



A VISION-BASED EXCAVATOR PRODUCTIVITY ANALYSIS IN VIETNAM

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Abstract. The process of determining the working parameters of reverse bucket excavators is mainly consulted through the Ministry of Construction norm. However, in the era of industrialization and modernization, machine and equipment are increasingly modern and innovative, making the determination of excavator productivity or parameters through the regulations in the old norms unsuitable. Furthermore, updating the norms through data collected in the field take tremendous amount of time and procedures as it is labor intensive. Therefore, this paper proposes a vision-based analysis in calculating excavator productivity using image processing applications and coding language to automatically determine the excavator productivity and bring results on the basis of analysing big data collected from validated construction sites. To be specific, this paper introduces a new method in calculating the excavator productivity by extracting crucial coefficients from hundred images of the excavators using an open-source software, then compare with the traditional method to identify and analyse the importance of this new method and the practical use it might bring to the construction industry.

Keywords: excavator, productivity analysis, technology, video interpretation, visual tracking, visual basic application

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1. INTRODUCTION

Excavators can be seen as a key construction machine for most of construction projects because they are involved in various earthworks. Therefore, an accurate calculation of excavator productivity is essential for controlling the cost of the project [1,2]. In developing

countries, the productivity of construction machines is mainly calculated based on the Ministry of Construction (MOC)'s regulated norms. However, in the era of industrialization and modernization, machines are significantly updated with modern and innovative technologies, making the traditional method of determination of excavator productivity and/or its parameters (i.e, the MOC's regulated norms) is not suitable. In addition, the traditional method requires frequent updates. These updates are time-consuming and labor intensive as they require multiple procedures and researches to change, which could take several years [1]. For that reason, an automatic method is urgently needed for developing countries. The automaticity is expected to accurately and efficiently analyze the excavator productivity by tracking its activities [1,3-6].

The literature review showed that there are several existing methods for automatically analysing the productivity of construction equipment through recognising the pattern and activities using computer vision-based videos [3,7-10]. Generally, these methods propose a solution to extract information from construction operation videos using advanced tools and/or equipments. It should be noted that the mentioned advanced equipments are costly, thus being unavailable for developing countries [11]. Moreover, vision-based computation methods usually require multiple licensed programs and/or paid vision tracking programs [3,7-9]. The cost for program license/update is considerably expensive in developing countries [12-14].

A notable approach for analysing construction machine activities is to use sensors attached to the machine. Several implementations of this approach include global positioning system (GPS), radio frequency identification (RFID) and ultra wideband (UWB) [15-19]. Data collected from these methods are accurate and insightful for machine studies [15]. However, these sensor-based tracking methods require constant monitoring, thus they are not suitable for developing countries since most projects in the countries have small and medium-scale and are usually adhere with low-tech machines. In addition, calculating equipment productivity requires precisely categorizing activities, which proved to be problematic for sensors since they cannot identify the activity accurately within the same position [1].

In sum, all the mentioned methods have been focusing on utilizing plentiful amount of resources and equipment on developed countries [20-22]. However, applying the same ideas into developing countries are an immense challenge for the construction industry, as they do not have access to advanced technology [11]. Therefore, it is unclear how these methods are applicable for the construction projects in developing countries.

In a notion of the above problems, this study proposes a vision-based interpretation method that extracts excavator productivity information from construction operations video. Notably, it synthesizes and analyses those data automatically using free and accessible programs. Under the framework of the proposed method, excavator productivity can be calculated in a more efficient way without any concern of high labor cost. Noted that all the activities involving monitoring within the site can be achieved using construction site cameras. The feasibility of the proposed method is tested and validated for real construction sites using collected construction surveillance videos. The rest of the paper is organized as follows. Section 2 describes the research framework. Section 3 shows the methodology of the paper. An empirical case study is presented in section 4 with video samples collected in various construction sites. Finally, section 5 wrap-ups findings of this study.

2. RESEARCH FRAMEWORK

To calculate the excavator productivity from construction site videos, this paper proposes the methodology shown in Figure 1.

