Advanced Engineering Informatics 30 (2016) 95–108

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Visualization environment for reviewing and experimenting with compaction equipment trajectories in context

A. Vasenev [a,*], T. Hartmann [c], S.R. Miller [b], A.G. Dorée [b]

[a] Services, Cybersecurity and Safety Research Group, University of Twente, The Netherlands
[b] Department of Engineering and Construction Management, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands
[c] Chair for Systems Engineering, Department of Civil Engineering, Technical University Berlin, Germany

ARTICLE INFO

Article history:
Received 20 January 2015
Received in revised form 1 February 2016
Accepted 4 February 2016
Available online 18 February 2016\

Keywords:
Visualization environment
GNSS sensor
Asphalt layer temperature
Paving
Compaction
Equipment trajectories

ABSTRACT

Visualization Environments (VEs) can assist construction professionals in studying intricate interrelations between construction equipment trajectories and their context. Such VEs typically support them in either reviewing earlier conducted work or experimenting with possible alternatives. In the first case, VEs represent equipment trajectories and their actual context sensed during actual construction processes. Trying out alternative trajectories in such VEs is problematic. In the second case, environments support experimenting with alternative equipment trajectories within an a priori defined context, but demand significant modeling efforts to reconstruct real-world projects. Although combining both functionalities within a singular VE will enable obtaining benefits pertinent to each of the visualization environments classes, such attempts were not made earlier. To overcome this gap, this study proposes a method for developing interactive simulation visualization environments suitable for both reviewing conducted and experimenting with alternative equipment trajectories. The suggested method concentrates on compaction operations and comprises two steps: (1) application of a "context-actions-trajectory-impact" framework to structure interrelations between compaction equipment trajectories and their context; and (2) operationalization of an organization scheme to devise a specialized VE with the desired functionality. To evaluate the applicability of the proposed method we applied it for the case of the asphalt compaction process. We developed a specialized visualization environment in consultation with asphalt paving professionals. Two test sessions with a paving specialist and two professional roller operators were conducted with the developed VE. The results from the sessions show that the environment developed according to the method offers the envisioned functionality. As illustrated by the test results, original and demonstrated equipment trajectories are commensurable and able to provide meaningful insights into compaction operations.

1. Introduction

Nowadays, employing construction equipment is critical in literally all residential, commercial, industrial, or highway constructions projects [24]. With the increasing industrialization of construction work, the role of on-site equipment and machinery is vital in achieving productivity and efficiency [66]. This dependency on construction equipment grows with the size and complexity of construction projects.

Given the vital role of equipment during on-site construction, analyzing previously conducted construction projects can provide valuable insights about the process. Specifically, construction personnel and students at professional educational facilities through such an analysis of past processes, can improve their understanding of construction processes. In particular, the analysis can help students and professionals in identifying equipment activity- and safety-related information [43], work zone safety features [52], and near-miss events (as noted in Vasenev et al. [60]). The thorough understanding of how equipment might move within specific project conditions can also contribute to planning future construction activities (see for instance Huang et al. [27] and Li et al. [36]).

To meaningfully study equipment movements the documented construction equipment paths – in other words, equipment trajectories – need to be considered in relation to the context where the trajectories take place. This context is formed by multiple factors and can include other equipment and operations that characterize the situation of an equipment and influence decisions of the equipment operator. Some examples of particular context factors are ambient weather conditions or locations of other equipment.

* Corresponding author.
E-mail address: a.vasenev@utwente.nl (A. Vasenev).

http://dx.doi.org/10.1016/j.aei.2016.02.002
1474-0346/

Interactions between the trajectories and their context can be carefully studied and assessed with the help of 3D Visualization Environments (VEs) due to their capabilities to "provide insights and understanding and reduce complexity of the phenomena under consideration" [33]. In line with VEs available in other domains, construction-oriented environments can be classified as either oriented to review conducted equipment trajectories in context (e.g. [40,61,51]) or to experiment with alternative trajectories for specific contexts (such as Turkiyyah [55] and Fang et al. [19]). Each of these two VE classes possesses distinct characteristics. The first VE class hones in on reviewing conducted equipment trajectories. The corresponding data processing procedures can automatically reconstruct specific context factors, such as ambient weather conditions. The shortcoming of such environments is its inability to experiment with alternatives to the construction process. In contrast, the VEs of the second class can assist in experimenting with alternative trajectories for particular contexts, but demand dedicated efforts to model the context of a specific project.

