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Development of compaction monitoring system for asphalt pavements

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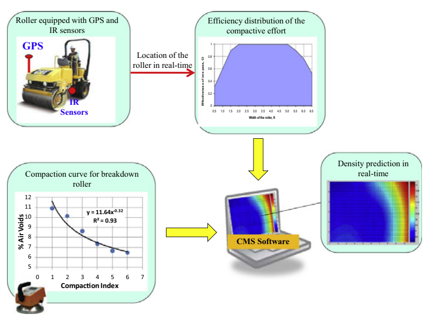
HIGHLIGHTS

- The CMS uses the latest global positioning system technologies and various sensors.
- The CMS can be mounted on any roller in a matter of minutes.
- The CMS provides the roller operator with real-time color displays of compaction information.
- A novel method for predicting the density of asphalt pavements in the field was verified.

GRAPHICAL ABSTRACT



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ABSTRACT

There is a great interest in developing and implementing new technologies for real-time evaluation of the uniformity of the construction of asphalt layers. In this study, the researchers developed a system for monitoring and documenting the compaction process of asphalt mixtures in the field. This system is called the compaction monitoring system (CMS). The CMS uses the latest global positioning system technologies and various sensors to provide full coverage of an asphalt layer. The new system can be mounted on any roller in a matter of minutes, and it provides the roller operator with real-time color displays of the number of passes of the entire mat, the compaction effectiveness, and the temperature at the first pass of the roller. This system was successfully tested in a number of field projects. The CMS was able to show some inconsistencies in the compaction process such as unequal compaction converge across the mat, non-uniform compaction effort and temperature, and delay in compaction after placement of asphalt mixtures. The compaction data are stored for post-processing analysis and evaluation. In addition, the researchers validated a proposed method for predicting the density of asphalt pavements in the field. The results showed good correlation between predicted and measured density.

1. Overview

Compaction is the process by which the volume of asphalt mixtures is reduced leading to an increase in density of asphalt mixtures [1,2]. Compaction is critical to the performance of asphalt pavements. Insufficient compaction leads to rutting, moisture damage, and excessive aging. Several factors such as amount of asphalt binder, aggregate gradation, aggregate characteristics, temperature, and roller type affect compaction of asphalt mixtures [1]. Several studies examined the relationship between field and laboratory compaction and mechanical properties of asphalt mixtures [3–9]. However, limited efforts were conducted to develop tools that could improve the uniformity of the compaction of asphalt pavements. Kassem et al. [8,9] developed an index called the compaction index (CI) to quantify the compaction effort at any point in a pavement. This index combines the number of passes of

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compaction roller and the effectiveness factor of each roller pass. Kassem et al. [9] found that the efficiency of the compactive effort across the steel rollers is non-uniform; a point on the mat closer to the center of the roller is subjected to more compaction than a point closer to the edge of the roller. The CI was found to be a good tool to provide uniform compaction effort and density across the mat [9]. In addition, the authors presented a new method to predict density of asphalt pavements. This method uses the compaction curve for each compaction roller and location of the roller on the mat to predict density in real time. The results showed good correlation between predicted and measured density [9].

Recently, Intelligent Compaction (IC) technology was used to monitor the field compaction of asphalt pavements in real time [10–12]. There are several IC systems that are used and commercially available [13–18]. The IC uses compaction rollers that can adapt the compactive effort to achieve certain stiffness. Maupin [10] found poor correlation between stiffness measurements from an IC roller and density of thin surface asphalt layers. The results showed that the IC roller was not superior to the conventional roller. The IC roller could not exert more compactive effort when needed. It is believed that the thickness of the asphalt layer and stiffness of the underlying layers affect the IC stiffness measurements. Other studies confirmed that the stiffness of the underlying layer has a great impact on the IC stiffness measurements of the asphalt layer being compacted [11]. Commuri et al. [12] developed a neural network-based Intelligent Asphalt Compaction Analyzer (IACA) to estimate the compaction quality of asphalt pavements. The results showed that density measured using the IACA method correlated well with the density in the field.