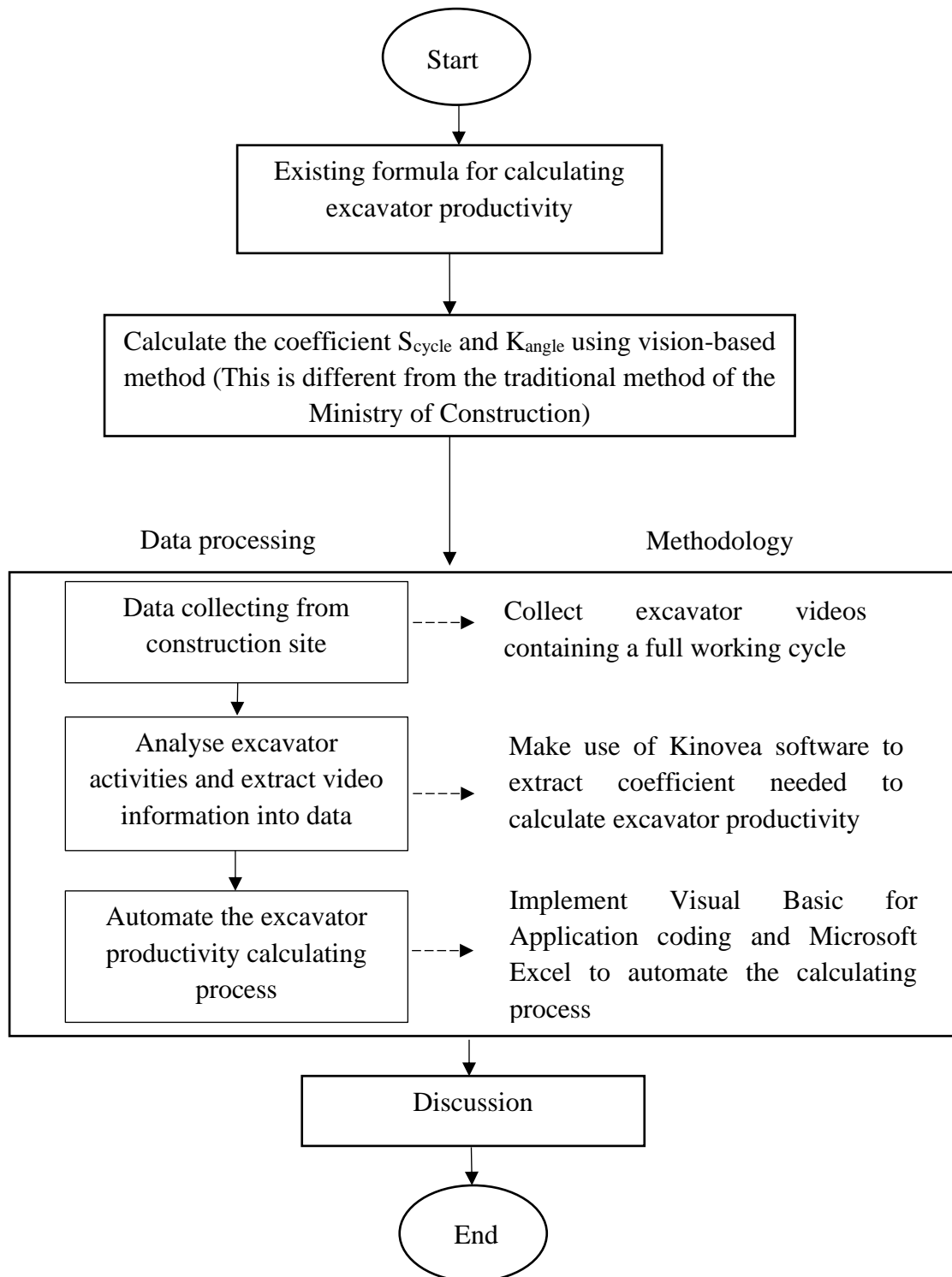


Figure 1. Research framework.

For this method, the norms published by the Ministry of Construction is shown to analyse the differences between the paper method and the norms. In data processing steps, construction videos are collected from various construction sites capturing different type of excavators. Afterwards, a free and open source program, specifically Kinovea, is used to analyse excavator activities, and extract those movement into useful information for calculating productivity. Finally, the amount of data collected is computerized to calculate the excavator productivity automatically using Microsoft Excel® and Visual Basic for Applications (VBA) programming language.

