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TESTING THE EXCAVATOR PERFORMANCE (USING TOPCON 3D EXCAVATOR X63 SYSTEM) ESPECIALLY FOR NAVIGATION AND EARTHWORK

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Abstract. Construction sites commonly utilize bulldozers, wheel loaders, excavators, scrapers, and graders. Among these, excavators are versatile hydraulic heavy-duty equipment operated by humans. They are employed for various tasks like digging, levelling the ground, transporting and dumping loads, as well as providing straight traction. However, certain hazardous environments, such as nuclear disasters or earthquakes, are not suitable for human on-site work. To enhance productivity, accuracy, and profitability in excavation projects, the adoption of 3D machine control is recommended. The Topcon 3D Excavator X63 System offers advanced and precise GNSS positioning technology, coupled with Hidromek with Assist and an intuitive software interface, to significantly improve excavation operations. In this study, the accuracy of the coordinates of the route followed by the Excavator was checked by using RTK GNSS method by using P1 reference point. While the differences obtained in horizontal coordinates are 2–2.5 cm and 4–6 cm in vertical coordinates. In addition, excavation calculations of the earthwork area were performed and checked with the number of bucket of the excavator. The differences obtained from the earthwork were calculated as 0.8 cubic meters for each bucket.

Keywords: excavator, RTK GNSS, volume, route, accuracy.

Introduction

Over the past few years, significant advancements have been made in the field of stake-less construction, revolutionizing the way earth-moving machinery operates. This innovative approach involves the real-time guidance of machinery using cutting-edge technologies such as GNSS receivers, robotic total stations, and laser levels. It is important to distinguish between machine control and machine guidance, as they serve distinct purposes in the construction process. Machine control refers to the active steering of heavy machinery using hydraulic systems, ensuring precise movements and positioning throughout the construction site. On the other hand, machine guidance acts as an assistive tool, providing operators with real-time feedback and notifications to adjust the direction or cutting edge of the machinery, aligning it with the intended design. The earthmoving sector of the construction industry has been at the forefront of adopting new sensing and information technologies to improve operational efficiency, increase productivity, and enhance safety measures. This industry has witnessed the emergence of various advanced features and systems for earth-moving equipment. For instance, proximity sensing sensors have been developed to provide early warning of potential accidents, automated machine guidance and control systems have been implemented to streamline operations, and fleet tracking and management systems have been introduced to optimize resource utilization. These technological advancements have played a crucial role in transforming the way construction projects are executed, leading to increased automation and improved performance.

Excavators, commonly used for earthmoving and foundation excavation on construction sites, play a pivotal role in achieving productivity, meeting quality standards, and ensuring contractor performance. However, operating an excavator involves working in close proximity to other personnel involved in excavation or related activities. Therefore, it becomes imperative to have accurate and real-time data from excavators to ensure safety and efficiency. Furthermore, with the increasing industrialization

