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Activity analysis of construction equipment using audio signals and support vector machines

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ABSTRACT

In the construction industry, especially for civil infrastructure projects, a large portion of overall project expenses are allocated towards various costs associated with heavy equipment. As a result, continuous tracking and monitoring of tasks performed by construction heavy equipment is vital for project managers and jobsite personnel. The current approaches for automated construction equipment monitoring include both location and action tracking methods. Current construction equipment action recognition and tracking methods can be divided into two major categories: 1) using active sensors such as accelerometers and gyroscopes and 2) implementing computer vision algorithms to extract information by processing images and videos. While both categories have their own advantages, the limitations of each mean that the industry still suffers from the lack of an efficient and automatic solution for the construction equipment activity analysis problem. In this paper we propose an innovative audio-based system for activity analysis (and tracking) of construction heavy equipment. Such equipment usually generates distinct sound patterns while performing certain tasks, and hence audio signal processing could be an alternative solution for solving the activity analysis problem within construction jobsites. The proposed system consists of multiple steps including filtering the audio signals, converting them into time-frequency representations, classifying these representations using machine learning techniques (e.g., a *support vector machine*), and window filtering the output of the classifier to differentiating between different patterns of activities. The proposed audio-based system has been implemented and evaluated using multiple case studies from several construction jobsites and the results demonstrate the potential capabilities of the system in accurately recognizing various actions of construction heavy equipment.

1. Introduction

It is an unfortunate fact that the construction industry suffers from lower productivity rates as compared to most manufacturing industries. According to the Lean Construction Institute [1], the productive time in the construction industry is only 43%, compared to 88% in manufacturing. One major factor contributing to this issue is that construction projects are all unique and it is typically very difficult to find completely similar projects/operations. As a consequence, in contrast to the manufacturing industries which includes highly repetitive processes, a single project management technique or a single set of fixed performance measures are rarely available in the construction industry. Thus, the first step towards improving productivity within the construction industry is to develop efficient techniques for assessing the performance and productivity of key resources that is sufficiently flexible to handle the widely varying conditions that arise across different jobsites. Since a large portion of total project costs typically derive from the costs of renting/owning/leasing/maintaining construction heavy equipment, we will focus on recognizing and tracking activities of construction heavy equipment. Note that beyond productivity assessment and analysis, monitoring of construction equipment is useful for emission control and monitoring [2], safety management [3], and analyzing/reducing idle times [4,5].

The common practice for recognizing and monitoring activities at construction jobsites is through manual data collection and direct observations. This process is known to be time consuming and labor intensive. In recent years a number of methods for automatically recognizing and tracking locations and actions of construction heavy equipment have been introduced. These methods include using active sensors (GPS (Global Positioning System), accelerometers, RFID (Radio-Frequency Identification) tags, etc.) or passive sensors (processing videos using computer vision algorithms). These methods are capable of producing promising results; however, as explained below, several constraints limit their application in real world construction jobsites. As

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a result, the construction industry still lacks a practical, real-time, and non-intrusive method for performance characterization and monitoring of jobsite operations.

To address the drawbacks of existing methods for activity analysis of construction equipment, and in order to further advance the knowledge in this area, this paper presents a novel activity analysis based on intelligent processing of audio signals. Audio signals, recorded and collected at construction jobsites, reflect corresponding activities that take place and can provide very useful information for project managers. The proposed system begins with recording the sounds generated by construction equipment during their routine operations by using commercially available microphones. The recorded audio file then goes through a signal enhancing and feature extraction algorithm to reduce unwanted background noise. The result is then in the form of a time-frequency decomposition which can be fed into a machine learning algorithm such as a *support vector machine (SVM)* for the purpose of classifying the time-frequency features as being characteristic of particular machines/activities.

The remainder of the manuscript is organized as follows. Section 2 outlines current states of practice and research for action/location tracking of construction heavy equipment. This is followed by the research methodology in Section 3. Section 4 summarizes necessary steps for running experiments to evaluate the performance of the proposed system and finally, conclusions and future research directions are presented in Section 5.

2. Location and action tracking of construction heavy equipment

2.1. Location tracking of construction heavy equipment

The current state of practice for monitoring construction operations at jobsites is based on manually collecting and analyzing the necessary data. The manual data collection process could take place either through direct observations or by watching real time video streams. Throughout this process, the operator must manually classify and record productive versus non-productive (or idle) times. The results, along with other useful information such as maintenance notes and qualities of accomplished work, are manually entered into timesheets or other types of records. The ultimate goal of this process is calculating the percentage of equipment time spent on value-adding activities and thus, evaluating the productivity rates of the machine which will be eventually used for time and cost analysis purposes.

