The importance of vision-based technologies for progress monitoring and productivity assessment of earthmoving operations

Prethodno priopćenje/ Preliminary communication
Primljen/Received: 5. 5. 2018.;
Prihvaćen/Accepted: 1. 6. 2018.

Martina Šopić, M.Eng.C.E.
University of Rijeka, Faculty of Civil Engineering
Mladen Vukomanović, Ph.D.
University of Zagreb, Faculty of Civil Engineering
Diana Car-Pušić, Ph.D.
University of Rijeka, Faculty of Civil Engineering

Abstract: Monitoring the progress of earthmoving operations while accurately estimating productivity of construction equipment provides a detailed insight into the performance, early detection of low productivity, as well as any other possible defects. It also provides feedback on the correctness of the decisions made and a more accurate report of the time and cost necessary for the activity. Early detection and warning of all the risky, unfavorable actions provides opportunities to timely take appropriate corrective measures and make improvements. Wireless technologies offer considerable potential for application in order to monitor work progress and evaluate productivity. However, the previous studies indicate shortcomings and limitations. Future research attention on their considerable potential is needed. The integration of various wireless technologies is a possible solution to the problem and complexity of monitoring work progress and productivity estimates. In this matter, vision-based technologies are an indispensable field of wireless technologies for the development of an appropriate, reliable, credible, fast and cost-effective methodology of monitoring the progress of earthmoving works with accurate estimation of the productivity of construction machines.

Key words: vision-based technologies, progress, productivity, earthmoving

Značaj vizualnih tehnologija za praćenje progresa i procjene produktivnosti zemljanih radova

Sažetak: Praćenje progresa izvedbe zemljanih radova uz točnu procjenu produktivnosti građevinskih strojeva omogućuje detaljan uvid u tijek izvedbe, ranu detekciju slabe produktivnosti, kao i svih ostalih mogućih nedostataka, povratnu informaciju ispravnosti donesnih odluka te precizniji iskaz potrebnog vremena i troška aktivnosti. Ranim uočavanjem, i alarmiranjem, svih rizičnih, nepovoljnih radnji, pružene su mogućnosti za pravodobno poduzimanje odgovarajućih, korektivnih mjera i provedbu poboljšanja. Bežične tehnologije pružaju znatan potencijal za primjenu u svrhu praćenja progresa rada i procjene produktivnosti. Međutim, dosadašnja istraživanja ukazuju na nedostatke i ograničenja. Potrebna su daljnja istraživanja njihovih velikih potencijala, a moguće rješenje problematike i kompleksnosti u praćenju progresa rada i procjene produktivnosti predstavlja integracija različitih bežičnih tehnologija. Vizualne tehnologije su, pritom, neizostavno područje bežičnih tehnologija za razvoj odgovarajuće, pouzdane, vjerodostojne, brze i ekonomične metodologije za praćenje progresa izvedbe zemljanih radova uz točnu procjenu produktivnosti građevinskih strojeva.

