On-line Process Management of Pavement Laying Using Wireless Communication Technologies

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Abstract

The research goal has been synchronizing the process of asphalt production, asphalt transportation and pavement laying by connecting different machines together using wireless technologies. Sensors and GPS positioning units were installed to the machines for measuring process variables (e.g. mass temperature) and detecting events (e.g. loading, unloading). The first prototype system (autumn 2007) was based on embedded wireless measurement and data collection modules. A more recent system uses a vehicle PC and a separate embedded system module with sensor interfaces and a short-range radio transmitter. Vehicles communicate with the database through a GPRS link and use a short-range radio as an RFID for authentication and a direct communication channel with the other vehicles. GPS position information is used for context recognition together with the short-range radio and sensor information. Process information is continuously stored to a database, to be used for quality control and process optimization.

Keywords: Automatic data collection, pavement laying, process management, wireless communication

1. Introduction

Since recent road pavement processes are not optimal and many process variables are usually unknown this research focused on the process management and the quality data collection of the asphalt paving process [Peyret et al. 2000]. A system for monitoring and controlling asphalt pavement process was developed by connecting the machines in this process together using real-time wireless communication in a similar way that production machines are typically connected inside a production plant. This enables information sharing between the machine operators and automatic data collection using sensors installed to the machines [Kilpeläinen, Heikkilä & Parkkila 2007]. This concept was evaluated by building two prototype systems that were tested at construction sites. The conceptual approach was chosen for reasons that firstly, most of the earlier research of road construction concerned the subprocesses like vehicle tracking [Lu et al. 2007], compacting [Peyret et al. 2000] or simulation [Nassar, Thabet & Beliveau 2003] and there were no automated processes researched and secondly, recent systems in use are mainly manual and not automated at all. Both of these prototype systems had GPS positioning unit and a wireless communication link (GPRS) that were installed to the machines in order to collect data from the paving process and to save this data to the database. These actions were aiming to the ultimate goal that is smoothly and continuously streaming paving process where resources are used with optimal efficiency.

One of the prototype systems was based on embedded measurement modules. The goal was to collect data as automatically as possible with minimum user interaction needed. This system was tested autumn 2007. [Kilpeläinen, Heikkilä & Parkkila 2007]

The more recent prototype system mainly described in this paper had a main focus on machine interaction and designing user interfaces for different machine operators were developed. Another new feature was a direct short-range communication link between the machines. Some more advanced features, like automatic reporting and billing, were also tested. In this prototype the work machines were equipped with in-vehicle PCs and embedded measurement and radio modules. The second prototype was tested autumn in 2008.

2. Prototype System Overview

2.1 Prototype system overview

The prototype system included three different operators: asphalt mixing plant unit in the asphalt mixing station and a vehicle unit with variations to a truck and to a paver. A compactor that is a natural part of paving process was left out of the scope in this time, since it is not having that many interactions between other operators. Both of the unit types had two different communication methods: long-range and short-range techniques. Also the external server with database and web pages was supporting the functionalities of the units. Figure 2 illustrates the complete prototype system.

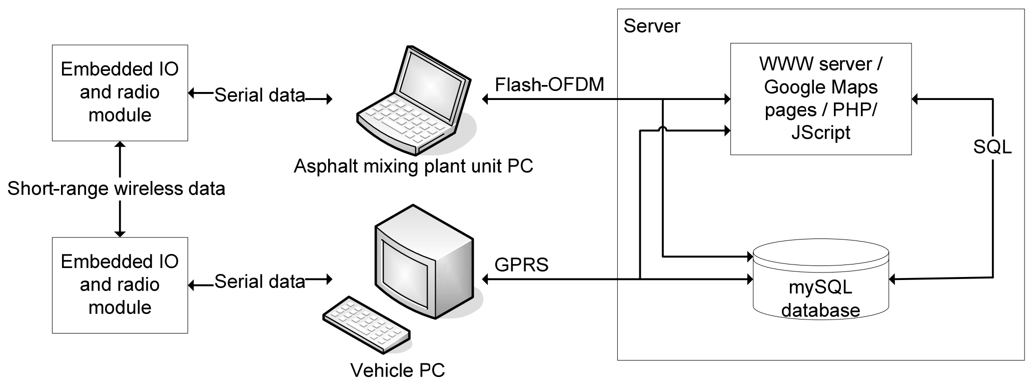

Figure 2. The prototype system.

2.2 Paver and Truck units

The paver and the truck units of the system consisted a SUNIT D12 vehicle PCs running Windows XP OS. The PC was equipped with a GPRS modem, a GPS module and a colour touch display with proprietary graphical user interface (GUI) for both the truck and the paver. The connections to the database and the web pages were done over the GPRS.