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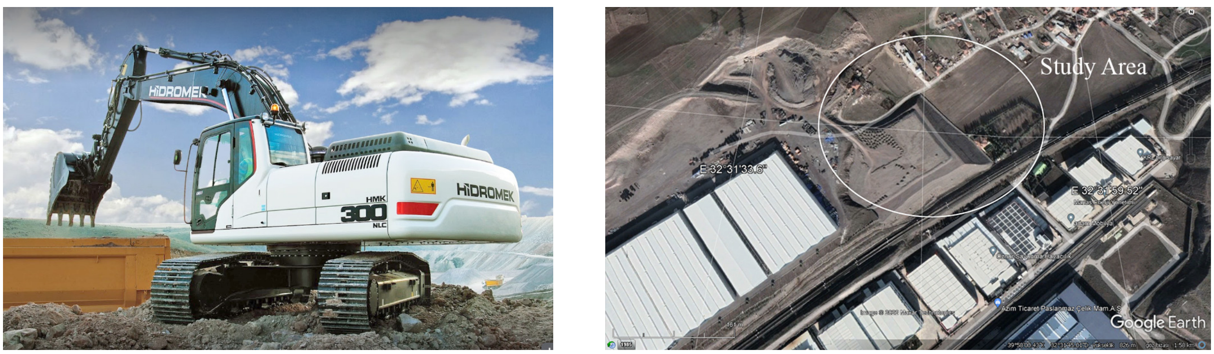
of construction activities, the use of advanced equipment has become essential to meet project requirements effectively. The Topcon Machine Control for Excavators X63 represents a technological breakthrough in the field of excavator operations. This system incorporates tilt sensors to monitor the position of the bucket and utilizes state-of-the-art GNSS technology to provide precise positioning information. The control box is equipped with a vibrant, colour touch screen that displays real-time data regarding the bucket's position, offering operators complete control and enhanced situational awareness. Users can select from various screen views, including plan, profile, cross-section, or the convenient cut/fill "scrolling tape" indicator, depending on their specific needs. By implementing the X63 system, the need for a grade checker to continuously monitor cuts is eliminated, resulting in improved safety and increased productivity on construction sites. In challenging construction environments where large metal barriers or towering structures limit satellite visibility required for GNSS guiding systems, the performance of traditional GPS systems may be compromised. However, modern GNSS constellations, such as GPS, Galileo, GLONASS, and BeiDou, offer improved satellite coverage. Receivers that support multiple constellations have a significant advantage as they can "see" a higher number of satellites, even in partially obscured or reflective environments. These receivers provide enhanced location availability by reducing the impact of multipath errors caused by signal reflections. Advanced tracking technologies, such as APME+, have been developed to mitigate the effects of multipath and ensure accurate positioning, particularly in the presence of obstacles like smooth surfaces, buildings, or rock faces. Algorithms like LOCK+ enable smooth tracking even during rapid changes in antenna location. Additionally, APME+ employs additional correlators in each tracking channel to estimate and rectify multipath errors, further enhancing location accuracy (Topcon Positioning System, 2022; Dadhich et al., 2016). Parker et al. (1993), Lawrence et al. (1995), and Kim et al. (2008) investigated the concept of tele operated excavator using force-feedback control. Studies conducted by Lu and Goldenberg (1995) and Ha et al. (1996) as well as Shimano et al. (2020) and Berljafa et al. (2018) have delved into the topic of robust impedance control for hydraulic excavators. Tafazoli et al. (2002) showcased the application of a position-based impedance controller in contact studies using an instrumented mini-excavator. On the other hand, Bernold (1993) and Singh (1995), Sun et al. (2020a), Shi et al. (2020), and Yuan et al. (2016) focused their research on motion and path planning for autonomous excavation, rather than excavation control approaches (Topcon Positioning System, 2022). Parker et al. (1993), Lawrence et al. (1995), and Kim et al. (2008) investigated the concept of tele operated excavator using force-feedback control. Studies conducted by Lu and Goldenberg (1995) and Ha et al. (1996) as well as Shimano et al. (2020) and Berljafa et al. (2018) have delved into the topic of robust impedance control for hydraulic excavators. Tafazoli et al. (2002) showcased the application of a position-based impedance controller in contact studies using an instrumented mini-excavator. On the other hand, Bernold (1993) and Singh (1995), Sun et al. (2020b), Shi et al. (2020), and Yuan et al. (2016), Lee et al. (2019) focused their research on motion and path planning for autonomous excavation, rather than excavation control approaches.

The need for precise real-time data retrieved from excavators is presented in this study, along with a classification of their significance within the workflow of an entire earthwork construction site. The analysis of vision- and non-vision-based technologies with sensor applications, such as IMU, Draw-wire, (infrared-) GNSS, and RFID, demonstrates the need for a higher-level data connection as well as additional data handling and management software in order to fully utilize the value potential and make it accessible to everyone on- or off-site.

The objectives this study are the accuracy of the coordinates of the route followed by the Excavator and volume values (cut and fill) of the bucket of Excavator was checked by using RTK GNSS method (Topcon 3D Excavator System).