Ključne riječi: vizualne tehnologije, progres, produktivnost, zemljani radovi

1. INTRODUCTION

Monitoring the progress of earthmoving operations while accurately estimating productivity of construction equipment provides a detailed insight into the performance, early detection of low productivity, as well as any other possible defects. It also provides feedback on the correctness of the decisions made and a more accurate report of the time and cost necessary for the activity. Early detection and warning of all the risky, unfavorable actions provides opportunities to timely take appropriate corrective measures and make improvements.
Manual on-site data collection and analysis based on personal experience are outdated, time-consuming and insufficiently accurate methods. For this reason, there is a particularly pronounced need for cost-effective, reliable and automated methods capable of supporting and covering the entire process of measuring, evaluating, monitoring and controlling the execution of works on construction site, applicable to various construction projects. (Golparvar-Fard *et al*., 2013). Application and development of automation has a marked efficiency, as it contributes to greater productivity, leads to reduced possibility of errors, allows easier operation and at the same time ensures that the construction project is more likely to be completed on time and within the planned budget, with high-quality performance (Tajeen and Zhu, 2014).
Wireless technologies provide significant potential for applying automation for the purpose of monitoring the progress of operations and estimating productivity. However, the current research indicates numerous disadvantages and limitations. Vision-based technologies are one of the examples of wireless technologies that have the possibility of recording and visually reproducing the actual environment in recording time, in the form of digital photos or videos.
Many research efforts so far have been related to monitoring the progress and estimating the productivity of performance on construction site, with support of digital photos or video recordings, in order to develop a reliable method for simultaneously monitoring multiple resources and creating daily reports of the course of past activities. (Bügler *et al*., 2017). Also, when monitoring performance of earthmoving operations, vision-based technologies represent relatively new methods with significant potential, especially because of the very characteristics of earthmoving works, to provide a clear, wide view and quickly identify resources (Rezazadeh Azar *et al*., 2013).
Advantages of vision-based technologies are reflected in the fact that they represent one of the most cost-efficient methods to automate monitoring of performance progress (Teizer, 2015), and compared to other resource-tracking wireless technologies, like sensing technologies, satellite radio navigation system for determining the current location (*Global Positioning System*, GPS), the technology that establishes communication between distinctive devices through radio waves (*Radio Frequency IDentification*, RFID), etc., their advantage is simpler implementation (Memarzadeh *et al*., 2013; Yang *et al*., 2015) as well as visual reproduction of the real, true view of the progress of on-site operations, in recording time.
Disadvantages of vision-based technologies are reduced visibility and data accuracy in bad weather conditions such as rain, snow, strong wind, fog, as well as in poor natural or artificial lighting conditions. In addition, during the progress of works, overlapping of resources may also occur in view when recording, which can also cause inaccurate data generation. Therefore, it is necessary to be particularly careful with selection of the recording spot. Investing in higher-performance equipment can mitigate the impact of poor weather conditions to some extent. However, construction work itself is usually stopped during exceptionally bad weather conditions (Teizer, 2015).
Despite significant progress in application of vision-based technologies during construction, numerous further studies are still required because the past development of vision-based

technologies points to their limited use and a large number of necessary manual operations (Rezazadeh Azar *et al*., 2013).

The paper by Šopić and Vukomanović (2017) emphasizes the potential of wireless technologies for viewing real conditions on construction site, accurate tracking of movement and operation of construction machines without disturbing their normal operation, higher productivity, quick and accurate processing of large amounts of data from construction site, considerably reduced influence of human factor and human error and eventually their potential for successful and high-quality completion of construction projects. In terms of shortcomings and limitations of each individual wireless technology, it also emphasizes the great importance of and need for integration of wireless technologies, which would make it possible to successfully overcome the inability to solve a particular problem using a single wireless technology by applying other wireless technologies.

In this matter, vision-based technologies are an indispensable field of wireless technologies for the development of an appropriate, reliable, credible, fast and cost-effective methodology for monitoring the progress of earthmoving works with accurate estimation of the productivity of construction machines.

In this connection, the research of Bügler *et al*. (2017) with application of vision-based technologies, more precisely combination of photogrammetry and video analysis, is described below as an example of promising proposal for integration with other wireless technologies, especially with RFID and GPS technologies, as well as advanced digital cartography (*Geographic Information System*, GIS), mobile communication systems (*Global System for Mobile communications*, GSM), with an analysis of advanced measuring systems and software solutions of the companies *Caterpillar, Komatsu, Trimble, Leica Geosystems, Topcon* etc. Also, the most recent research for monitoring operation of a construction machine, by Yuan *et al*., (2016) and Zhu *et al*. (2016), are also mentioned in order to present other current trends in the development of vision-based technologies.