On-site positioning technologies can facilitate tracking of construction rollers and provide an automated data collection means for sophisticated, data-driven analytical techniques. In the past, there were some efforts for developing automated methods for monitoring the compaction during the paving construction. These automated methods include the compaction documentation system, laser, and global positioning system (GPS) [19]. Later, studies began to use new technologies to track the position of the compactors in real time. These technologies include the laser and GPS. The laser positioning system is very accurate but requires many laser targets, which act as receivers [19]. The GPS is relatively less expensive, and its measurements should be accurate enough to be applicable in the pavement project application [19]. Roberts et al. [20] applied the GPS to aid autonomous control and guidance of construction plants. Peyret et al. [21] also evaluated the precision of using the real-time kinematic GPS for the elevation control of the screed of an asphalt paver. Oloufa [22] showed the applicability of using a GPS-based system for monitoring multiple compactors in real time during paving construction.

2. Problem statement

Providing the required and uniform compaction effort to an asphalt layer would improve the uniformity of density distribution and improve the overall performance of asphalt pavements. This study complements previous efforts by the authors in developing methods to improve the construction of asphalt pavements that provide 100 percent coverage of the new layer. The authors developed methods to provide uniform compaction effort and avoid thermal segregation during construction. In this study, the authors integrated these methods in an automated system that is easy to install on a compaction roller to provide the operator with real-time feedback on the compaction process and guide the operator to apply a uniform compaction effort across the mat by adjusting the compaction pattern (number of passes, overlapping of roller pass, and overhanging the roller on the edge of the mat). In addition, the authors verified a method they proposed for predicting the density of the asphalt pavement in typical field projects. This method can be integrated in the proposed compaction monitoring system (CMS) to provide density prediction in real time during construction.

3. Objectives

The main objectives of this study were:

(1) Develop an automated system that is capable of tracking the location of the compaction roller on the mat, measuring the temperature distribution, producing maps for the distribution of compaction effort or compaction index across the mat in real time, and storing the compaction data.
(2) Develop post-processing utility for review and evaluation of the collected and stored compaction data.
(3) Test the developed system in typical field projects to assess its benefits in monitoring and documenting the compaction process.
(4) Verify a proposed method by the authors for predicting the density of asphalt pavements in the field and assess the applicability of integrating this method into the CMS to provide continuous density prediction tool.

4. Research tasks

The following tasks were completed:

(1) Used the latest GPS technologies and advanced sensors to develop an automated system to monitor the compaction of asphalt pavement. Such system should be easy to use and install on the compaction roller and accurate enough to track the location of roller on the mat in real time.
(2) Tested the accuracy of the proposed system in pilot experiments.
(3) Wrote a program for post-processing the compaction data. Such utility should be flexible and interactive that allows the user to examine certain sections of the projects and provide detailed information for single location in a project.
(4) Tested the CMS in typical field projects in Texas.
(5) Analyzed the collected data using the post-processing utility.
(6) Documented the benefits of the proposed system in improving the compaction process of asphalt pavements.
(7) Verified and evaluated a proposed method for predicting the density of asphalt pavements and assess the applicability of implementing this method in the CMS.

5. Compaction monitoring system

In previous studies [8,9], the authors developed the compaction index to quantify the compaction effort at any point of the mat to improve the uniformity of new hot mix asphalt layer construction. In this study, the authors took this method one step further by developing an accurate GPS tracker for compaction rolling so that the compaction effort applied can be monitored for 100 percent of the new surface. The CMS consisted of a GPS unit mounted on the roller to track the location of the roller on the mat. Temperature sensors were attached to the sides of the roller to record the mat surface temperature. In addition, an accelerometer sensor was mounted on the roller to determine the mode of operation—static or vibratory. The CMS monitored the location of the roller on the mat and the number of passes across the mat. Each