VISUALIZATION WORKFLOW AND ITS IMPLEMENTATION AT ASPHALT PAVING CONSTRUCTION SITE

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ABSTRACT

Presently important changes are occurring in the road construction industry, resulting in changing roles of road agencies and contractors. Additionally, a lot of new asphalt mixes with new properties are introduced, such as warm or even cold asphalt mixes, thin surfaces, etc. Despite these changes, the current asphalt paving process still heavily relies on the skills and experiences craftsmanship. Instruments to monitor key process parameters are seldom applicable. To overcome these limitations, real-time visualizations of key indicators such as asphalt temperature could provide decisive information to working teams oriented to adjust their operations on site. To move towards real-time decision making support, this paper introduces a workflow to deliver information in meaningful way by providing close to real-time and easily understandable visualizations of asphalt temperatures to roller operators. Using modern technologies like DGPS, temperature linescanner, and wireless connection on site it is possible to deliver visual information about asphalt temperature to support roller operators' decision making regarding working paths. To implement user-oriented visualization we outlined an overall workflow including equipment selection, infrastructure organization, data processing and visualization phases. We validated the feasibility of workflow implementation through visualization of asphalt temperature on a real-world asphalt paving project.

Keywords: Asphalt paving, construction, infrared thermography, visualization.

1. INTRODUCTION

Important changes are occurring in the road construction industry, resulting in changing roles of road agencies and contractors. Road agencies currently seem to concentrate on their core tasks (governing and exploitation) and contractors take over additional design tasks beside the construction. Because of these changing roles, risks shift from road agencies to contractors (Ter Huerne, 2005). Within these new roles and contracts, the contractors are more accountable for the quality they deliver, because of longer guarantee periods (Ang et al., 2005). Additionally, a lot of new asphalt mixes with new properties are introduced, such as warm or even cold asphalt mixes. Despite these changes, the current asphalt paving process still heavily relies on the skills and experiences of people working on the construction site and depends on personnel craftsmanship often without instruments to monitor key process parameters. Also fewer research effort was put into systematic mapping and analysis of the asphalt paving process (Miller, 2010), which makes it difficult to learn from previous projects and does not support decisions making during this process itself. Therefore, changes are occurring in the industry while the process is still mainly based on former experience and craftsmanship. This tendency might move many of the operations aside of the well-known experience-domain of the asphalt team, making the results of the paving process uncertain (Ter Huerne, 2004). To overcome this issue contractors seek for better control over the paving process.

To develop mapping and analyzing of the asphalt paving process, additional research regarding the Hot Mix Asphalt (HMA) construction process is desired to make the paving process more explicit and provide the asphalt team with information to make decisions during the paving process. Recently (Miller, 2010) introduced scheme to document the working methods of the asphalt team and show the variability in these methods and final results using set of technologies (GPS, laser linescanner and infrared camera). Combination of technologies was oriented to measure surface and in-asphalt temperatures, density progression and movements of machinery on the construction site. Conducted research has shown that asphalt operators can meaningfully analyze their process behaviour using visualizations of construction machines paths and HMA temperature data collected with GPS sensors and temperature sensors (Miller et al, 2010). However, this solution still require intensive post-processing phase and so far the generation of the visualizations was only possible in retrospective and lessons learned could only be applied to future projects. Overcoming these limitations, the next step in professionalizing the paving process is to move towards real-time visualizations on the construction site to provide the asphalt team with information that would allow them to adjust their operations during the process. Such visualizations provide extended information to machine operators to make decisions based on procedures and known phenomena and in this way support the transition from experienced based routines to method based operations. A step in this direction is to provide roller operators with real-time information about the surface temperature of the asphalt mixture.

To move towards real-time operators' decision making support to deliver information in meaningful way by providing close to real-time and easily understandable visualizations of asphalt temperatures to roller operators we utilized workflow, described in this paper. The merits of this workflow are demonstrated by a real construction project. The paper is structured as follows. We start with a short introduction of the compaction process and roller operations and the importance of temperature data. Next, we describe the proposed workflow for user-oriented temperature visualizations and demonstrate two approaches to deliver real-time information to roller operators on a real construction project. Finally, we outline conclusions of this research and describe further directions to proceed with information support targeted to asphalt teams.