2. VISION-BASED TECHNOLOGIES

2.1 Photogrammetry and video analysis

Photogrammetry is the science, technique and art of defining the form, contour, shape, spatial position, meanings, size, structure, as well as the possibility of obtaining information on changes within a certain time period, of an observed physical object, by the process of recording, measuring and interpreting photographic images, recorded using special calibrated photographic cameras. Considering the position of photographic cameras, we distinguish between aerial and terrestrial photogrammetry. Aerial photogrammetry means taking photographs of objects from the air through cameras mounted on an aircraft, while terrestrial photogrammetry means taking photographs of objects from the ground. The coverage of a photograph taken by aerial photogrammetry is much larger than the coverage of a photograph taken by terrestrial photogrammetry. Photogrammetry has a wide application. Its application in geodesy and engineering, as well as in archeology, geography, geology, culture, architecture and more recently in medicine and industry is particularly important.

Bügler *et al*. (2017) presented a methodology for monitoring the progress and estimating the productivity of earthmoving operations by using two different individual vision-based technologies, more precisely by combining photogrammetry and video analysis. The advantage of using photogrammetry is the accurate information on the volume of material excavated and removed or transported from the construction site (Figure 1), while the advantage of using video analysis is the visual reproduction of the real, true view of work progress and interaction of machines on the construction site in recording time. According to Bügler *et al*. (2017), combination of these two vision-based technologies results in a powerful

tool for monitoring progress and evaluating productivity of earthmoving work in short time intervals.
Thus, using photographic images, photogrammetry can create a 3D view of the construction site space and quantify the volume of excavated material. For this purpose, the associated photogrammetry algorithms first need to locate characteristic points on individual photographic images. Characteristic points of individual photographic images should then be matched. It is necessary to have at least three photographic images with characteristic points, which are used by associated photogrammetry algorithms, after locating and matching, for linking and creating a 3D view of construction site space. Generally, characteristic points form a 3D point cloud, and using photogrammetry algorithms it is also possible to add information or obtain more detailed surface views.

Figure 1. Overview of photogrammetry application (taken over: Bügler *et al*., 2017)

The application of video analysis in Bügler *et al*. (2017) includes installation of a video camera at the required viewpoint height, so that the installed video camera could cover the operation of excavators and dump trucks at the construction site, and processing of video segments. Bügler *et al*. (2017) used and improved the Ogunmakin *et al*. (2013) model to process segments of video recordings.
Processing of recorded video segments (Figure 2) includes construction site background modeling, detection of machines appearing in the analyzed segment, tracking operation of the detected machines and defining all activities that take place within the recorded segment. Using the data obtained in this way and entering them into the event detection processor, the processor can generate data such as average duration of registered activities, standard deviations of average durations of registered activities, information on the number of machines appearing in the recorded segment, information on the number of loaded excavator buckets filling the dump truck box etc. Video analysis processing can indicate a deviation from usual or expected performance values and in these cases it is necessary to establish the reasons of poor performance.
The output data of the event detection processor that Bügler *et al*. (2017) collected for their research were the number of dump trucks that entered the construction site, time spent by dump trucks on the construction site, dump truck box loading time, the number of excavator buckets loaded in each of the dump truck boxes and machine idling time on the construction site without any activities. Activities of the machines on the construction site were grouped in the stages of absence of the machine from the construction site, machine idling on the construction site (i.e. static), machine moving, and loading (i.e. filling) (Figure 3).

