AsphaltOpen – an interactive visualization tool for asphalt concrete paving operations

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Abstract

This paper presents AsphaltOpen, a visualization tool for Hot Mix Asphalt (HMA) paving operations. AsphaltOpen visualizes site-specific GIS data and GPS path tracing of equipments' motions with the HMA's physical properties, such as the cooling of the asphalt layer and its compaction. AsphaltOpen stores all data in a central database to allow the company wide access on previous asphalting operations. AsphaltOpen's interface is based on action research that we conducted with HMA paving operators to ensure the application's usability. AsphaltOpen offers an easy-to-use tool for HMA paving companies to visualize previous asphalting operations. In this way, it opens up new ways for HMA paving contractors to improve and professionalize their paving operations.

Keywords: asphalt concrete, construction, visualization, temperature, GPS

Introduction

Experts in the field of Hot Mix Asphalt (HMA) technology suggest that: (a) the HMA paving process depends heavily on craftsmanship; (b) the work is generally carried out without the instruments to monitor the key process parameters, such as temperature, compaction and layer thickness; and (c) the work methods and equipment are selected based on tradition and custom (Dorée and ter Huerne 2005).

At the same time new technologies on the equipment that promise to overcome the above problems create an information overload for the operators. The

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average operator on site has difficulties in understanding complex data visualizations and abstract information provided by these technologies. There is a need for easy-to-use applications that visualize Hot Mix Asphalt (HMA) paving operations. Such visualizations can play a vital role in enabling paving operators to reflect on their work and to learn from previous operations. This paper presents AsphaltOpen, a visualization tool for HMA paving operations that we developed in close collaboration with operators. AsphaltOpen integrates site-specific GIS data and GPS path tracing of equipments' motions with the HMA's physical properties, such as the cooling of the layer and its compaction.

This paper is organized as follows: In the introduction, we sketch the difficulties machine operators have in understanding complex data visualizations of the HMA paving process. Afterwards, we describe previous technology initiatives to map HMA temperature and HMA compaction operations. We then describe the data source to visualization process used in our research. Next, we propose AsphaltOpen, a new data visualization tool and database scheme to visualize HMA paving operations. We conclude by discussing the tool in the context of the advantages it offers to improve the HMA paving process and by sketching our vision for the HMA asphalt paving process.

Using technology to map the HMA paving process

Two of the most important factors affecting the quality of the HMA layer are the temperature of the HMA during paving operations and the final density achieved after laydown and roller compaction (Asphalt-Institute 1989). This section describes these factors affecting the final quality and current technology used to measure these factors during the HMA paving process.

Compaction of the HMA mat is an important task during laydown operations aiming to produce a mat of specific density. Although the compaction process appears rather simple and straightforward, it is, in reality, a procedure requiring skill and knowledge on the part of the roller operator (Roberts et al. 1996). Several industry-aided research initiatives exist to assist construction machine operators perform their tasks. These include methods to monitor HMA paving and compaction using GPS and other IT technologies (Krishnamurthy et al. 1998; Peyret et al. 2000; Oloufa 2002).

Factors affecting the maximum compaction (density) attainable by a set of compactor rollers in the field are the physical properties of the HMA and the surrounding environmental conditions (Asphalt-Institute 1989; Roberts et al. 1996). Physical properties include mix characteristics, the temperature at laydown, layer thickness, and firmness of the founding layer. Environmental conditions comprise air temperature, wind velocity and humidity, and solar radiation levels. Most of these factors directly affect the cooling rate of the HMA and the time available for compaction. In addition, temperature differentials in the HMA layer produce density differentials, which affect the life of the pavement (Read 1997; Mahoney et al. 2000; Willoughby et al. 2002). Temperature differentials occurring during HMA paving operations can be detected, located and measured using infrared cameras (Brock and Jakob 1997; Stroup-Gardiner et al. 2002; Stroup-Gardiner et al. 2004).

Although some temperature and compaction research initiatives made the transition to industrial applications, it appears that few are widely accepted by industry and frequently used on the HMA paving construction sites. To widen and deepen the understanding of the operational strategies for paving and compaction process paving contractors need to adopt new technology. Yet, the adoption of new technology appears to fail because the tools are not tailored to the mental frame and operational strategies of those involved in the process. Consequently, developing improved operational strategies requires adoption of new technologies, but new technologies are not adopted due to insufficient, explicit understanding of current operational strategies (the common practice). This resembles a "chicken or egg" problem, a causality dilemma. Against that background, this research project develops a visualization tool, AsphaltOpen, following an action research strategy, where we alternate steps of technology introduction and mapping of operational strategies (Schon 1983; Chisholm and Elden 1993; Hartmann et al. 2008). It involves the machine operators directly in the research project by making behavior explicit using computer visualizations (Akenine-Moeller & Haines 2002; Foley et al. 1997). We expect that such explicit visualizations will help machine operators synthesize their tacit knowledge and promote learning processes within the HMA paving process. The next sections describe this visualization tool in detail.