3. METHODOLOGY

3.1. Proposed method for excavator productivity calibration

Over the past decade, to calculate the excavator productivity, Vietnam has been following the regulations in the norms issued by the Ministry of Construction, which can be seen in the Eq. (1):

$$\text{Productivity} = (8 * (S_{\text{cycle}} * K_{\text{angle}} * K_{\text{time}})) * (V_b * K_{\text{fb}}) \quad (1)$$

Where S_{cycle} is the number of standard cycles (dig-load) per working hour, K_{angle} is the coefficient considering the effect of actual digging depth combined with the camera rotation angle from the excavation to the dumping site, K_{time} is the coefficient of time usage (coefficient of work efficiency), V_b is the capacity of the bucket (m^3), and K_{fb} is the coefficient of filled bucket [23,24]. These coefficients have been validated by data analysing and measuring in various experiments from different construction sites, thus making them widely used in all construction projects within the country. Further study about data analysing can be seen in the work of H. Kim et. al. [2]. However, as discussed before, updating the norms through data analysing take tremendous amount of time and procedures as it is labor intensive, while the construction industry never stops evolving. In addition, the number of cycles per working hour (S_{cycle}) is affected by many aspects, including human factors such as machine handling experience by the worker, avoiding passing workers or changing truck positions. Therefore, using a computer vision based interpretation method can identify these problems effectively, as the whole process in analysing are solved using images and videos [1]. S_{cycle} and K_{angle} can be calculated using the Eq. (2):

$$S_{\text{cycle}} * K_{\text{angle}} = 3600/T_c \quad (2)$$

where T_c is the average duration of one working cycle of the excavator (second), with T_c being calculated over the average time of images and videos included in the study using Eq. (3):

$$T_c = \frac{T_{c_1} + T_{c_2} + T_{c_3} + \dots + T_{c_n}}{1 + 2 + 3 + \dots + n} \quad (3)$$

However, in the regulations, the bucket capacity is calculated in struck capacity, while the bucket's volume presented in the videos are heaped capacity, shown in Fig. 2 from SAE J296, an American standard [25]:

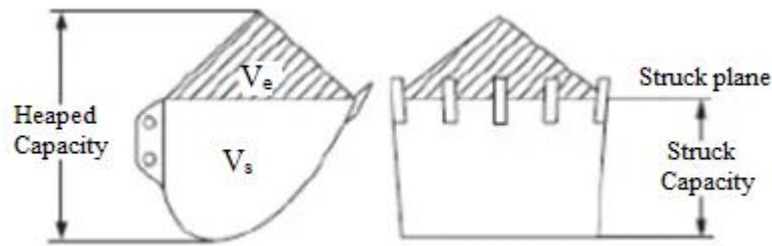


Figure 2. Bucket struck and heaped capacities.

Therefore, to compare between the norm and this research, the coefficient of filled bucket K_{fb} in Eq. (1) is considered. Following the SAE J296, Eq. (4) – (7) are used to calculate excavator heaped capacity [25]:

$$K_{fb} = \frac{V_h}{V_s} \cdot 100\% \quad (4)$$

Where, V_h is the heaped capacity and V_s is the struck capacity.

$$V_h = V_e + V_s \quad (5)$$

Where, V_e is the excess material capacity heaped at 1:1 angle of repose according to the america standard.

$$V_s = P_{Area} \left(\frac{W_f + W_r}{2} \right) \quad (6)$$

Where, P_{Area} is the side profile area of bucket, bounded by the inside contour and the strike plane of the bucket, W_f is the inside width front, measured at cutting edge or side protectors, W_r is the inside width rear, measured at narrowest part in the back of the bucket.

$$V_e = \left(\frac{L_B \cdot W_f^2}{4} - \frac{W_f^3}{12} \right) \quad (7)$$

Where, L_B is the bucket opening, measured from cutting edge to end of bucket base rear plate, as shown in Fig. 3. [25]

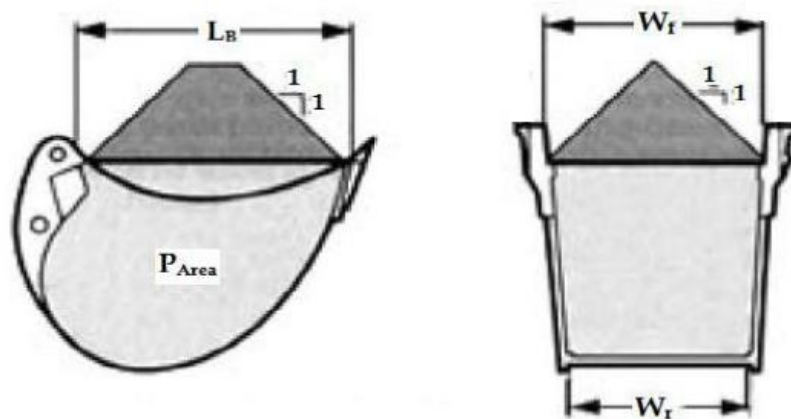


Figure 3. Bucket capacity rating according to SAE J296.