The PC was connected to the external embedded IO and radio module (Figure 2) through the serial port. The embedded module included a short-range radio and a sensor interface.

2.3. Asphalt mixing plant unit

The asphalt mixing plant unit was a laptop PC with Windows XP. For internet connection a wireless Flash-OFDM technique was used. Flash-OFDM is a proprietary wireless broadband network connection using operation frequency of 450 MHz. It is used only in couple of countries, e.g. Finland, Slovakia and Ireland, because in most European countries the 450 MHz frequency range is preserved for other purposes. The maximum cell radius of the Flash-OFDM is about 30 km. This is significantly longer compared to the 3G mobile phone networks, where cell radius is about 5 km. This makes Flash-OFDM technique applicable in sparsely populated areas. The asphalt mixing plant unit was also connected to the embedded IO and radio module in order to send and receive short range messages. [Arjona, Kerttula & Yla-Jaaski 2008, Tinkler 2006]

2.4 Embedded IO and radio module

The embedded IO and radio module, illustrated in Figure 3 with part numbers, contained a main box (1) and was connected to PCs with the serial bus and build on processor card with ATMEL32 (2) processor, four AD-channels and interface for the NanoNET TRX (Nanotron Tech, GmbH) short-range industrial radio card.

The radio and antenna (3) was earlier tested in VTT projects [Keski-Säntti J., Parkkila T., Leinonen J. & Leinonen P. 2006] and was shown to be usable in difficult environments.

2.5 Sensors

Three different sensing elements were connected to the AD-channels in order to provide process and status data. There were two different types of temperature sensors connected in order to compare and verify the output values. Functionalities of sensors were platinum resistance (PT-100, 4) and infrared (IR, 5).

PT sensors were placed to the bottom of the truck platforms to measure the heat conduction through the platform core and insulated with plywood boards and insulation wool against the cold weather and wind. PT sensors are robust and cheap, but with slow response.

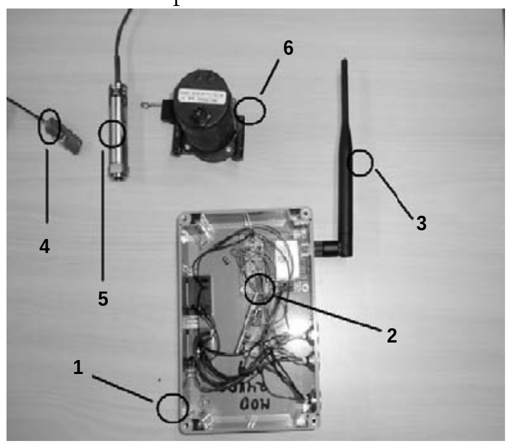

Figure 3. Embedded sensing and radio unit.

Truck IR sensors were placed to a backboard, as shown in Figure 4, and to a special stand in the paver, both pointing to processed mass. IR sensors have fast response, but they are error prone and quite expensive.

Figure 4. IR sensor in the backboard of a truck.

In addition there was a potentiometer based sensing element (6) to detect the operation status of the truck. The potentiometer was connected between the platform and the skeleton of the truck to tell to the system when the unloading was in process.

2.5 Server unit

The system process data was stored to a MySQL type database tables. The database contained five different tables for vehicle, delivery, target, customer and order data. The data was used in order to automate process and offer important information for the operator use.

Other part of the server unit was web pages. There were two different web pages. Other was a complete view of the process units used by asphalt mixing plant unit in a map view with the table providing relevant data of each unit. The process view can be seen in Figure 5.

The other page was also a map and it showed a route and a distance of the corresponding truck to the paver it was supposed to meet. Both maps were read using the Google Maps API. Languages used in web site building were PHP and JavaScript.

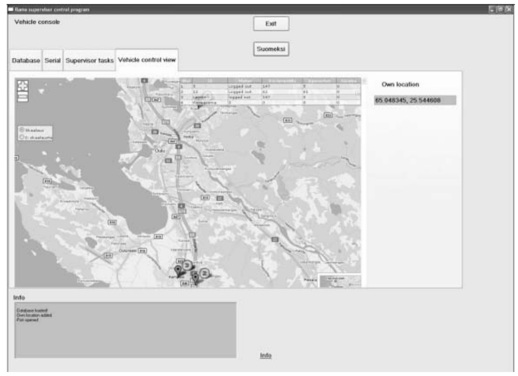

Figure 5. The asphalt mixing plant unit map view.