1. Materials and methods

The Global Navigation Satellite System (GNSS) has an impact on every business, from navigation to farming, building, and archaeology. Real-Time Kinematics (RTK) GNSS is a technology that minimizes mistakes to provide precise results and better positional data down to centimetre



a) b)

Figure 1. Hidromek Excavator (a) and study area in Ankara, Turkey (b) (Hidromek, 2020)

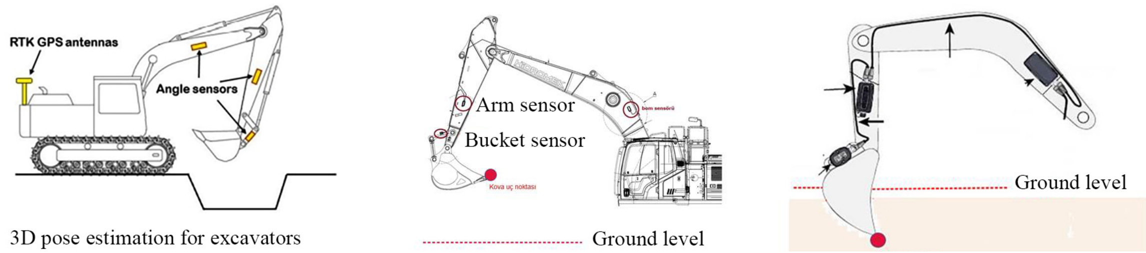


Figure 2. Three dimensional pose estimation for excavators

resolution. RTK requires two GNSS receivers: one static and referred to as a "base station", and one mobile and referred to as a "rover". While both receivers watch the same satellites at the same time, the static base station is located at a known coordinate location. The base sends corrections to the moving rover based on known coordinates and received satellite signals. This way, the rover can obtain sub-centimetre accurate positioning. Grading tasks can now be accomplished without relying heavily on construction stakes or grade foremen, thanks to the utilization of GNSS receivers, robotic total stations, sonic receptors, and lasers to guide equipment operators. These operators are assisted by an on-board computer that continuously updates cut and fill information. Machine guidance and control systems have been implemented in various equipment, including dozers, hoes, pans, graders, and trucks.

Excavators are heavy construction machinery consisting of a boom, dipper (or stick), bucket, and cab situated on a rotating platform called the "house". The house is supported by an undercarriage comprising rails or wheels. They have evolved from steam shovels and are sometimes mistakenly referred to as power shovels. Hydraulic fluid, hydraulic cylinders, and hydraulic motors are responsible for the movement and operations of hydraulic excavators, which operate differently from cable-operated excavators that rely on winches and steel ropes for motion.

Hidromek is a prominent manufacturer of earth-moving construction machinery, specializing in backhoe loaders, hydraulic excavators, wheel loaders, and motor graders. They introduced their first excavator in 2000 and have production and assembly facilities in Ankara and Izmir, as well as overseas facilities in Spain, Russia, and Thailand (Figure 2).

2. Results

2.1. Controlling navigation of Hidromek excavator

In Figure 3, the control graphic of the navigation process of the Excavator in the area of the Hidromek Factory (Figure 1b) is shown. First of all, the routes from Point 1 to 11 were marked on the land. Then, using the Topcon X63 Software with Excavator, these points were passed with the bucket of the Excavator. While passing through these points, the middle crane of the bucket of the Excavator was accepted as the basis, and the coordinates were recorded (Figures 2 and 3), (Ji et al., 2020).

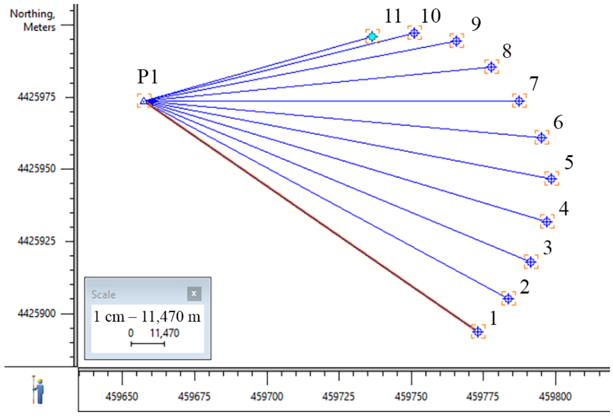


Figure 3. Bucket tip trajectories when all joints are moving simultaneously

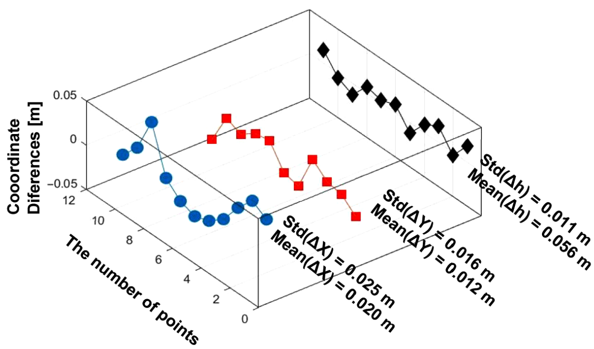


Figure 4. Compare all of the coordinates of the stake-out points in all days by using P1 reference point

The individual test results demonstrate a high level of consistency in the horizontal coordinates of the test points. The variances in horizontal coordinates range from a few centimetres to approximately 2.5 cm when comparing the RTK GNSS measurements of the tests.