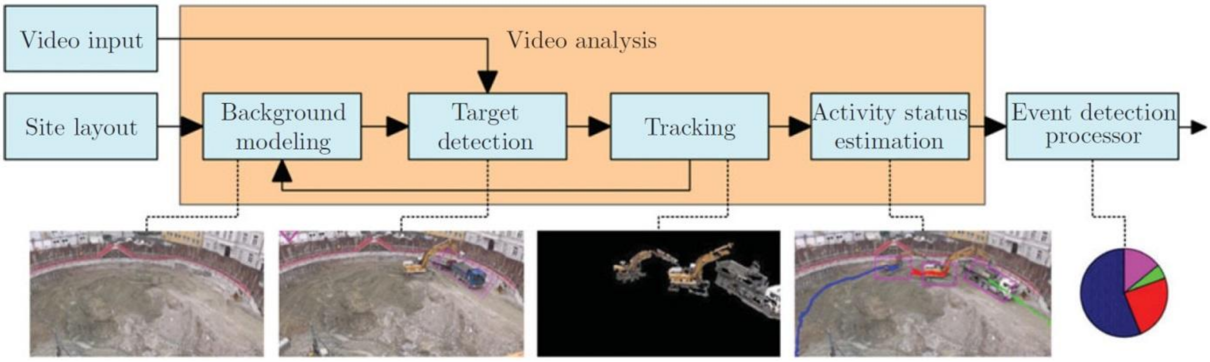

Figure 2. Overview of video analysis application (taken over: Bügler *et al*., 2017)

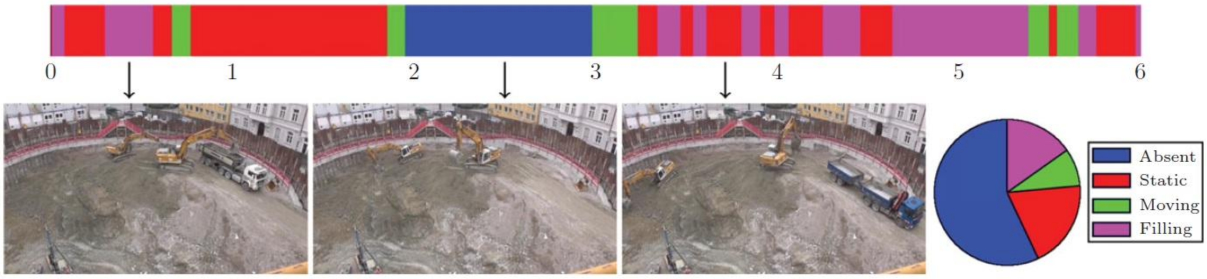

Figure 3. An example of dump truck activities in a video segment of 6 minutes duration (taken over: Bügler *et al*., 2017)

2.1.1 Progress monitoring and productivity estimation

Productivity of earthmoving operations can be expressed in different ways by the rate of excavation, removal, filling, leveling, compacting, etc. quantities performed in a certain period of time, like measuring the volume of excavated material in a time period, by the number of loaded dump truck boxes in a time period, by measuring the cycle time of a machine of a certain volume of bucket or box etc.

Bügler *et al*. (2017), wanted to monitor the progress of performance and productivity of earthmoving works through the volume of material excavated and removed from the construction site during one hour, but also for shorter periods of time. In their example, the productivity measure of earthmoving operations was increasing proportionately with greater amounts of excavation and loading, as well as removal of the excavated material to the dump site, performed in a high-quality manner in the shortest possible time, with minimum stages of machines idling on the construction site.

Because of the complexities in performance of earthmoving operations, photogrammetry can be used to observe and measure more significant progress in excavation and removal of material, roughly to present at shortest total daily volumes of material excavated and removed from the construction site. Daily excavation and removal progress reports cannot provide a detailed, deeper insight into the course of performance, and possible poor performance is registered late. It is for this reason that the advantages of using video analysis are particularly manifested, in addition to photogrammetry. Video analysis, in contrast, can calculate productivity in one hour as well as a shorter period of time, for example by measuring the total number of loaded excavator buckets within the measured time using the factory-specified bucket volume.

For the sake of simplicity and for adjustment of the two individual vision-based technologies, Bügler *et al*. (2017) assume that the same productivity measure would be obtained by separately using photogrammetry and video analysis. Also, the volume of material held by the excavator bucket may be different from the factory-specified excavator bucket volume depending on soil categories. For overcoming the bucket volume limitation, as well as for convenience, adjustment and simplicity of application, in combination of the two individual vision-based technologies, the volume of excavator bucket was estimated by dividing the total volume of material daily excavated and removed from the site, using photogrammetry, with the total number of excavator buckets daily loaded in dump truck boxes, registered using video analysis. An estimated value of the excavator bucket volume was obtained in this way. For a certain period of time, productivity of performance in that time period can be expressed by the number of loaded buckets using the resulting bucket volume. Both low productivity and excellent productivity can be detected with productivity values in short time intervals, such as one hour, but also shorter, and insight into the reasons and causes of a certain productivity can be obtained by processing the video recording and analyzing it. Being aware of the progress and productivity, it is possible to track the advancement and dynamics of performance, more accurately calculate the time and cost of activities, but also to timely detect unacceptable, risky and unfavorable actions, which is of particular importance in order to timely take appropriate corrective measures.