2. ASPHALT PAVING DOMAIN CHARACTERISTICS

The paving process can be divided into the following main steps: asphalt production at the asphalt plant, transportation of the asphalt from the plant to the construction site, asphalt lay-down with a paver to spread the mixture to a certain layer thickness and finally compaction of the asphalt with rollers to reach a certain density and quality level. In this paper we focus on lay-down and compaction process, to provide roller operators with real-time temperature information, because possible operational discontinuities can directly affect the final quality of the pavement.

Compaction reduces the volume of voids in the asphalt mixture through the application of external forces and thereby increasing the density. Thus, it is a process of reducing the void content in the asphalt mixture. A mixture with a too high void content will lead to disintegration of the aggregate (raveling), while a mixture with a too low void content will lead to a unstable mixture which can lead to rutting (Chadbourn, 1998). Usually this process is executed by different types of rollers with the objective to achieve a desired density and provide a smooth surface (Ter Huerne, 2004).

Operational choices for the roller operator within the compaction process include choosing the number and type of rollers, when to start rolling, the number of roller passes within different temperature windows and when the last roller pass should be executed. Two main variables to make these decisions during the compaction process are temperature of the asphalt mixture and the density progression during rolling. For the density progression roller operators can communicate with a technologist who conducts nuclear density measurements. However, roller operators have very little information about the temperature of the asphalt mixture during the process, as well as initial lay-down mixture temperature as cooling rate of the asphalt mixture during the process. Roller operators nowadays estimate the temperature of the asphalt mixture, based on the behavior of the asphalt mixture underneath the roller due to the operators' visual observation. For example, the mixture is too hot if it sticks to the roll or it is too cold if no density progression is reached. Another issue in this estimation process is number of different temperatures to measure, for example the surface temperature with in general high variability, in-asphalt temperatures and temperatures at the bottom of the asphalt mixture at the underlying layer (asphalt or foundation).

The compaction process and the influence of temperature and density differentials on the HMA from a material and post-processing perspective has been studied extensively (Chadbourn et al 1998; Asphalt-Institute 1989; Timm et al 2001; Stroup-Gardiner et al 2002; Willoughby et al 2002; Miller

2010). The theory points to an optimal compaction temperature frame to compact the asphalt mixture, logically resulting in an optimal compaction time frame because of the cooling process of the asphalt mixture during time. If the asphalt mixture is compacted within these frames from experience we know the intended design properties of the asphalt mixture are, with a high degree of probability, gained. If the mixture is not compacted within this window there are high risks to negatively influence the final quality of the pavement. Therefore it is important to have real-time information about temperature of the asphalt mixture during compacting operations to support the roller operator.

Overall, the roller operators have to deal with a lot variables to estimate the temperature of the asphalt mixture at a certain time at different locations and sometimes even during night. Also, the compaction process is mainly based on experience of operators and this experience comes from education and training (in practice). By introducing the visualization workflow we intend to provide operators with relevant information at particular time and support decision making "when" and "how" to proceed with compaction procedure.

3. WORKFLOW OF THE ASPHALT PAVING VISUALIZATION ON CONSTRUCTION SITE

While awareness of the temperature might result in decision making and compactors movement behavior, it is required to document asphalt temperature for operative and future reference. Nowadays the value of measuring the asphalt temperature during the process is proved by continuous introduction of new technological solutions on the international market. Examples are a system to visualize and record the asphalt temperatures with geographic coordinates (PAVE-IR) developed by MOBA or a compaction control system by Trimble related to analysis of temperature and degree of compaction of the asphalt mixture during the process (CCS900). PAVE-IR system use infrared sensors on an IR-bar and feeding information to logging computer, together with analysis of distance information from a weel-mounted distance encoder [Swaner, 2010]. In combination with GPS, the described system provides a powerful dataset to review and evaluate HMA construction thermal profiles, but additional equipment, such as a distance wheel is still needed for data acquisition [Sebesta et al., 2010].