3. Prototype System Functionality

The functionality of the prototype system was designed to run in parallel with the normal recent system in paving process. The test system contained following operators:

- asphalt mixing station controller
- transporting truck driver
- paver driver

3.1 Features

Identification of trucks using short-range radio

Before all the interactions, receiving vehicle confirmed the identification of the sending vehicle. All the short-range messages contained a field for a vehicle licence number. Using that number, the corresponding vehicle was searched from the database and its location was compared to receiver's own location. If the location was too far away or the corresponding vehicle is not found, the message was then omitted. This RFID functionality was realised using the industrial short-range radios.

Material tracking

Since one of the most important objectives of this project was quality assurance, the material tracking was also improved. During the transportation, the location and the temperature of the mass were saved to a hard drive of the truck PC and the collection of the status data, so called delivery note was saved finally to a database after the unloading. Also the paver was all the time storing the temperature and the location of the mass to the memory. These measures assure that a mass temperature could be checked afterwards in any location of the process from the mixing station to the pavement.

Since the material data was stored all the time to the database with related information, the usage of receipts and paperwork could be reduced.

Functionality automation

Few manual process tasks were also automated in order to streamline the process. Such tasks were for example an order data delivery to the truck driver and a load data delivery to the paver driver.

Virtual delivery note and automatic billing

A concept of automatic bill generation was tested. The bill was assembled using a virtual delivery note containing mass amount, temperature and location data collected during the transportation. The bill was later sent to the customer using the e-mail right after the unloading.

3.2 Communication during work circulation

Figure 6 shows messages exchange between the process participants.

Arriving to the mixing station

When the truck arrives to the mixing station area, the arrival is detected using the GPS module. The short-range radio is then switched on and used for an identification and communication with the mixing station.

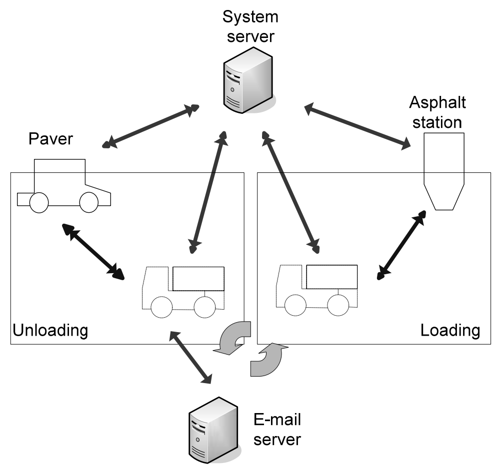

Figure 6. Process message exchange during a work circulation

Loading and weighing

After the truck identification the corresponding order number was sent by the asphalt station controller to the truck. The truck used the order number to get the order data from the database. Based on the order, data was printed to the truck drivers GUI.

Again, based on the order data the truck driver accepted the task and filled in the truck and weighted it. The weighting system sent the data to the database and the required mass variable was updated.

Transporting mass to the paver

After the weighting the truck then started its journey to the correct paver. The mass temperature and location data were logged in 10 seconds interval to a specific delivery note with the order information to store process data for quality assertion. The route view was also updated continuously in same interval in order to guide the driver. Also the truck data to the database was updated simultaneously.

Arriving to the paver

When the truck arrived to the correct paver, similar handshaking like with the mixing station took place. The short-range radio was used and the location of the truck was compared from the database. The truck program also sent the mass status data to the paver and it was printed to the paver driver GUI screen. The paver driver could then be sure of the mass correctness and accept it.

Unloading

If the paver driver accepted the load, the truck driver got the note to the GUI screen and unloaded the mass to the paver. Since unloading was done, the paver driver sent a short-range radio confirmation message to the truck. After the message, the delivery note was stored completely to the database and the summary of the delivery was sent to the customer's e-mail address. In addition, a temperature of paved mass is measured and logged with the location within the paver too.

3.3. User interfaces

Since all the used system platforms were based on PC and Windows XP OS techniques, all the user interfaces were graphic. GUI programs provided information of the process status and enabled interaction between process entities etc.

There were three different GUIs for trucks, paver and asphalt mixer station. Truck and paver versions were designed to be used with touch screen.

Truck GUI

The truck GUI for example showed information of a suggested and performed orders and show information of the transported mass and platform pose that is seen in Figure 7.