On Site Data Collection, data pre-processing and the visualization tool

This section describes mobile measurement devices we use to collect temperature and GPS data of the HMA paving operations.

Table 1 summarizes the measurement setup. The current data source to data transformation to visualization is rather cumbersome. Most of the tasks and routines are undertaken in several steps requiring data transformation using text files, spreadsheets and various software. We automate the data source to visualization using AsphaltOpen's structured and integrated database environment. Figure 1 shows the architecture of the visualization tool.

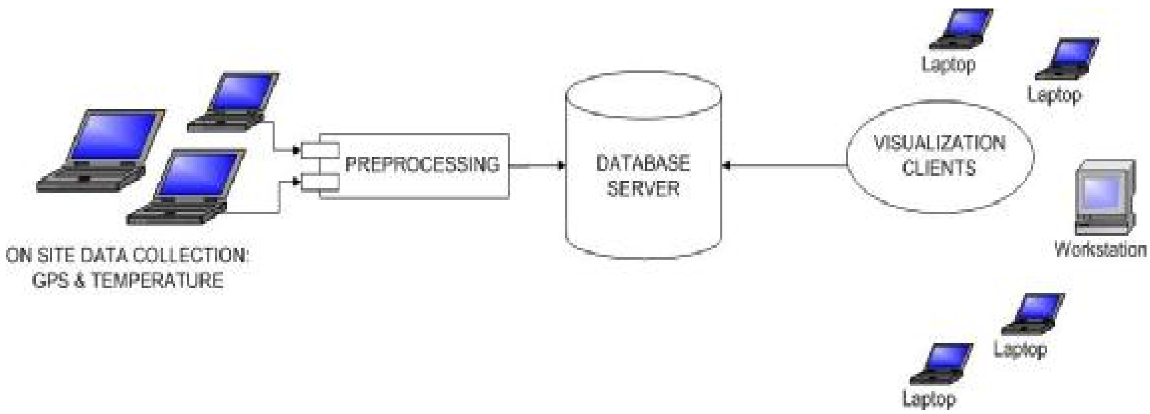

Figure 1 - Overview of the visualization tool

During asphalt paving operations mobile measurement devices and software collect temperature and GPS data of the operations. Several data preprocessing engines then remove outliners from the temperature and GPS data and integrate both in one central database located on a database server.

After completion of the HMA paving operations, all data are initially downloaded and stored on a portable computer. We conduct several manual preprocessing tasks of the surface temperature images collected using the automatic and hand-held infrared cameras. The cameras are set to take images of the entire width of the HMA surfacing during paving operations allowing an analysis of the variation in temperature across the width of the surfacing. Using the FLIR ThermaCAM Researcher™ software, we "tag" spot asphalt surface temperatures at predetermined intervals, across the width of the road surface. We transfer these spot temperatures to a matrix in Microsoft Excel™ using a Visual Basic™ program. The Visual Basic program is embedded in Microsoft Excel™ and enables a rapid transfer of the infrared image data. The Excel matrix is now ready for transfer into AsphaltOpen's database. We apply a similar process to the asphalt surface temperature data collected using the Raytech™ laser line scanner with data transfer from the line scanner software into an Excel matrix using a similar Visual Basic™ program.

We then separately transfer the automatically logged in-asphalt temperature and the weather data directly into Excel matrices for entry into AsphaltOpen's database.

During GPS data collection, we set up a stationery GPS base station next to the construction site and mount GPS receivers on the moving asphalt machinery viz. the HMA asphalt paver and the roller compactors. We require an accuracy of less than 10cm to accurately map the asphalt machinery's positions during paving and compaction operations. This high level of accuracy is necessary to capture turning movements of the roller compactors and the overlapping of compaction passes. Two accuracy levels are possible using the Trimble™ GPS equipment. Using Differential Global Positioning System (DGPS) results in 25cm accuracy and using Real-Time Kinetic (RTK) positioning results in an accuracy of approximately 10mm.