The above industrial applications have some limitation according to their oriented target audience and predefined origin of the system, for example, no integration of GPS for real-time processing, requirement for initial road geometry definition or measuring temperature only beneath/in front of the roller. Automatic generation of a paved surface, based on coordinates and temperature information behind the paver would give more flexibility in support of complex road design while working in urban areas with number of curves, intersections, roundabouts, etc. This type of visualization does not require the previous definition of the road, but have more dependencies on precision of location data. This can be implemented by utilization GPS with intensive filtering, sensors and communication infrastructure on site. Named elements can be referred as component of the overall visual data representation workflow on Figure 1. To proceed with temperature data visualization oriented to a roller operator we made consequent steps of choosing, organization of utilization of available technologies. Elements marked on Figure 1 with asterisks were used for illustrative system implementation.

The workflow of implementation user-oriented visualization is divided into 2 parts: a hardware-related and a software-related part. The workflow starts with selecting instruments to measure desired information which can be decisive for operators of the asphalt team. In the asphalt pavement domain different sensors can be used to document movements of the machinery at the construction site or the temperature of the asphalt mixture. Instruments referred as processing units are the main nodes of the overall hardware structure on site, for example a server and clients, oriented for data processing and visualization.

After equipment is selected, an infrastructure need to be organized to connect the hardware for effective delivery of valuable information to respective personal to support decision making. Infrastructure can be created using wired connections, Wi-Fi, Bluetooth or radio components. Additional continuous power support to the equipment needs to be provided, for example linescanner can be connected to a paver 24V or 220V and laptops can use batteries, or AC sources.

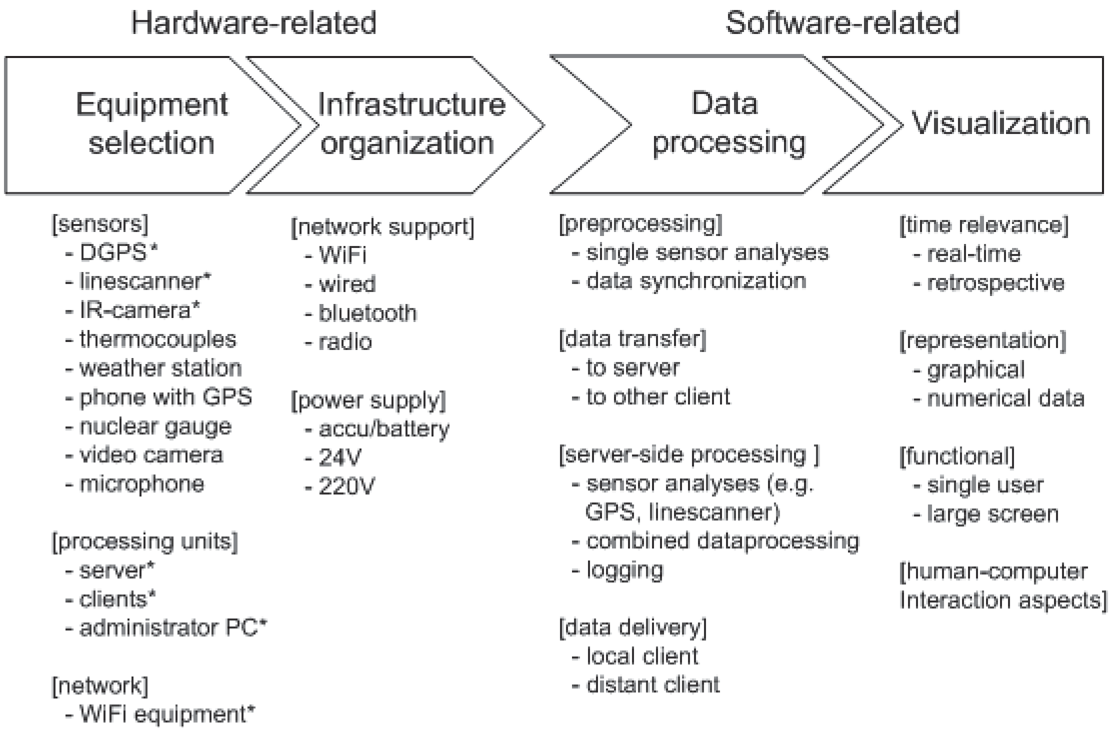

Figure 1: Workflow for visual data representation on a construction site

The next step of data processing includes pre-processing (e.g. synchronization of linescanner and GPS data), the transfer information to a server, and data combination/processing from different sources. The last step is to present effective visualization of the data in an easy and understandable format to the asphalt paving team. The form of visualization can differ with respect to the target audience, i.e. single person, several operators or to a group of workers using large screen. To achieve better results of close to real-time rate information delivery consideration of human-computer interactions techniques might have an additional value.