2.1.2 Advantages and disadvantages

Bügler *et al*. (2017) applied their progress monitoring and productivity evaluation methodology to two major construction projects. One was construction of a car parking garage and the other was an extension of a hospital. Massive quantities of material excavation with removal were present in both construction projects.
Application of photogrammetry and video analysis to the construction projects emphasized shortcomings of the methodology. Poor weather conditions like rain, snow, strong wind, or low natural or artificial lighting conditions may degrade the quality of photographic images and reduce the accuracy in creating 3D views of construction site space. The impact of poor weather conditions on the quality of photographic images can be mitigated to some extent by investing in higher-performance equipment. In addition, if a video camera is improperly mounted, overlapping of resources can occur in video display, which can also cause inaccurate data generation.
The benefits of photogrammetry and video analysis are in obtaining a detailed insight into the progress of works, which results in better decision making, greater probability of optimal machine allocation, and achievement of project savings. Also, long-term application of photogrammetry and video analysis would make it possible to create a database with valuable information for future similar projects. Bügler *et al*. (2017) emphasized simplicity and cost-effectiveness of photogrammetry and video analysis, as well as their application without interfering with machines at work. They particularly emphasized the significance of their application for the purpose of developing valuable support for management of construction projects and better control and greater efficiency in execution of works. According to Bügler *et al*. (2017), further research would include mounting more video cameras and processing a combination of video recordings in order to reduce the possibility of inaccurate data generations caused by overlapping resources in video display.

2.2 Stereo camera and triangulation

Yuan *et al*. (2016) presented a study for further research for the purpose of recognizing a construction machine, locating it and tracking its dynamic, movable and fast operation during the execution of works. They applied their research to the operation of an excavator (Figure 4). The backbone of their study is to show the operation of a construction machine,

especially its kinematic articulated tools, by using stereo cameras, 2D tracking algorithm, and triangulation algorithm for 3D tracking. Stereo camera is a camera that has two or more lenses with separate sensor systems on each lens, thus achieving the possibility of 3D viewing. Triangulation is a method of determining positions of certain main points (i.e. key nodes), in this study of the excavator arm (i.e. boom and stick) and bucket, using known lengths and measures of all three angles accompanying it.
Yuan *et al*. (2016) emphasized that further research would be conducted with the purpose of installing more video cameras in order to reduce the possibility of inaccurate motion detection caused by overlapping resources in video display, as well as decreasing geometric uncertainty for long-distance views.

Figure 4. An example of tracking the arm (i.e. boom and stick) and bucket of an excavator (taken over and cropped up: Yuan *et al*., 2016)

According to Yuan *et al*. (2016), implementation of their study would contribute to automation and development of the methods using wireless technologies, such as *Automated Machine Guidance* (AMG), *Automated Machine Control* (AMC), for progress monitoring and productivity estimation, but also for increasing construction site safety and improving productivity. AMG and AMC are systems that use wireless sensing technologies, like GPS, with increased precision (*Real-Time Kinematic*, RTK GPS), various sensors, lasers and the like, to provide accurate information on the position of the machine tool, in order to perform work operations faster, better and safer, while reducing the possibility of errors.