Figure 4 illustrates the average variations observed across all stations. The height component likewise exhibited consistency, with variations across RTK GNSS sessions at the same location ranging from a few millimetres to 5–6 centimetres.

As a consequence of the estimation procedure, the accuracy of the RTK GNSS data is shown (Figure 4). The average and standard deviation values of the test's easting (Y), northing (X), and height (H) components are shown in Figure 4. With a standard variation of 1.6–2.5 cm, the coordinates (easting, northing) of all survey sites were generally adequate. Because the mean values at the same stations between the RTK-GNSS tests by utilizing the P1 reference point sometimes varied by 1–6 cm (Figure 4), the horizontal and vertical components were inconsistent. The findings indicate that the RTK GNSS technology is a reliable and consistent system capable of achieving centimetre-level accuracy in various operational conditions. This level of precision is particularly noteworthy considering the dynamic nature of the test and the evolving satellite geometry. The accuracy of the results of this study for tracking the path of the excavator (the location of the bucket) was centimetres.

2.2. Volume computation

Surveyors are typically used to estimate the volume of different types of material. For instance, a lot of construction projects need a lot of concrete and earthwork. To ascertain the capacity of containers such as bins, tanks, reservoirs, and buildings, as well as to determine the quantity of stockpiled materials like coal or gravel, volume calculations are essential. Additionally, it is necessary to calculate the volume of water discharged by rivers and streams per unit of time. The standard unit for volume measurement is often a cube with each side measuring one unit.

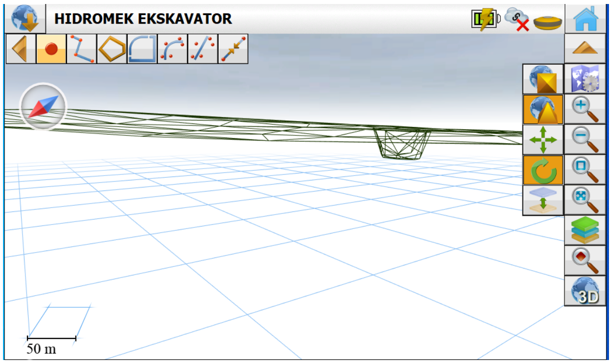


Figure 5. Bottom view of the excavation site

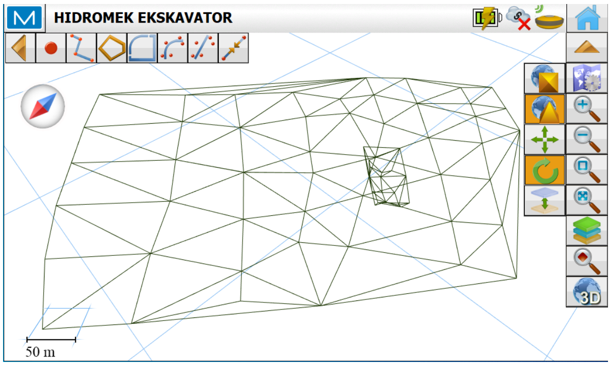
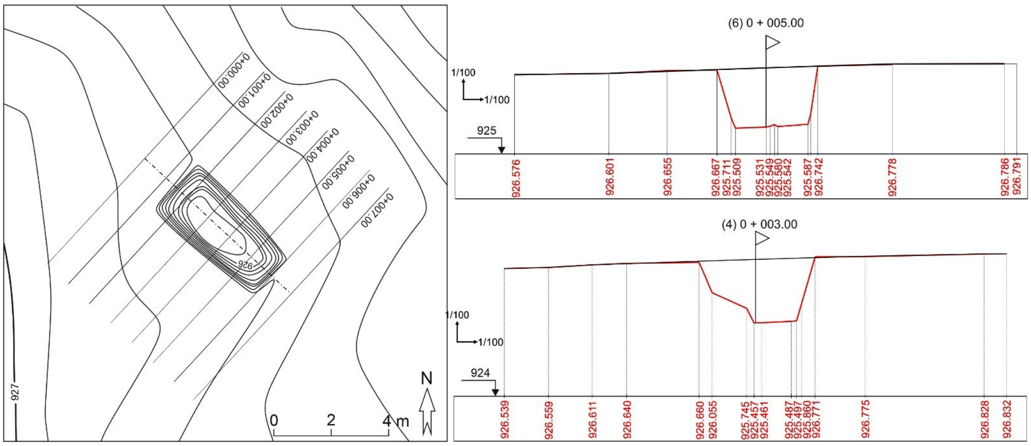