There is no prerequisite that all elements of the workflow are to be present within one particular solution, but changes within every step may have direct influence to overall system implementation. Following chapters are organized to represent consequent workflow illustrative implementation to deliver temperature information to the roller and paver operators on a construction site.

4. EQUIPMENT SELECTION FOR ILLUSTRATIVE IMPLEMENTATION OF THE VISUALIZATION WORKFLOW

To measure the temperature of the mixture during the asphalt paving process we utilize a linescanner, thermocouples and an infrared (IR) camera. In this case linescanner or infrared sensors can provide information about surface temperature for thermal segregation detection, when quality control and quality assurance are major aspects to concentrate. The linescanner is mounted behind the screed of the paver and continuously measures temperature along a line during asphalt lay-down process (Figure 2). We mounted the linescanner behind the paver at the height about 3 meters. This enabled us to collect data in a non-intrusive way and in a high resolution: up to 150 lines per second and 1024 measurements point per line. For later data processing amount of information can be reduced or particular zones of interest defined, making data convenient for visualization. Moreover, options to support OPC (Open Process Control) server or DDE (Dynamical Data Exchange) give to linescanner number of options of integration within data collection infrastructure on site, giving flexibility to system integration.

Figure 2: Linescanner mounted behind a paver

Although utilization of a linescanner as measuring equipment offers number of positive options, obtained data is hard to use effectively on a construction site. Feedback from the asphalt team during discussion sessions outlined that time-based information from the linescanner was not appreciated because of two reasons: on the one hand the roller operators could not observe the linescanner data real-time and on the other hand it was difficult to relate the visualization of the linescanner data to the real position on the construction site. For example, if a relatively cold place was noticed it was difficult to localize that place on a site. Weak or no relation of temperature data to real spot might become critical issue preventing the data from using during operations. This can be solved using GPS in synchronization with temperature information, or roller operator can measure temperature using another set of equipment, related to roller position. Therefore, additional equipment was decided to use on a site. The infraredcamera was put on the roller to give the roller operator a thermographic view of the asphalt layer at the front or at the back of the roller, which is shown in Figure 3.

Figure 3: IR camera attached to a roller using magnet

The infraredcamera is connected to a laptop in the cabin to provide live-streaming information about the temperature at the front or at the back of the roller. Using magnets the installation of the equipment can be done in a few minutes. This fast and simple way to install the camera gives flexibility to use it on different paving machines and rollers.

In described workflow the equipment selection based on needs of user-oriented visualization is the basic step preceding network organization. Nevertheless, for effective information delivery, processing and documentation infrastructure organization is crucial.

5. INFRASTRUCTURE ORGANIZATION ON THE CONSTRUCTION SITE

For better control of the pavement process it is important to continuously obtain and deliver information to operators on site. To achieve such an effective data delivery a number of requirements have to be fulfilled. For example, network might be scalable and its realization has to be done without interventions into construction process, while users are constantly moving Utilization of wireless communication can be an adequate solution to this problem. A literature review showed that network infrastructure on site might significantly differ with respect to project needs. For example, the AutoPave [Krishnamurthy et al., 1998] real-time guidance system utilized two radio modems on a roller (one for receiving positional data from the paver and the other to receive roller position data from GPS base station) and two radio/data modem on a paver unit (to transmit data to the roller and receive positional data from the base station). The amount of possible users of this scheme is limited and it is complicated to organize multi-user interaction within such network. Another example of a wireless network organization [E. Viljamaa et al., 2009] involves asphalt mixing plant unit, transport vehicle and a paver, while compactors were left out of the scope of the system. This set of users is different from AutoPave, therefore due to a large distance between them GPRS (General Packet Radio Service) and Flash-OFDM (Fast Low-latency Access with Seamless Handoff Orthogonal Frequency Division Multiplexing) network technologies were utilized in addition to short-range radio module.