The manual process of monitoring construction equipment activities is labor intensive, time consuming, and error prone [6]. As a result, both practitioners and researchers in the area of construction engineering and management have recognized a substantial need for real time, accurate, and dynamic systems for activity analysis and monitoring purposes. Spatial location tracking of construction machines was the first attempt to tackle this issue. The localization and tracking of construction equipment (and other construction resources) is now a common practice within the construction industry. Currently, a number of companies (Giga Trak, Navman wireless, Fleetmatics, Linxup, Fleetilla, LiveViewGPS, etc.) offer commercial packages and services for location tracking of construction machinery. Accurately localizing and tracking construction equipment enables project managers and machine owners to better manage their assets in terms of fuel consumptions, security concerns, and assessing the performance of operators.

Several remote sensing technologies such as GPS (Global Positioning System), RFID (Radio-Frequency Identification), and Ultra-Wideband (UWB) sensors can be used for location tracking of construction machines. These technologies are all based on the time-of-arrival principle: “the propagation time of a signal can be directly converted into distance if the propagation speed in known” [7]. The most popular localization system is GPS which provides location and time information anywhere on the earth if there is an unobstructed line of sight to four or more earth orbiting satellites [8]. Although the service is available worldwide for free, attaching a high-precision GPS receiver to every worker or equipment could become costly [9]. An alternative approach is to use active RFID tags. Each tag includes an on-board power source and a locally installed antenna for the signaling electronics. These battery-powered tags can effectively communicate with a receiver for distances of up to 100 m and their unit cost is in the order of tens of dollars. Another advantage of these tags is the ability to operate without line of sight at long distances which makes them a good candidate for dynamic and crowded construction sites. The main issue, however, is the identification problem: “a reasoning mechanism is required in order to locate-tagged construction items on jobsites” [9]. UWB sensing is a special form of active RFID that can locate objects from communications between multiple tags and receivers. Tags emit signals that can be captured and processed by fixed receivers. UWB has shown several advantages in comparison to other active sensing technologies: longer range, higher measurement rates, improved measurement accuracy, and immunity to interference from rain, fog, or clutter [7]. However, the presence of a dense and expensive network of stationary receivers (i.e., measurement infrastructure) is necessary for this purpose.

The remote sensing technologies described here, facilitate 3D location tracking; however, the primary issue that still remains challenging is to recognize the equipment actions from indirect data (i.e., accurately distinguish various productive actions from non-value-adding ones). Moreover, the technologies described above are often viewed as intrusive by equipment operators as a sensor needs to be installed on each machine to record their every movement. The issue becomes even more problematic for rental equipment due to the effort and cost of repeatedly installing and removing sensing units from the equipment and, consequently, the need to continuously update the monitoring software database [10].

2.2. Action recognition of construction equipment using active sensors

Location tracking of heavy equipment provides very useful information; however, projects managers are typically more interested in monitoring various operations performed by the machine over time, instead of merely tracking locations. For this reason, researchers have recently investigated several approaches to recognizing various actions of equipment using active sensors. The application of sensors such as gyroscopes and accelerometers for activity analysis purposes has been studied in a number of other contexts, including healthcare, sport management, and computer science [11–14]. Such sensors are able to accurately provide acceleration and rotation rates in three dimensions (on the x, y, and z axes). This information is particularly helpful for activity tracking of construction equipment as the acceleration rates differ for various tasks performed by the machines. In the study conducted by Ahn et al. [15], accelerometer data was used to differentiate between three modes of an excavator operation: engine-off, idling, and working. Their study illustrated very promising results; however, the level of detail in describing activities was limited to these three categories. In addition, the necessity of mounting active sensors on machines is still a serious problem. To overcome this issue, Akhavian and Behzadan [6] investigated the use of built-in smartphone sensors to extract accelerations and rotation information. Using smartphones greatly facilitate the application of active sensors for activity recognition. However, the installation setting is not always feasible: The sensor(s) need to directly be attached to the equipment (or place in the operator's cabin). This setting is not always practical especially for some smaller equipment/construction tools such as jack hammers, concrete cutting saw, small concrete mixers and so on. For those cases, a passive or indirect sensing system, without the need for being directly attached to the machine, is more desired.