Further studies about excavator bucket capacity and angle of repose can be seen within chapter 7 of the SAE standard [25].

Therefore, the goal of this study is to determine T_c through video analysis, then calculate S_{cycle} and multiply with K_{fb} to demonstrate the differences between the two methods.

3.2. Data processing

3.2.1. Data collecting method

Firstly, the dataset of videos containing excavators are collected by manually capturing with digital camera in construction site, and by surveillance camera with clear and broad view from the internet. Each video contains a full or multiple cycles of digging, loading and swinging. The excavator type is divided by bucket capacity and the type of soil the same machine is working on, since the main propose of this method is to compare with the current norm, including the coefficient S_{cycle} and K_{angle} from Eq. (1).

To collect data efficiently, the excavators included in the study must be available in most developing countries, varying in characteristics, brand, bucket capacity and weight.

3.2.2. Video processing by using Kinovea software

Kinovea is a free, open source program which utilize in capturing, slowing down, studying, comparing, annotating and measuring technical performances [26,27]. Although the main purpose of this program is to analyse sport-related activities, with simple interface, it can measure angles, distances and times of any object, including machine. Furthermore, with the program being used mainly for sport, it can track high speed objects in optimum accuracy, at distances up to 5 meters [28]. Moreover, compared to other similar softwares, Kinovea is vastly superior in measuring kinematic parameters at multiple different angles.

The key reason for using Kinovea in this research rather than other construction-based programs is its easy accessibility to developing countries with a high level of accuracy, making it just as good, if not better than other softwares. Additionally, Kinovea has a built-in system to export video analysis into spreadsheet formats, for further process and scientific study.

To calculate excavator productivity, all the datasets collected before will be analysed using Kinovea. The whole process this paper presents can be separated into 5 steps. In the first step (1), a stopwatch has to be set in the video to calculate the amount of time required to finish a cycle in the video. The video is then required to run normally while starting the stopwatch, or by fast-forwarding the whole video to make the program automatically calculate a full cycle. For the next step (2), an angle between the excavator and the dumping truck is required, as it is fundamental in comparing with the current formula. Step (3) involves in using Line function in add-ons toolbar to measure the exact distance in pixels unit. For step (4), begin generating trackpath by right-clicking within the video frame, which can be made use of tracking the movement with exact coordinates every two frames. However, it is important to note that the

trackpath location must be visible throughout the video, as the program cannot track hidden or blocked objects. For the final step (5), all data analysed are generated into an extensible markup language (XML) format for further measuring by using ‘Export to spreadsheet’ within the File toolbar. The Kinovea graphical interface is shown in Fig. 4 with major elements labeled.