2.3 Particle filtering technique

Zhu *et al*. (2016) developed a method for visual tracking of resources on construction site using the particle filtering technique. Their method involves installation of a *High Definition* (HD) video camera and recording of activities on construction site. When using the particle filtering technique, to analyze a video recording, the resource that needs to be tracked, usually a construction machine or worker, should be manually enclosed by a rectangle. Hundreds of tiny particles are generated in the marked rectangle, or on the tracked resource. The rectangle (or filter) with particles follows and tracks movements of the resource.
Zhu *et al*. (2016) emphasized that monitoring of resources on construction site is of exceptional importance for a detailed insight into the course of operations, thus making it possible to detect defects and risks. In their research, they devoted the greatest attention to solving the problem of tracking when the resource passes behind an object, because it results in overlapping in video display and possible incorrect data generation (Figure 5).

Figure 5. An example of tracking an off-road articulated dump truck (taken over and cropped up: Zhu *et al*., 2016)

The advantage of particle filtering technique is the ability to continuously track a resource, even if it is behind a certain object, but it must not completely covered by it. However, if the tracked resource is found behind or within an on-site object that is of such a size as to completely occlude the tracked resource, the connection of the resource with the rectangle with particles is lost and the resource tracking is paused until the resource is again visible on the video recording. The biggest disadvantage of their method is the ability to track only one resource. That is why further research and modifications are necessary in order to be able to simultaneously track multiple objects.

3. RESEARCH SUGGESTION AND CONCLUSION

As a possible solution to the problem and complexity of monitoring the progress of earthmoving works and accurate estimation of productivity of construction machines, the paper Šopić and Vukomanović (2017) presented integration of different wireless technologies. In particular it considered the solution of integration of RFID technology with other wireless technologies, like GPS and GIS technologies, the fast-growing communication GSM technology, with analysis of advanced measurement systems and software solutions of the companies *Caterpillar, Komatsu, Trimble, Leica Geosystems, Topcon* and others.
RFID technology proved to be a successful and simple method for measuring the actual productivity of dump trucks and scrapers (Montaser and Moselhi, 2012 and 2013), as well as for monitoring positions of construction machines in order to prevent collisions, achieve good layout and protect lives of people on construction site (Lu *et al*., 2011, Teizer *et al*., 2010, Karthik *et al*., 2014). The combination of GPS and GIS technologies also proved to be a successful and simple method for estimating the actual productivity of transportation assets, as well as for predicting the necessary time and cost resulting from the operations of transportation assets (Alshibani and Moselhi, 2016).
Vision-based technologies have the ability to record and visually reproduce the actual view on construction site, which makes it possible to easier track the resource and show its interaction with other resources and objects.
The combination of photogrammetry and video analysis proved to be a powerful tool for monitoring progress and estimating productivity of earthmoving operations in short time intervals. Both low productivity and excellent productivity can be timely detected with productivity values in short time intervals, and their reasons and causes examined by processing the video recording and analyzing it.
In their application, vision-based technologies provide a valuable contribution because, in relation to other wireless technologies, they are the only ones that can show the real, true view of a complex, dynamic and unique environment prevailing on a construction site. They are also an indispensable step towards development of an appropriate, reliable, credible, fast, and cost-effective methodology for monitoring the progress of earthmoving operations

with accurate estimation of productivity of construction machines. Integration of different wireless technologies with sensing, visual and communication possibilities is especially important in this connection.

In the integration of wireless technologies, the combination of photogrammetry and video analysis would provide a contribution in performance of earthmoving operations, especially for massive quantities of excavation and removal, typical of building construction works. In the integration of wireless technologies, photogrammetry and video analysis would be used to present progress and productivity of earthmoving works, especially for coordination between excavators and dump trucks during excavation and loading of the material from excavation, while RFID and/or GPS and GIS technologies would be used to measure the productivity of dump trucks.

With an insight into the progress and productivity, it is possible to track the advancement and dynamics of performance, more accurately calculate the time and cost of activities, but also to timely detect unacceptable, risky and unfavorable actions, which is of particular importance for taking appropriate timely corrective measures.

Wireless technologies offer considerable potential for application in order to monitor work progress and evaluate productivity. However, the previous studies indicate shortcomings and limitations. The literature also points to the modest contribution to research using integration of wireless technologies, especially for tracking progress of earthmoving works and estimating productivity of construction equipment. Further research of the great potentials of wireless technologies is needed, above all in their integration.