Figure 6. Top view of the excavation site



Kilometre	Distance (m)	Area (m²) CUT	FILL	Volume (m³) CUT	FILL	Cumulative Volume (m³) CUT	FILL	Bruckner Values
	0.00			–	–			
0+000.00		–	0.041			–	–	+0.000
	1.00			–	0.061			
0+001.00		–	0.080			–	0.061	–0.061
	1.00			0.728	0.071			
0+002.00		1.533	0.061			0.728	0.131	+0.597
	1.00			1.824	0.035			
0+003.00		2.115	0.009			2.552	0.166	+2.386
	1.00			2.266	0.009			
0+004.00		2.417	0.008			4.818	0.175	+4.644
	1.00			2.236	0.010			
0+005.00		2.054	0.012			7.054	0.185	+6.869
	1.00			1.124	0.021			
0+006.00		0.193	0.030			8.177	0.206	+7.972
	1.00			0.090	0.023			
0+007.00		–	0.015			8.267	0.228	+8.039
	0.39			–	0.005			
0+007.39		–	0.008			8.267	0.233	+8.035

Figure 7. Computation of the volume values and cross-section in the field

Surveying calculations commonly employ cubic feet, cubic yards, and cubic meters, with cubic yards and cubic meters being the prevalent units for earthwork calculations. For this study, a different region was selected on the land belonging to the Hidromek Factory in Ankara. The cutting volume value was given for the bucket of Hidromek brand Excavator (Figure 1a) was tested. Four buckets of soil were excavated in the field and the volume value was calculated as 8 cubic meters with the Topcon 3D Excavator System. It has been previously determined that one bucket of Hidromek Excavator takes 1.8 cubic meters. Thus, the volume of the Hidromek Excavator's bucket was also verified (Figures 5, 6 and 7).

Conclusions

An extensive range of equipment utilized in industries such as construction, mining, forestry, agriculture, cleaning, and various others is collectively known as "earth-moving machinery". Mobile working machine automation is becoming more popular nowadays. GNSS Intelligent Excavator Guidance System uses GNSS real-time dynamic positioning technology to obtain the real-time and accurate 3D position information of the bucket by reading various tilt sensors installed on the excavator. In this study satisfy all construction needs for excavator: the real-time positioning accuracy can be obtained up to ±2–6 cm (route). Work faster and more efficiently by guiding excavator operations, including improving operation efficiency, reducing auxiliary measurement operators, improving the accuracy of operation results, and reducing repeated data checks. In addition, excavation calculations of the earthwork area were performed with the bucket of the excavator. The accuracy of the earthwork calculation was carried out by considering the number of buckets. The cutting value is given for the bucket of Hidromek brand Excavator was tested in this study region. Four buckets of soil were excavated in the study region and the volume value was calculated as 8 cubic meters with the Topcon 3D Excavator System. It has been previously determined that one bucket of Hidromek Excavator takes 1.8 cubic meters. Thus, the volume value of the bucket of the Hidromek Excavator was also checked. The differences obtained from the earthwork were calculated as 0.8 cubic meters for each bucket. It is obvious that utilizing an excavator machine has several advantages, including increased safety, adaptability, efficiency, power, and strength. Excavators have finely tuned controls and tools that enable the operator to do jobs precisely and under control. They include control panels and joysticks that make it simple for the operator to move the machine and manage the attachments.

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