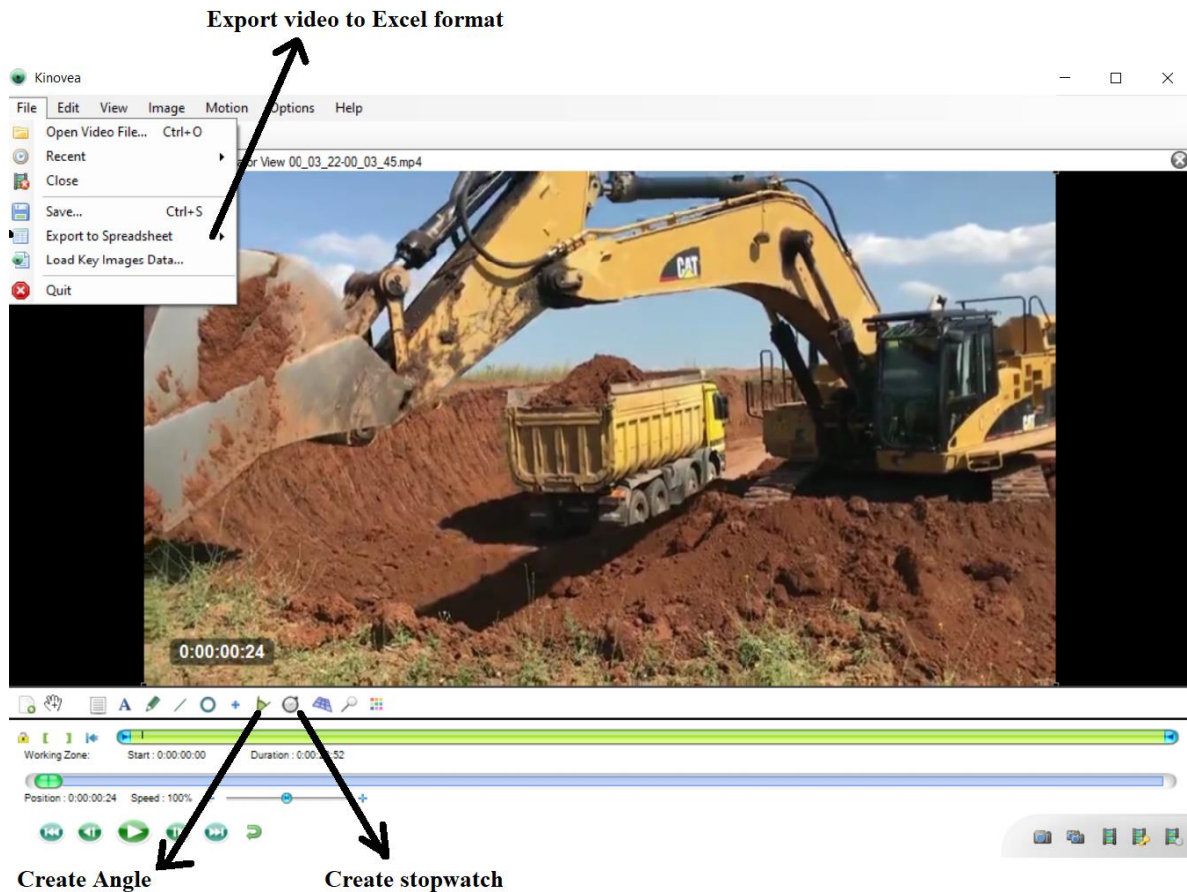


Figure 4. Software interface.

After exporting all said information into the spreadsheet, the software will generate the following datas: (1) the height between the vertical excavator position and the lowest ground position: H_{max} , (2) the height between the vertical digging position and the lowest ground position: H , (3) the coefficient of excavator rotation: Angle, (4) the average duration of one working cycle of the excavator: T_c .

For these data, (1), (2), (3) are the coefficients provided to calculate S_{cycle} and K_{angle} in Eq. (1), while data (4) is applied to calculate in Eq. (3), which is the core element of this research.

While Kinovea only offer semi-automatic functions, as most of the process are executed manually, all the steps can be executed within 25 to 35 seconds, based on the angle of the camera. Fig. 5 illustrates all the data shown within the program after various key steps finished.



Figure 5. The image data analysed using Kinovea.

3.2.3. Automate the calculation of excavator productivity using VBA

With the data exported into Microsoft Excel format, the file will then run in an automatic process using Visual Basic for Applications programming language (VBA) to collect data and calculate the necessary formula [29-33]. The exact line of codes is shown below to synthesize all the data into a summarize file for ease in calculating [30].

```

“
Sub Copy_all()
Dim FileToOpen As Variant
Dim OpenBook As Workbook
Dim path As String
path = "F:\File nguon Kinovea\Komatsu PC3000-6\Sheet"
' This is the path leading to Excel files generated by Kinovea
Dim file_name As String
Dim i As Integer
' i: the number of files required to synthesize
Dim WS As Worksheet
Set WS = Workbooks("Final.xlsx").Worksheets("Sheet5")
' The file format can be either .xlsx or .xml

```


For i = 1 To 12

file_name = path & Str(i) & ".xml"

Set OpenBook = Workbooks.Open(file_name)

WS.Cells(3 + i, 2) = OpenBook.Sheets(1).Range("B4").Value

' The line WS.Cells (3+i,2) means that all the files will be put respectively in column 2, row 3 + number of files (i)

OpenBook.Close

Next

End Sub

“

For this code to work, all the videos have to be analysed with angle, measuring line and the average duration of one working hour T_c , which can be achieved in step (1) – (4) in Kinovea process. By doing so, all the data exported will line up within the same cell for all the sheets, thus making synthesizing much more straightforward.

4. EMPIRICAL STUDY

4.1. Input

The total set of 126 videos were collected from 10 different construction sites, with 10 types of excavators to validate the research. The detailed information of the dataset is shown in Table 1.

Table 1. Statistics information of the dataset.

Excavator type with bucket capacity	Number of videos taken on soil type		Total number of videos	Number of excavators	Sources
	Soft soil	Medium soil			
Medium capacity (3,8-7,6 m ³)	76	17	93	7	Internet
Large capacity (≥7,6 m ³)	0	33	33	3	

10 types of excavators are considered in this study, shown in Fig. 6.