In illustrative implementation of user-oriented visualization workflow we considered paver and roller operators as central users of the system and provided temperature information might be mainly oriented to support their activities. As additional clients for the network we consider manager/quality control personal on site and on certain distance, therefore solution should provide opportunity to deliver information far beyond the site, e.g. to office of a contractor. For the development of wireless infrastructure on site we consider the distances between paver and rollers on a construction site to be limited to hundred(s) meters. According to the fact that a number of machinist/operators take part in construction activities and are constantly in movement we consider wireless communication on site as an appropriate way to establish simple and flexible infrastructure. In these conditions we see Wi-Fi network as an appropriate solution. The overall organization of a wireless network can be seen in Figure 4. It includes an infrared camera, a temperature linescanner and a Differential Global Positioning System (DGPS), connected via Wi-Fi. In a first approach a wireless hub can be deployed to the paver and attached to 220 V power supply. A more sophisticated network can utilize more powerful Wi-Fi router, external antennas, a specialized Outdoor Access Points, and Wireless Distribution Systems to cover large construction site with complex geometry.

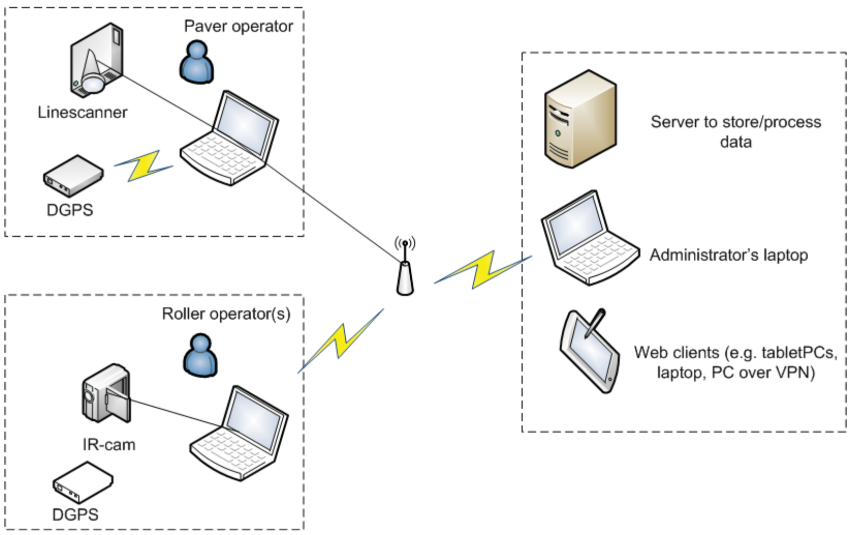

Figure 4. Organization of wireless network on construction site

In the illustrative implementation case we established wireless network and used software for remote administration to control distance equipment, adjust setting and support functionality of the devices without interrupting the work procedures on site. According to the presented workflow all hardware elements were connected to power supplies and to network to deliver information from multiple sources to different operators. Visual data from linescanner and IR-cam were available via webserver within the network and, therefore, was available to large number of consumer electronic devices, including PC, smartphones, tabletPCs to personal on site or to distant clients via Virtual Private Networks. The given infrastructure delivers temperature information in close to real time rate, being at the same time flexible to extension and easy to maintain because of standard components utilization.

6. DATA PROCESSING AND VISUALIZATION OF ASPHALT TEMPERATURE DURING OPERATIONS ON SITE

Visualization of asphalt temperature was previously done by academic and industry researchers using software solution for post-processing or real-time analysis. For example, the visualization environment AsphaltOpen integrates asphalt temperature and GPS data with site-specific GIS data and provides functionality to meaningfully overlay these different data. Post-processing analysis are supported by Java3d graphic libraries and oriented to support quality improvement processes at asphalt paving contractors [S.R. Miller, et al. (2011)]. Such analysis make sense of previous paving operations, but are not fully applicable to support operative decision making by operators on site in close to real-time rate.

To provide information to roller operators we delivered real-time infrared temperature video to machinists' cabin. Such infrared vision could be valuable addition to traditional methods, when operators saw "color of the asphalt mat" as the most telling parameter [ter Huerne, 2007]. Implementation of infrared cameras on a roller include live streaming video to laptop with a number of parameters that can be easily read (Figure 5): numerical temperature at central point of the camera view, the lowest and highest temperatures within the visible range and, most valuable for decision making, the distribution of temperature over a certain area.