The GPS measurements are in the form of National Marine Electronics Association (NMEA) strings containing date stamps, time stamps and geographic positioning in terms of latitude and longitude (National Marine Electronics Association 2002). The measurements do not require any significant filtering because of the high accuracy of the GPS equipment. However, some preprocessing of the raw GPS data is necessary. We undertake this preprocessing using road design drawings and a preconstruction site calibration exercise (Trimble 2008) to filter any GPS "noise" or outliners that may occur when the GPS is unavailable due to obstructions or high buildings that may be in the vicinity of the HMA paving work. The filtered GPS data is now ready for transfer into AsphaltOpen's database.

Table 1 – Mobile measuring devices used during the HMA paving process

Task	Instrument	Method	Measurement accuracy & frequency
Monitor weather conditions	Vantage Pro 2 weather station	Weather station set up next to the construction site to log local conditions	Ambient temperature, wind speed, relative humidity and solar radiation data logged at 5-minute intervals
Measure asphalt surface temperature behind paver screed	A handheld FLIR InfraCAM	Infrared images taken manually	Every 10m behind the HMA asphalt paver screed
Measure asphalt surface temperature behind paver screed	FLIR A320 ThermaCAM	Camera is mounted on the back of the HMA asphalt paver.	Infrared images are taken automatically at 5-second intervals. Camera is focused on the HMA behind the paver screed
Measure asphalt surface temperature behind paver screed	Raytech line scanner	Laser line scanner mounted on the back of the asphalt paver	A laser scans the asphalt's surface temperature across the width of the road at preset intervals and at resolutions of 128 pixels and higher
Measure surface temperature cooling rate	3 handheld FLIR InfraCAMs	Cameras set up on tripods at 3 fixed positions approx. 250m apart	Images taken manually every 30 seconds
Measure in-asphalt temperature cooling rate	Voltcraft plus – 2 channel thermometer	Thermo-coupler placed in the asphalt layer	Temperature logged automatically every 30 seconds
Monitor the movements of all asphalt paving machinery	Trimble™ SPS 851 GPS receivers	Base station set up on the construction site and GPS receivers mounted on the HMA paver and compaction rollers.	Differential GPS accuracy of < 10 centimeters, Data logged at 1-second intervals
Measure asphalt density	2 nuclear density gauges	Density measured after every roller pass at the 3 fixed temperature logging positions	
Record noteworthy incidents on site	Sony IC recorder	Record incidents as they occur	

Database scheme

The database scheme is shown in Figure 2. Finally, machine operators and their foremen and project managers can use a client application that is installed on several client machines to visualize the information from the database to discuss operational improvements. This architecture allows us to independently change the on-site data collection processes and the visualization clients. In this way the architecture fulfills the requirements to flexibly adjust the environment throughout the different iterations of the action research process.

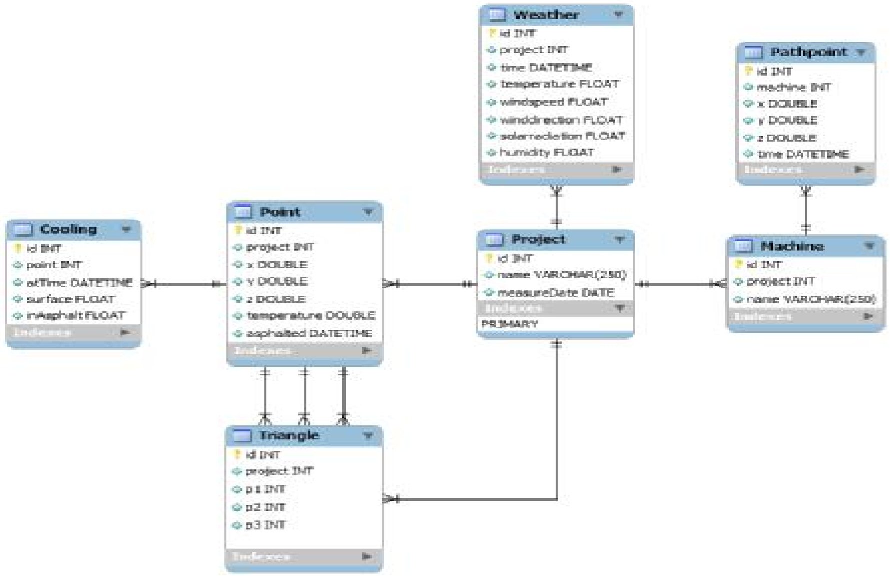

Figure 2 - AsphaltOpen database scheme

Visualization Client

We developed the visualization client in Java using the 3D Graphic libraries Java3D. The client is developed as a standard PC application that users have to install on their client machines. The visualization client shown in Figure 3 is available as the Open Source project AsphaltOpen (AsphaltOpen 2008). Thus, the interested reader has the possibility to take an in-depth look at the source code. At the current state of development, the client is able to visualize the asphalt temperature and the asphalt paver's and rollers' paths.