Figure 6. 10 types of excavators included in the study.

Table 2 calculates the coefficient K_{fb} using the Eq. (4) and (5) and the machine specifications, based on SAE standard.

Table 2. Calculating the heaped capacity for each machine in the study.

Excavators included in the study	Calculate the excess material capacity heaped V_e			Calculate the struck capacity V_s			The coefficient of filled bucket K_{fb} for video-based method
	L_B (mm)	W_f (mm)	V_e (m ³)	P_{Area} (mm ²)	W_r (mm)	V_s (m ³)	
	391	315	0.007	66836	305	0.0207	1.3

The coefficient K_{fb} from the norm will be approximately 1, as there is no heaped capacity from the standard, and the study mainly focuses around soft and medium soil.

4.2. Output

The results show that the time it takes to complete a full cycle for an excavator ranges from 20-30 seconds in soft soils, and 20-35 seconds in medium soils, depending on the capacity of the bucket, shown in Fig. 7.

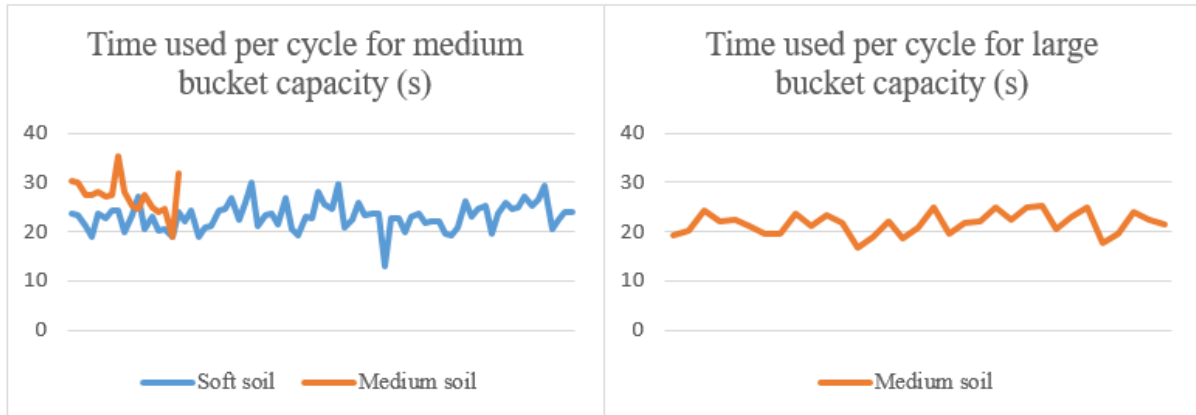


Figure 7. The time for excavator in different capacity to complete a full working cycle.

Since other coefficients in Eq. (1) aside from S_{cycle} and K_{fb} are the same within the two methods, this paper will only calculate the differences between those coefficients. Table 3 shows a comparison between video processing and current norms using Eq. (1), (2) and the results from Table 2.

Table 3. The results of comparison between video processing and the norm.

Excavator type with bucket capacity	S_{cycle} calculated through video processing (cycles/h)		The productivity through video processing (only factor S_{cycle} and K_{fb})		The productivity through current norm (only factor S_{cycle} and K_{fb})	
	Soft soil	Medium soil	Soft soil	Medium soil	Soft soil	Medium soil
Medium capacity (3,8-7,6 m ³)	155	132	201	172	198	176
Large capacity (≥7,6 m ³)	0	166	0	216	0	179

4.3. Discussion

In general, there is a clear variation in the number of excavation cycles within the large capacity section, calculated by analysing between video processing and the Ministry of Construction's norm. Although the results from medium capacity are approximately the same,

in large capacity, the number of cycles after multiplying with the coefficient are 20% greater than the norm. The reason is that actual machine performance varies from cycle to cycle, due to factors involved in the operator of the machine and the ability to control the machine. Another factor involves the bucket capacity, as the excavators from the video loads a higher volume than standard method. The digging time between each cycle also varies significantly when the analysis shows that the actual time measured in video processing is usually longer than the norm by 1 to 4 seconds depending on the situation.

5. CONCLUSION

By creating new paths in applying video to analyse, the excavator productivity can be determined with optimum accuracy. Furthermore, the study establishes an automated sequence to aggregate and analyse data without manually collecting and working, making the analysis of large amounts of data faster and more secure. Consequently, the application of this method into practice for excavators in general and construction machines in particular is completely feasible, saving a great deal of implementation and analysis costs compared to traditional methods.