Combining functionalities of both classes would resolve the limitations specific for each of the VE classes. Such a combination could enable VE users to both (1) review actual equipment trajectories shortly after the completion of the construction project and to (2) experiment with alternative trajectories within the context of the conducted project. However, despite the potential to combine the advantages of different VEs, the topic how such environments could be developed did not receive significant attention. According to the authors' best knowledge, how to organize such VEs for the construction domain has not been proposed yet.

Two challenges seem to have hampered the development of environments with the combined functionalities for the needs of the construction domain. Firstly, because each construction process is unique, it is not easy to provide a suitable approach to disentangle intricate interrelations between the context of equipment trajectories, equipment trajectories themselves, and actions of equipment operators, which in a way link the context and the trajectories. Without structuring these interrelations the possibility to develop such VEs is hindered. Secondly, an adequate organization scheme of a VE consisting of components to acquire, process, and represent both actual and simulated data has not been suggested. Since these two challenges are closely interrelated, both should be dealt with simultaneously in the development of these VEs.

This research contributes to the development of such VEs by suggesting a method that provides a basis for future research and discussions. We investigate how to develop specialized interactive simulation visualization environments for compaction tasks (such as soil, asphalt, and waste compaction) as a particular type of construction activity. For this purpose, the paper presents: (1) a framework to assist structuring interrelations between equipment trajectories and their context; and (2) an organization scheme, which advises how a specialized environment can be arranged according to the framework's concepts. The framework suggests disentangling intricate links between context, operator's actions, and outcomes of these actions. Then, the framework's concepts and their interrelations guide the organization of a specialized visualization environment.

To illustrate the proposed method we operationalized it for the case of the asphalt compaction process. The operationalized method guided the development of a corresponding VE, which was tested during two sessions. The tests investigated if the developed VE can be used to review actual roller trajectories as well as support experimentation with alternative trajectories within the context reconstructed from the documented sensor readings.

To provide the background of this research, the next section briefly reviews visualization environments focused on VEs developed for the needs of the construction domain. Afterwards, a method to organize VEs with the combined functionalities for compaction activities is suggested. Then, the paper describes how this method can be applied for the case of asphalt compaction. Finally, this paper portrays the details of the VE developed according to the operationalized methods, describes two test sessions conducted with the involvement of practitioners, and finishes with discussions and conclusions.

2. Background

Numerous VEs were recently developed in a number of domains, including medical technologies (see, for instance a review by Vapenstad and Buzink [58]), aerospace (e.g. [5]), virtual manufacturing [34,14,41], and construction [7,9,23,69]. This section briefly overviews VEs from several domains, including those related to construction processes. The section points out why it remains difficult and how it can be beneficial to bridge the gap in representing sensed data and modeling alternative processes.

2.1. Examples of VEs from different domains

Although VEs can effectively support a number of diverse tasks in different domains, one can notice that aligning simulations to specific real world cases remains a common challenge. For instance, this can be observed in the medical domain. Even though multiple VEs were designed to support their users in simulating surgery activities, the question of reconstructing specific cases received much less attention. Functionality of patient-specific rehearsal, also known as mission rehearsal, is present only in a relatively small amount of environments [58]. The task of reconstructing a specific surgery process conducted in reality appears to be even more challenging. First, it requires collecting relevant contextual information about the process. Second, it demands investing significant efforts in reconstructing the process.

The same hampers reconstructing real-world events and processes in the aerospace domain. Even though flight recorders can provide an abundant amount of context data, only initial steps were made to fill in-flight simulators with data collected in the real-world. One example of such an attempt is described in Aragon and Hearst [5], where a helicopter flight simulator with accurate aerodynamic models was provided with actual airflow data from shipboard flight tests. Still, the task of reconstructing real-world trajectories of planes and helicopters in context appears to be a formidable modeling challenge. This can be partially explained in that significant efforts are needed to reconstruct airplane trajectories and their context on a scale that matches an airplane behavior model.

Similarly to the aerospace domain, the topic of generating simulations based on trajectories in the field of virtual manufacturing received attention only recently [64].

Altogether, these examples indicate that even for relatively 'enclosed' manufacturing and highly critical medical and aerospace domains, the topic of reconstructing specific trajectories in context has received only limited attention. It appears that the difficulty to track and relate sensed data to available models is the major challenge. In other words, the modeling task should account for the same type and level of context details, as the data collected in the field. This challenge is particularly relevant for the construction domain, because construction processes are often unique, less structured, and highly depend on decisions made by the field personnel. The next subsection illustrates this in more detail.

2.2. Construction-specific VEs

In the construction domain it is acknowledged that the development and utilization of specialized VEs is one of the promising