REFERENCES

1. Golparvar-Fard M., Heydarian A. and Niebles J.C.: *Vision-based action recognition of earthmoving equipment using spatio-temporal features and support vector machine classifiers*, Advanced Engineering Informatics, 2013, 27(4), 652–663.
2. Tajeen H. and Zhu Z.: *Image dataset development for measuring construction equipment recognition performance*, Automation in Construction, 2014, 48, 1–10.
3. Rezazadeh Azar E., Dickinson S. and McCabe B.: *Server-Customer Interaction Tracker: Computer Vision–Based System to Estimate Dirt-Loading Cycles*, Journal of Construction Engineering and Management, 2013, 139(7), 785–794.
4. Bügler M., Borrmann A., Ogunmakin G., Vela P. A. and Teizer J.: *Fusion of Photogrammetry and Video Analysis for Productivity Assessment of Earthwork Processes*, Computer-Aided Civil and Infrastructure Engineering, 2017, 32(2), 107-123.
5. Teizer J.: *Status quo and open challenges in vision-based sensing and tracking of temporary resources on infrastructure construction sites*, Advanced Engineering Informatics, 2015, 29(2), 225-238.
6. Memarzadeh M., Golparvar-Fard M. and Niebles J. C.: *Automated 2D detection of construction equipment and workers from site video streams using histograms of oriented gradients and colors*. Automation in Construction, 2013, 32, 24–37.
7. Yang J., Park M. W., Vela P. A. and Golparvar-Fard M.: *Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future*, Advanced Engineering Informatics, 2015, 29(2), 211-224.
8. Šopić, M., Vukomanović, M.: *Praćenje i kontrola produktivnosti građevinske mehanizacije integracijom bežičnih tehnologija*, 3. Simpozij doktorskog studija građevinarstva, Sveučilište u Zagrebu, Građevinski fakultet, (en. *Tracking and control of the productivity of construction machinery by integrating wireless technologies*, 3rd Symposium of doctoral study in civil engineering, University of Zagreb, Faculty of Civil Engineering), 2017, 95-104.
9. Ogunmakin, G., Teizer, J. & Vela, P.: *Quantifying interactions amongst construction site machines*, in Proceedings of the EG-ICE Workshop on Intelligent Computing in Engineering, Vienna, Austria, 2013.

10. Yuan C., Li S. and Cai H.: *Vision-Based Excavator Detection and Tracking Using Hybrid Kinematic Shapes and Key Nodes*, Journal of Computing in Civil Engineering, 2016, 31(1), 04016038.
11. Zhu Z., Ren X. and Chen Z.: *Visual Tracking of Construction Jobsite Workforce and Equipment with Particle Filtering*, Journal of Computing in Civil Engineering, 2016, 30(6), 04016023.
12. Montaser A., Moselhi O.: *RFID+ for Tracking Earthmoving Operations*, Construction Research Congress 2012: Construction Challenges in a Flat World, West Lafayette, Indiana, pp. 1011-1020, 2012.
13. Montaser A., Moselhi O.: *Tracking Scraper-Pusher Fleet Operations Using Wireless Technologies*, 4th Construction Specialty Conference, Montreal, Quebec, 2013.
14. Lu W., Huang G. Q., Li H.: *Scenarios for applying RFID technology in construction project management*, Automation in Construction, 2011, 20(2), 101-106.
15. Teizer J., Allread B. S., Fullerton C. E., Hinze, J.: *Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system*, Automation in Construction, 2010, 19(5), 630-640.
16. Karthik G., Jayanthu S., Rammohan P., Rahman A.: *Utilisation of mobile communication in opencast mines*, International Journal of Computer Science and Mobile Computing, 2014, 3(7), 373-378.
17. Alshibani A., Moselhi O.: *Productivity based method for forecasting cost & time of earthmoving operations using sampling GPS data*, Journal of Information Technology in Construction (ITcon), 2016, 21(3), 39-56.