However, substantial amount of data is required in order to demonstrate the distinctly different in calculating excavator productivity between two methods, while this study is limited in terms of video quantities. In addition, images must be captured clearly within the whole video, with a reasonable angle for analysing the entire construction site. The changes in capturing angle by the excavator rotation also greatly affect its ability to automate data analysis.

Although the amount of data is not sufficient to fully assess the variation in dig-load time per cycle and the actual excavator productivity, the introduction of automation models through construction vision-based video in analysing construction machine in general and excavators in particular will help calculate the actual productivity, paving the way for many future studies.

REFERENCES

- [1] C. Chen, Z. Zhu, A. Hammad, Automated excavators activity recognition and productivity analysis from construction site surveillance videos, *Automation in Construction*, 110 (2020) 21-24. <https://doi.org/10.1016/j.autcon.2019.103045>
- [2] H. Kim et al., Application of dynamic time warping to the recognition of mixed equipment activities in cycle time measurement, *Automation in Construction*, 87 (2018) 225-234. <https://doi.org/10.1016/j.autcon.2017.12.014>
- [3] J. Gong, C. H. Caldas, Computer vision-based video interpretation model for automated productivity analysis of construction operations, *Journal of Computing Civil Engineering*, 24 (2010) 252-263. [https://doi.org/10.1061/\(ASCE\)CP.1943-5487.0000027](https://doi.org/10.1061/(ASCE)CP.1943-5487.0000027)
- [4] J. J. Adrian, L. T. Boyer, Modeling method-productivity, *Journal of the Construction Division*, 102 (1976) 34-37. <https://cedb.asce.org/CEDBsearch/record.jsp?dockey=0006550>
- [5] C. H. Oglesby, H. W. Parker, G. A. Howell, Productivity improvement in construction, McGraw Hill Series In Construction Engineering And Project Management, 1989. <https://www.biblio.com/9780070478022>
- [6] Y. Y. Su, L. Y. Liu, A case study of monitoring construction operations using automated position tracking system, *Civil and Environmental Engineering*, 19 (2006) 312-317. <https://experts.illinois.edu/en/publications/>
- [7] J. Abeid et al., Photo-net II: a computer-based monitoring system applied to project management,

- Automation in Construction, 12 (2003) 603-616. [https://doi.org/10.1016/S0926-5805\(03\)00042-6](https://doi.org/10.1016/S0926-5805(03)00042-6)
- [8] J. Yang et al., Vision-based tower crane tracking for understanding construction activity, Journal of Computing in Civil Engineering, 28 (2014) 103-112. [http://doi.org/10.1061/\(ASCE\)CP.1943-5487.0000242](http://doi.org/10.1061/(ASCE)CP.1943-5487.0000242)
- [9] J. Kim, S. Chi, J. Seo, Interaction analysis for vision-based activity identification of earthmoving excavators and dump trucks, Automation in Construction, 87 (2018) 294-312. <https://doi.org/10.1016/j.autcon.2017.12.016>
- [10] J. Yang, Z. Shi, Z. Wu, Vision-based action recognition of construction workers using dense trajectories, Advanced Engineering Informatics, 30 (2016) 327-336. <https://doi.org/10.1016/j.aei.2016.04.009>
- [11] G. Ofori, Construction in developing countries, Construction management and economics, 25 (2007) 1-6. <https://doi.org/10.1080/01446190601114134>
- [12] J. Park, D. Ryu, K. Lee, What determines the economic size of a nation in the world: Determinants of a nation's share in world GDP vs. per capita GDP, Structure change and economic dynamics, 51 (2019) 203-214. <https://doi.org/10.1016/j.strueco.2019.09.001>
- [13] S. Knack, P. Keefer, Institutions and economic performance: Cross-country tests using alternative institutional measures, Economics and politics, 7 (1995) 207-227. <https://doi.org/10.1111/j.1468-0343.1995.tb00111.x>
- [14] J.W.Sun, Energy intensity versus per capita GDP in seven developing countries, Fuel and Energy Abstracts, 46 (2005) 66-67. [https://doi.org/10.1016/S0140-6701\(05\)80509-0](https://doi.org/10.1016/S0140-6701(05)80509-0)
- [15] R. Akhavian, A. H. Behzadan, Construction equipment activity recognition for simulation input modeling using mobile sensors and machine learning classifiers, Advanced Engineering Informatics, 29 (2015) 867-877. <https://doi.org/10.1016/j.aei.2015.03.001>
- [16] N. Pradhananga, J. Teizer, Automatic spatio-temporal analysis of construction site equipment operations using GPS data, Automation in Construction, 29 (2013) 107-122. <https://doi.org/10.1016/j.autcon.2012.09.004>
- [17] P. Goodrum, M. McLaren, A. Durfee, The application of active radio frequency identification technology for tool tracking on construction job sites, Automation in Construction, 15 (2006) 292-302. <https://doi.org/10.1016/j.autcon.2005.06.004>
- [18] D. Grau et al., Assessing the impact of materials tracking technologies on construction craft productivity, Automation in Construction, 18 (2009) 903-911. <https://doi.org/10.1016/j.autcon.2009.04.001>
- [19] E. J. Jaselskis, T. El-Misalami, Implementing radio frequency identification in the construction process, Journal of Construction Engineering and Management, 129 (2003) 680-688. [https://ascelibrary.org/doi/10.1061/\(ASCE\)0733-9364\(2003\)129:6\(680\)](https://ascelibrary.org/doi/10.1061/(ASCE)0733-9364(2003)129:6(680))
- [20] I. Niskanen et al., 4D modeling of soil surface during excavation using a solid-state 2D profilometer mounted on the arm of an excavator, Automation in Construction, 112 (2020) 43-46. <https://doi.org/10.1016/j.autcon.2020.103112>
- [21] J. Kim, D. Lee, J. Seo, Task planning strategy and path similarity analysis for an autonomous excavator, Automation in Construction, 112 (2020) 53-57. <https://doi.org/10.1016/j.autcon.2020.103108>
- [22] Y. Shi et al., Intelligent identification for working-cycle stages of excavator based on main pump pressure, Automation in Construction, 109 (2020) 23-26. <https://doi.org/10.1016/j.autcon.2019.102991>
- [23] S.W. Nunnally, Construction methods and management, Pentice Hall US, (1998) 45-52. <https://www.civilengineerspk.com/construction-methods-management-s-w-nunnally/>
- [24] N. D. Thuan, Using Construction Machine for constructing road, Vietnam transportation publisher, 2001. <https://www.vinabook.com/su-dung-may-xay-dung-va-lam-duong-p9250.html>
- [25] SAE standard, Excavator, Mini-excavator, and Backhoe Hoe Bucket Volumetric Rating, SAE

