prototype test were arranged to test this concept. All the phases from the survey using a car mounted surveying system to the repair design and automatic machine control were completed. Finally achieved quality was measured.

Although there exists some problems e.g. in the calibration of the machine control system, the presented automatic control method is applicable. It is also important to that the user can choose between manual and automatic features according to the situation. This was also taken into account during the design of the control system and the presented system is also useful in work sites, where no surveying and design is made beforehand.

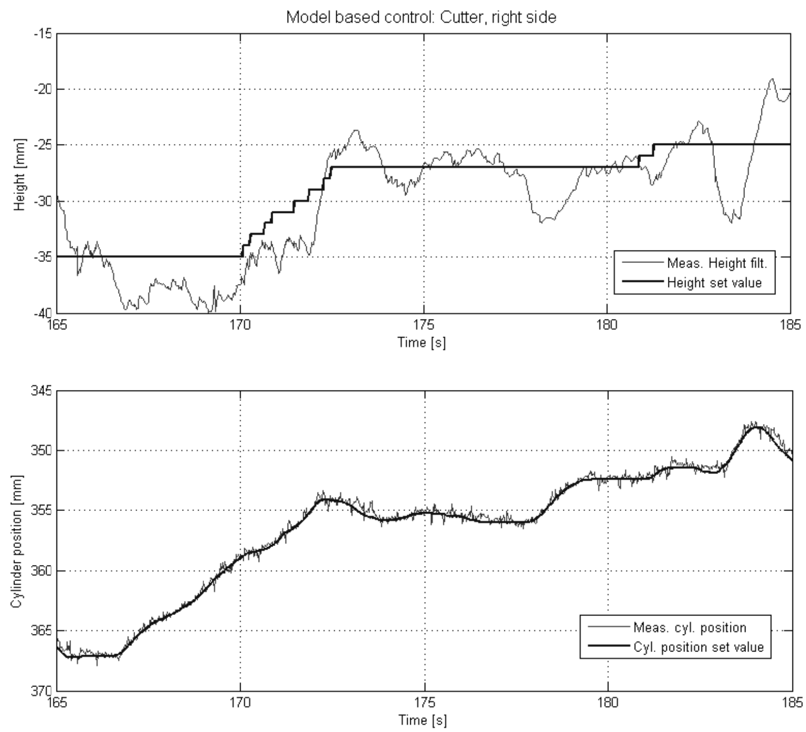

Figure 8. Automatic control of the right side of the cutter.

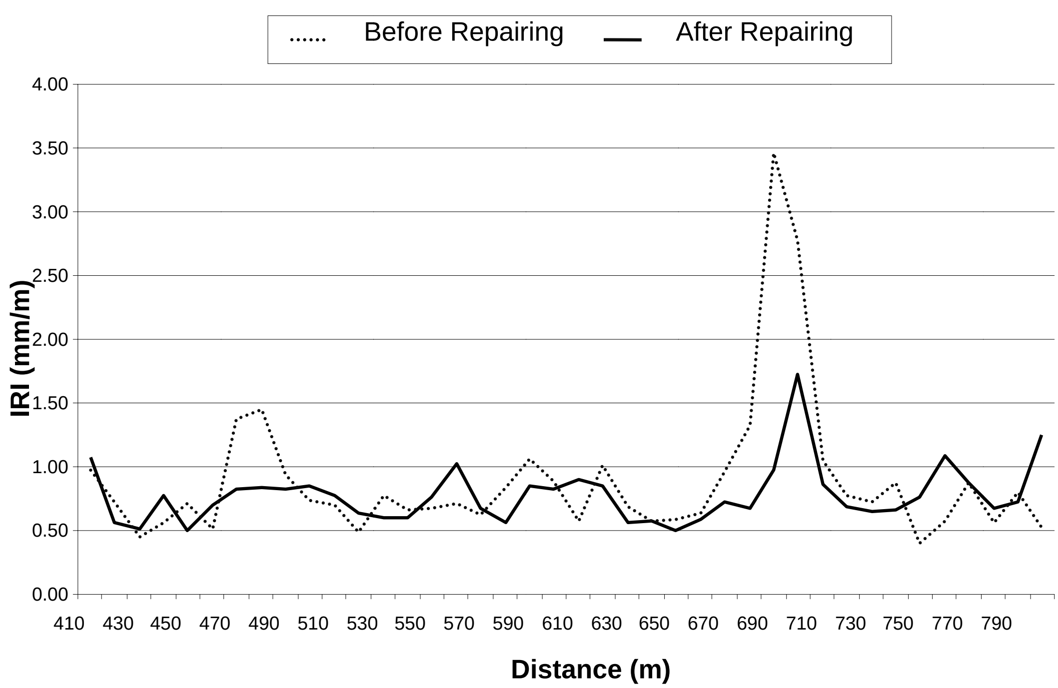

Figure 9. Road quality before and after the repairing work.

During the short period of testing it was not possible to fully evaluate the benefits of the system. The next goal is to take the presented process into common use.

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