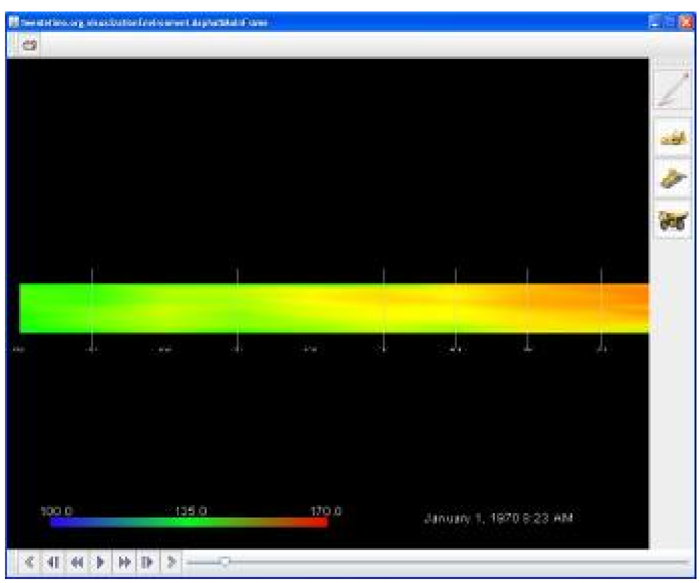

Figure 3 - Screenshot of the AsphaltOpen tool

The application allows the user to connect to a database server and select a specific project database on it. After selection, the application reads the initial asphalting temperature and the GPS points of the machine paths into local memory and displays the project data at the start of the project. The applications displays the street from a birds-eye view and allows users to dynamically zoom into the road and to pan the road to the left, right, up, and down. We did not implement the possibility to orbit in three-dimensional (3D) space because the results from the action research showed that 3D viewing did not help users to understand asphalting operations better. Overall, the application visualizes the street surface as a triangle patch.

Several time navigation functions allow users to navigate in time. We defined the start time of the project as either the earliest timestamp associated with the initial temperature data of the road surface or with the earliest timestamp that is associated with a GPS machine path point. We defined the end time of the project vice-versa, it displays street surface points grey if the selected point in time is before the timestamp that is associated with the asphalting time of the point. At user selected times that are after a surface point's time stamp, the application visualizes the street points temperature using a linear temperature scale that ranges from a dark blue to a dark red. All colors to represent temperatures in between these two extremes are linearly interpolated using the HSB color scale (Foley et al. 1997). To visualize the street patch's temperature independent from the spatial accuracy of the measurements, the application linearly interpolates the colors of the three different street points over each of the patch's triangles.

The application offers two functionalities to display the surface temperature of the street's triangle patch. First, the application can visualize the initial asphalting temperature without the cooling. This function allows users to understand how the temperature varies at asphalting time over the road. Additionally, the application can visualize how asphalted parts of the road cool over time. Hereby, the application calculates the respective temperature of each street surface point according to the generic asphalt cooling formula for a porous asphalt layer that we derived during previous research efforts (Miller et al. 2007; Miller and Dorée 2008) :

$$T_{t_i} = T_{t_0} \times e^{C_w \times t_i}$$

with

T_t - asphalt surface temperature at time t,
t_0 as initial time, and
t_i as time relative to the initial time $t_{0.}$, *and*
and, C_w - cooling rate constant depending on ambient weather conditions.

The application visualizes the machine paths as linear animation between the GPS measurement points read from the database. In the current version of the application, it simply displays machines using simple squares with a 1-meter side. The application colors different machines of the same project differently to allow users the possibility to distinguish between them.