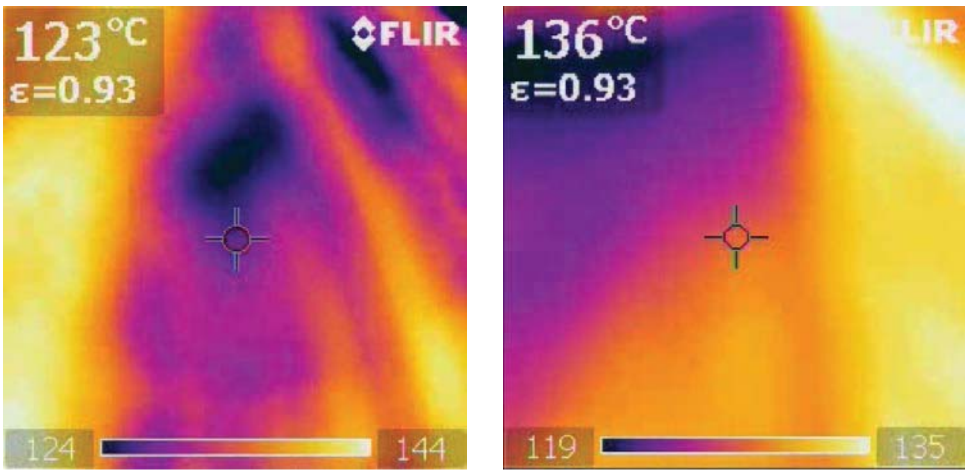

Figure 5: Examples of real-time IR imaging of temperature in front of a roller

More sophisticated infrastructure is needed for illustrative implementation of the visualization workflow for linescanner and GPS: network infrastructure might support preprocessing (synchronization data from both sources at a laptop in paver's cabin), wireless connection to transmit data to server, visualization and data delivery to clients. This solution provides the option to deliver temperature information to the users in close to real time mode (within a seconds) and imply precisely documentation of temperature information with relation to measurement points. Preprocessing of location data is desired as information might potentially have noise, introducing difficulties to relation of position and measured data. Different instruments can be used for improving location estimation, such as software filters, or hardware components, e.g. 1D weel-mounted distance sensors (PAVE-IR), a Robotic Totalstation (OSYRIS - Open SYstem for Road Information Support) or a satellite-based DGPS. The listed instruments have certain limitations for its usage – additional information about heading direction might be required or the interrupted visual line or noise from GPS signal may affect positioning.

To develop and test our prototype we used DGPS with a base station. The signal received from the GPS and GLONASS navigation systems with a correction from the base station normally have relatively high precision. Nevertheless, still some noise is introduces because of visibility of satellites, atmospheric effects and instrumental biases. Therefore, it is reasonable to apply Kalman real-time filtering to GPS signal [F.R. Bijleveld, et al. (2011)]. Resulted machinery path with less noise can be used to combine coordinates information with temperature data from linescanner for visual representation of temperature surface. To reduce computation load at clients PC side we processed data on a server using Matlab and resulting temperature contour plot (Figure 6) can be seen within network by personal on site and over the distance using thin clients terminals. This kind of a visualization can be used for future references in case of investigations about quality at a particular spot on a road. Moreover, temperature plot represents temperature homogeneity and may be potentially valuable for examining efficiency of new technologies during pavement process and utilization of specialized machinery, oriented to deliver uniform asphalt mix. For example, additional feeder (shuttle buggy) machine can be used between truck and paver can as an intermediate step in conveying asphalt mix from the trucks to a paving machine. Although potential of using such geo-referenced temperature visualization goes far beyond need of the roller operator, information presented in close to real time rate was originally oriented to support decision making and influence operators' behavior on construction site.