International, 1999. https://www.sae.org/standards/content/j296_199901/

[26] B. Pueo, A. Tomas, J. Olmedo, Validity, reliability and usefulness of smartphone and kinovea motion analysis software for direct measurement of vertical jump height, *Physiology & Behavior*, 227 (2020) 41-44. <https://doi.org/10.1016/j.physbeh.2020.113144>

[27] A. Divi et al., Validity and reliability of the Kinovea program in obtaining angles and distances using coordinates in 4 perspectives, *Plos One Journal*, 14 (2019) 1-14. <https://doi.org/10.1371/journal.pone.0216448>

[28] N. Adnan et al., Biomechanical analysis using Kinovea for sports application, *IOP Conference Series Materials Science and Engineering*, 342 (2018) 012097. <http://doi.org/10.1088/1757-899X/342/1/012097>

[29] M. Sipos, R. Sweeney, Behavioral data management using visual basic for applications to automate data capture and analysis. *Journal of Neuroscience Methods*, 128 (2003) 53-65. [https://doi.org/10.1016/S0165-0270\(03\)00150-X](https://doi.org/10.1016/S0165-0270(03)00150-X)

[30] B. Bertheussen, Power to business professors: Automatic grading of problem-solving tasks in a spreadsheet, *Journal of Accounting Education*, 32 (2014) 76-87. <https://doi.org/10.1016/j.jaccedu.2014.01.002>

[31] K. Hyde, H. Maier, Distance-based and stochastic uncertainty analysis for multi-criteria decision analysis in Excel using Visual Basic for Applications, *Environmental Modelling & Software*, 21 (2006) 1695-1710. <https://doi.org/10.1016/j.envsoft.2005.08.004>

[32] S. Ozkaya, Superpose-An excel visual basic program for fracture modeling based on the stress superposition method, *Computers & Geosciences*, 64 (2014) 41-51. <https://doi.org/10.1016/j.cageo.2013.11.011>

[33] S. Snedecor et al., Comparative Computation Speed of Excel, Visual Basic for Applications, R, and Java in Execution of a Microsimulation Model With Probabilistic Sensitivity Analysis, *Value in Health*, 15 (2012) 472. <https://doi.org/10.1016/j.jval.2012.08.1531>