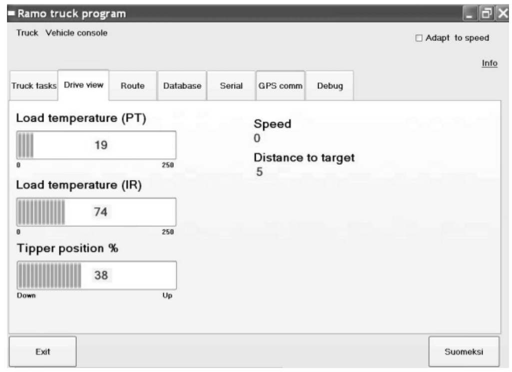

Figure 7. The driver view of the truck GUI

The truck GUI also had a feature of updating route map realised using a help of the Google Maps API. The route map was a web page in the server that received two coordinates and showed the route with the distance between the coordinates and the estimated driving time to destination. The route map is illustrated in Figure 8.

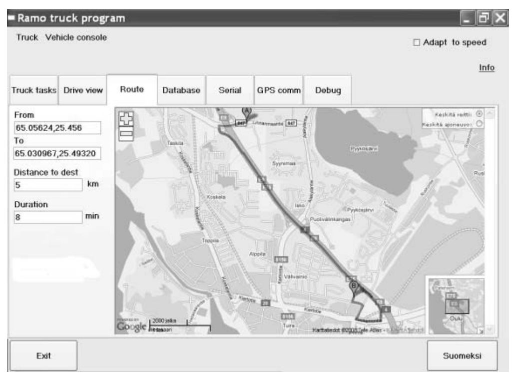

Figure 8. A route in the truck GUI

There was also an adaptive feature in the truck GUI. If the adaptation option was selected, only the most important data was printed to the GUI when the truck speed exceeded 30 km/h.

Paver GUI

In the paver GUI, the map view was also a web page using the Google Maps API. The map showed all the vehicles of the test system with a table of status data like estimated arrival time of the trucks. The paver GUI showed also the mass temperature from the laid mass and the transported mass data from the truck in the case of the unloading.

Asphalt mixing station GUI

The asphalt mixing station's GUI show simply the process view map with all the vehicles.

4. PROTOTYPE SYSTEM FIELD TESTING

A purpose of the system field testing phase was to implement and test the system with a real life environment and equipment. The field tests consisted one paver, three trucks and a mixing station, all instrumented with equipment described in Table 1.

During the tests the vehicles drove and performed their normal process tasks normally and the tests were done in parallel with the normal process flow causing some problems in debugging and data collection.

Since the prototype system was tested in a real environment, there were some malfunctioning and disadvantages found.

4.1 Testing of the wireless communication techniques

The suitability of the communication methods like GPRS, Flash-OFDM and NanoNET was followed.

Some specific performance tests were done for the Flash-OFDM technique.

Table 1. The field test equipment.

	Sensors	Radios
Asphalti station	-	Flash-OFDM, NanoNET
Truck 1	IR, PT, tipper	GPRS, NanoNET
Truck 2	PT, tipper	GPRS, NanoNET
Truck 3	PT, tipper	GPRS, NanoNET
Paver	IR	GPRS, NanoNET

GPRS

Also the GPRS based internet connection caused some problems during the tests. The weak signal in rural areas was not fast enough for some functionalities and connection was lost every now and then too.

Flash-OFDM

Performance of the Flash-OFDM technique was tested on a moving vehicle. Average ping time to the VTT's server was 69 ms, typical download speed was between 500 – 800 kb/s and upload speed was between 180 – 250 kb/s. The speed of the vehicle was about 100 km/h. On areas were Flash-OFDM network coverage is good this technique offers reliable internet connection for moving vehicles.

NanoNET

A vehicle to vehicle communication was done using the robust NanoNET TRX short-range industrial radio. The range was between 20 and 200 meters depending on a used antenna type.
Different kind of antennas was tested in order to improve the message delivery between the NanoNET terminals. The antennas that were originally used were too directional and the narrow close-field reached too far. These features caused problems in close-range communication and RFID identification. Problems could be solved with omni-directional antennas.

4.2 Asphalt mass temperature measurements

One very interesting topic of the tests was a correctness of the sensor values. Both IR and PT sensor values were logged and compared together. Figure 9 shows the mass temperature comparison of truck load between the different sensors during a load transport. As it can be seen the PT sensor with the black curve reacts slower to the mass temperature changes. Moments of unloading can be seen from the green tipper pose curve where non-zero values show the unloading timings. The unloading of a one load is usually done in several phases, also in the case.

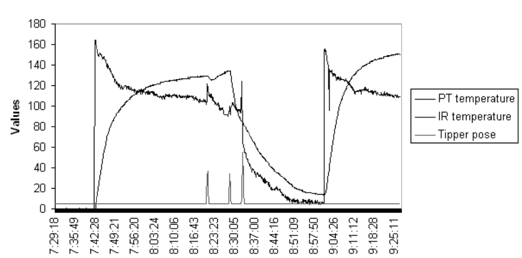

Figure 9. The functionality of temperature sensors.