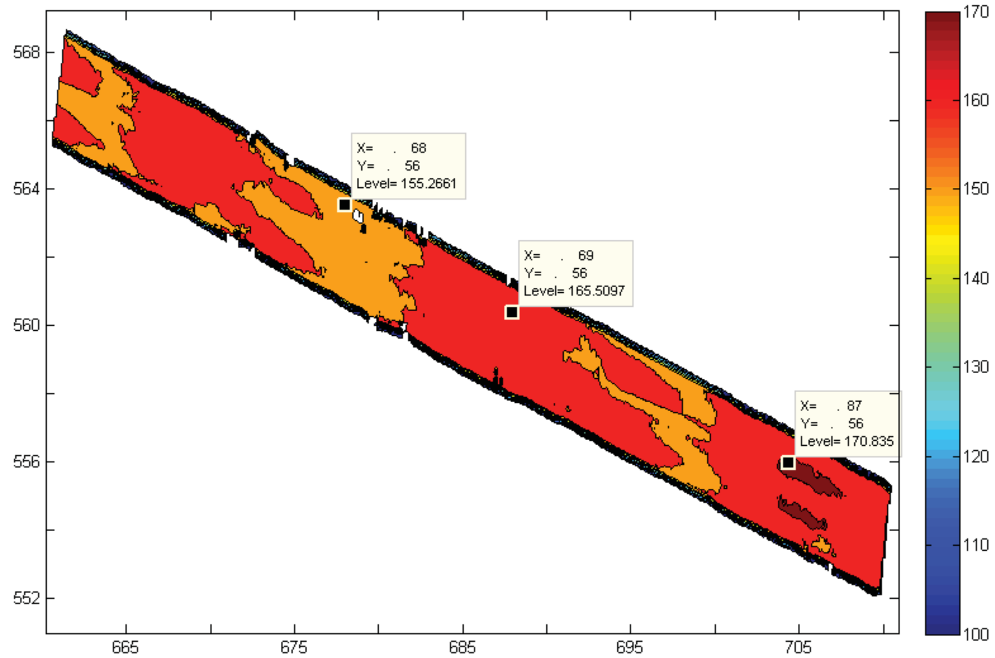

Figure 6: Example of visualization asphalt temperature based on DGPS and linescanner data

Both of the here presented visualization solutions were built according to the described visualization workflow and oriented to display temperature to paver and roller operators. Output visualization and relevant measurements are documented and used for operative and strategic decision making, retrospective analysis, evaluation and best practice identification. Although particular infrastructure on site was developed to support two defined solutions, it can be easily adjusted according to described workflow.

CONCLUSIONS

The compaction process of an asphalt mixture is a versatile task. The set of required information for roller operators to make decisions include initial lay-down temperature, the cooling rate of the asphalt mixture and also the previous executed roller passes. Using modern technologies like DGPS, temperature linescanner and network connection on site it is possible to deliver visual information about asphalt temperature in close to real time rate to support roller operators' decision making regarding working paths.

To implement the user-oriented visualization we outlined a workflow that allows integrating number of technologies on a construction site in consequent way, including equipment selection, infrastructure organization, data processing and visualization steps.

We validated the feasibility of the workflow implementation through implementation of two user-specific visualization on a real-world asphalt paving project.

DISCUSSION AND FUTURE WORK

In this paper we described and illustrated a workflow model for real time gathering and visual representation of process data on road construction sites. We consider this proposed model as a mean to structure [a] the visualization tasks, [b] the interaction between the paving specialists and the visualization experts, [c] decisions on further development steps, and [d] the research trajectory. The effectiveness of this workflow model is illustrated by the relative short timespan needed to create the visualization in the described case. Whilst implementing new developments we continuously evaluate effectiveness with PUEU (Perceived Usefulness and Ease of Use) questionnaires [Davis, 1989] and interactive feedback sessions with machine operators. The outcomes of the questionnaires and feedback session scope and drive the next steps in development. As an experiment we built a realtime visual representation of HMA surface temperature in the roller cabin. The PUEU and the feedback sessions expressed the usefulness but also provided pointers for improvement. Our preliminary research showed indicated that time-based temperature information is less preferable than location-based information. During the next illustrative visualization GPS positioning data was introduced to provide machine operators with additional information. In general, machine operators, managers and personal on site agreed that enhanced information might assist them in their daily operations; As such showing the importance and value of the engaged research approach (as in [Van de Ven, 2007]), deepening the insight into the operational choices, the design of the use interface and hardware issues.

Beside the described illustrative visualizations different information could influence operators' decision making process in addition to surface temperature data. The next step would be to proceed with information delivery regarding in-asphalt temperature and mix cooling rate under certain weather conditions. Also, temperature information can be useful for evaluating new technologies to improve delivery of homogenious asphalt mix, such as feeders (shuttle buggy). The set of previously collected information could be also used to build a virtual construction site to train and educate operators and demonstrate them the consequences of different choices within the paving process.

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