Future developments

In the future, we plan to develop additional algorithms to visualize HMA compaction effort related to roller compactor movements in the form of dynamic visualizations that show the movements of all HMA machinery on the paving site. The dynamic visualizations provide explicit evidence of all paving and compaction activities on distance and time-lines and the extent of co-operation between the HMA paver and the roller compactors. In addition to being able to observe and analyze the operational behavior of the compaction rollers using the dynamic visualization, we will use the GPS data to prepare static Compaction Contour Plots (see the example in Figure 4) showing the number of passes applied to specific areas of the paved lanes. This results in a more detailed analysis of the compaction process i.e. it shows the outcome of the compaction process. To achieve this, we divide the road into rectangular tiles and, for each roller compactor, we calculate the number of times the vehicle's road contact surface touches each tile. This process yields a matrix for each roller compactor with the number of passes over each tile i.e. each roller compactor's compaction effort.

Further, we plan to implement meaningful visualizations to match these mathematical predictions with additionally measured data of the asphalt's surface temperature, inner temperature, and core density.

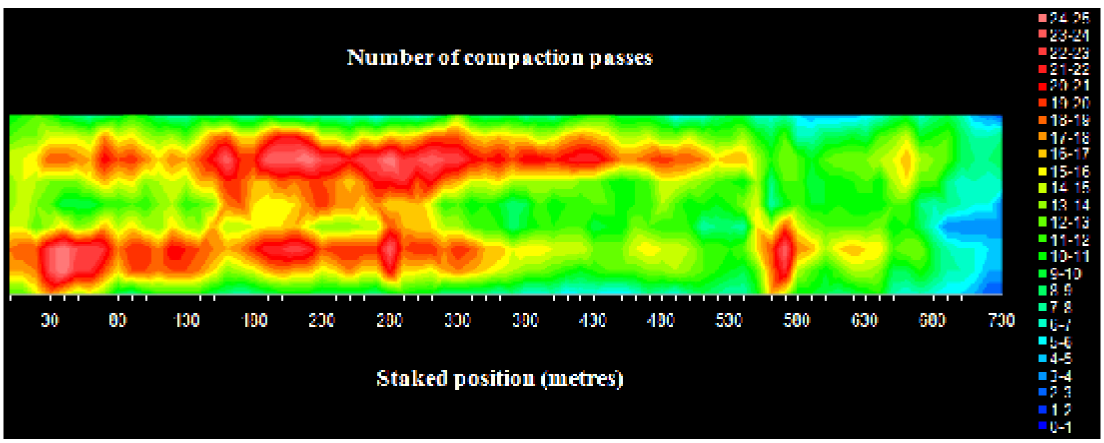

Figure 4 - Typical Compaction Contour Plot derived from the GPS data

Discussion

This paper describes a tool to visualize temperature and cooling processes during the HMA paving and compaction process. The tool consistently visualizes data collected with advanced GPS and temperature devices and presents them a format that is meaningful and understandable for the people involved in the paving process. In particular, the tool collects data from different sources, converts, calibrates, filters, structures and stores them in a database. Through offering display options and a time slider, the tool makes it possible to monitor and analyze the initial temperatures and the cooling processes at different points in time. As such, it provides insights into the physical characteristics of the material, into consistency of the paving operations and into potential quality issues that are easily understandable by HMA paving operators.

Additionally, the database filled with project data, weather data, temperature data and GPS data will serve as a record of all historical paving operations of a HMA paving company. This is a valuable archive in case of quality issues and road surface failure.

The AsphaltOpen tool is a first step to move HMA paving from an industry based on tradition and custom towards a modern industry working in a method-based manner. To maintain the coherence in the transition this project combines tool development, experiments, process improvement, and training simultaneously in an action research approach. In close cooperation with the industry, we will expand the presented temperature visualization tool and database structure towards an integrated paving operation information tool in the future. Co-development and short cycle action research secures the benefit of IT for the people and companies involved, through improved and more consistent road surface quality also for the road users.

In the long run, action research methods such as the one presented in this paper will support the road construction industry to cope with new technology developments. Worldwide we observe the development of new sensors, improved communication systems (pervasive internet), increasing micro-computing powers, RFID tagging, track and tracing, GPS application, and SMART (Self-Monitoring, Analysis, and Reporting Technology) environments. Design will be more driven by Information Model systems/approaches. The construction site environment will become more intelligent and data rich. Construction equipment will become more sophisticated. This trend is not stoppable. The road construction industry, traditionally a late adopter of new technologies, will have to cope with this trend, absorb these new technologies and at the same time improve quality and consistency (Halpin and Kueckmann 2002). This can only be done when the people active in paving operations learn to understand and work with the new technologies. Action research methodology supports the development of IT applications that (1) are custom tailored to work situations and practices that are currently dominated by craftsmanship and experience based learning, and (2) support the transition from experienced based routines to method based operations.

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