Mass temperatures from the paver IR sensor was measured and compared to values from a handheld Raytek MX4 thermometer. Figure 10 shows the temperature values in a time window. Handheld thermometer values point also out the times when the unloading of the certain truck load starts.

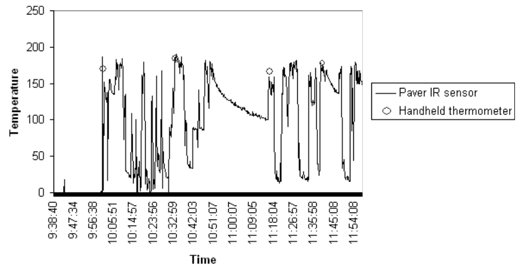

Figure 10. The paver IR sensor and thermometer temperatures.

For the further research and PT sensor ideal location, thermographic camera pictures were also taken. More exact heat distribution of the load could be seen from these pictures. Figure 11 shows an example of these pictures.

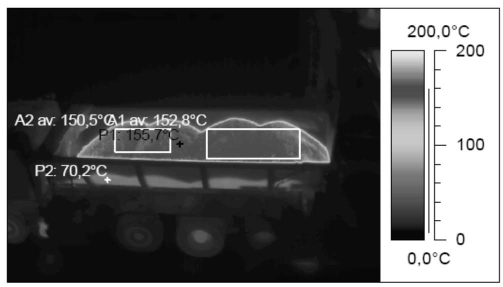

Figure 11. A thermographic camera image after a truck loading.

4.3 Usability of the system

There were plenty of specific topics that were evaluated during the tests. The stability of the GUI programs and actions performed within were naturally vital. Also the usability of the few needed operator interventions in the GUI program during the process flow were tested by asking about use experiences from the drivers.

Drivers are clearly willing to adopt new technology, but it could be seen that this kind of system must be designed to be used with as few user interventions as possible.

5. Conclusions

In this paper, the system, that can be used to control asphalt paving process, was demonstrated. This control process requires for real-time follow-up that involves data collection, storing and using in order to automate and control the paving process to gain new benefits.

Wireless communication is an enabler for collecting data in real time from a construction process. VTT has studied different approaches for this. Mobile phone technology was used in “Wireless construction site” – project, where a system for managing mass transportation tasks in road construction was developed and tested. [Rannanjärvi L. 2003] The main advantages of using mobile phone technology are low cost portable devices. This makes easy to take the system into the use. However, in this approach it totally depends on the user how reliable and up-to-date the collected data is.

Another approach was to use embedded platform with sensors to enable process management tasks. [Kilpeläinen, Heikkilä & Parkkila 2007] Embedded systems are cheaper and easier to install compared to complete in-vehicle PCs, but on the contrary they don’t provide that much possibilities concerning especially user interfaces.

This paper presents more automated data collection methods using sensors installed to the work machines with PCs. The most obvious disadvantage is that constant installations to the machines are needed. On the contrary some of the data collection tasks (e.g. material tracking) can be automated so that minimum effort is needed from the user. In practise a combination of interactive user based and automatic sensor based data collection is the most practical approach.

The large graphical touch-screens in vehicles fulfilled its task very well providing essential information of the process. Also the use of RFID –like identification helped to automate some tasks and provided also optional communications link between vehicles.

One big issue is what to do with all the data collected. Of course the data can be stored to the database and used for quality assurance and reporting purposes. In this project, that data was also used in real-time to control the process. The critical process data is displayed to the process operators and some of the decision-making process is transferred from the operators to the programs.

The prototype system designed and tested in this project in fall 2008 supports a conclusion that there could be plenty of process improving acts done in the asphalt paving process. The quality control could be made much more efficient and accurate. The vehicle guidance could be improved much too with the security matters. Also the process safety could be improved with help of technical solutions. One of the most important perception is that the prototype system improves the functionality not only the certain construction site but the all the sites that gets the asphalt mass from the certain asphalt mixer.

Since PCs in professional vehicles are getting more and more common, the system like the tested one could be implemented easier and cheaper that makes it extremely reasonable to develop it further. Wireless technologies are developing rapidly and broadband internet access can be available to the vehicles and work machines more commonly. Also existing vehicle bus architectures like CAN should be exploited more vastly when connecting external sensors and terminals to the system. Truck load scale could also enable complete automation to the billing since the sub-loads could be measured in a case where one truck-load would be dispensed to different locations.

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