Technical Review of Automated System Application to Earthworks in Australia

Nayab Ahmed[a], Abraham JW Hong[b], Hyeonggyun Ku[c], Sungkon Moon[d], and Sungwoo Moon[e]

[a]Department of Civil and Construction Engineering, School of Engineering, c, Melbourne, VIC 3122, Australia
[b]Acciona Infrastructure Australia, Sydney, NSW 2033, Australia
[c]Department of Civil and Environmental Engineering, Pusan National University, Busan 609735, Korea
[d]Department of Civil and Construction Engineering; and Centre for Sustainable Infrastructure, School of Engineering, Swinburne University of Technology, Melbourne, VIC 3122, Australia
[e]Department of Civil and Environmental Engineering, Pusan National University, Busan 609735, Korea
(Corresponding Author)

E-mail: nayab.jatoi@gmail.com; abraham_hong@outlook.com; hunet100@naver.com; sungkon.moon@gmail.com; sngwmoon@pusan.ac.kr

Abstract

This paper is a technical review of the smart excavator guidance system being used in Australia, which indicates the automated system. The construction industry contributes towards 8% of the country's GDP (Gross Domestic Product) which makes it one of the largest sectors of the nation's economy. Efficient earthworks have a significant impact on all construction activities in terms of time and cost. Since earthwork activities are repetitive in nature, they offer various opportunities for automation to improve machine utilization and lower the dependence on the operator skill and workload, hence improving the overall construction efficiency. Researchers around the globe have identified these opportunities and introduced various smart machine guidance technologies in order to improve productivity. Construction companies throughout the world, including Australia, have adopted these technologies. However, there is not quantitative understanding of how much these technologies have permeated into the Australian construction industry. This paper will try to address this issue and will try to determine what earthworks market size is, what type of guidance technologies have been adopted by the country and at what scale these technologies have been used. Firstly, this research will try to get an overview of the Australian construction sector. Secondly, an analysis of the previous research projects and inventions will be carried out by looking at various patents of researchers. The literature review will be focus on five broad technological advancements which include the development of machine control systems, laser leveling guidance systems, GPS systems, radio guidance systems display technologies for machine guidance. Thirdly, the adaptation of earthwork technologies in Australia is discussed in the paper regarding the application of construction equipment guidance systems and how these technologies are executed. Research results indicate that the Australian excavation industry is still lagging behind in adopting smart guidance technologies with 64% companies still using laser-levelling systems and 29% companies using advanced GPS systems. State-by-state review also shows similar results with only 15% and 12% of the excavation markets in Victoria and New South Wales adopting GPS-based guidance systems. Data collection will include case studies, phone interviews and internet searches. Finally, all the data will be summarised to get an overview of the adaptation of smart excavator guidance technologies in Australia.

Keywords –Machine Control Systems, Laser Leveling Guidance Systems, GPS Systems, Radio Guidance Systems, 2D & 3D Laser and Radio Positioning Guidance System

1 Introduction

Australia is the 6th largest country in the world in terms of area (United Nations, 2013) with a low population density of 3.3 people per sq. km (Statistics, 2016). It is a culturally diverse country which is politically stable, and most of the country does not have a language barrier (Global, 2015). This country already has an extensive mining, industrial, transportation equipment, food processing, chemical, and steel industry (Limited, 2012). However, the construction sector is one of the most rapidly growing industries in

Australia contributing to 6.8% of the countries' GDP (Stastics, 2010).

The Australian construction industry consists of around 330,000 businesses around the country and employs over one million people (9% of the total Australian workforce) (Team, 2015). This huge demand for construction and infrastructure development is driven by various factors that include growth in population and income levels, rapid changes in technology, inflation, commodity cycles and interest rates. Looking at this context, it is evident the Australian construction industry is going to thrive in the coming years with various large scale projects planned for future development.

Excavation has a significant part in construction apart from earth removal, mining and general earthworks. The main role of excavator in any construction projects is its ability to set the site and dig the foundation. There are various advantages of using excavators including digging deep in a confined area, time saving, cost effectiveness and precision. However, after years of increase in machine size and power, practical limits are now being reached and there is a need for automation for further improvement in productivity and efficiency (Le Quang et al., 2011). Engineers throughout the world realized the practical impact earthworks has on the construction projects in terms of time, cost and quality, hence they have tried to introduce various smart technologies to the improve the efficiency of the excavators (Ebay, 2013).

As excavation and earthmoving activities are repetitive in nature, they offer various opportunities for automation to improve machine utilization and lower the dependence on the operator skill and workload (MRAD et al., 2002). Researchers throughout the world have identified those possibilities and have come up with various smart technologies that would aid excavation activities and improve construction productivity. These technologies include systems for monitoring movement of the excavators, joystick controls for excavators, bucket positioning and control systems, laser guidance systems for grade control, distance measuring systems, laser based grade control systems and GPS-based machine control systems.

Construction industries have adopted these smart technologies around the world and Australia is no different. Earthworks contractors throughout Australia have also been able to adopt these technologies but there is not quantitative understanding of how much these technologies have permeated into the Australian construction industry. This Report will try to address this issue and will try to determine what earthworks market size is, what type of guidance technologies have been adopted by the country and at what scale these technologies have been used.

2 Literature Review

This section initially reviews the previous works regarding smart technologies in excavators. The review will include technologies such as stand-alone machine control systems, laser-based depth control systems, smart displays in excavators, GPS positioning systems and radio and GPS-based machine control systems. In addition, works of major companies will be discussed which offer latest smart excavation technologies. It will provide a general perspective of smart technologies, which are currently being used around the world.

A review of the Australian construction market will be conducted along with the earthworks market in the country. The current status of the construction industry will be discussed, this analysis will include sector-wise review and a state-by-state overview along with future trends of the market. Australian excavation market will also be reviewed to identify the market volume by analyzing different sectors and states in which excavator contractors operate.

The importance of carrying out a review of previous works, Australian construction market, and the excavation market is realized because it will give an outlook of different excavation guidance technologies being used and the overall market size of the excavation industry. It will develop a general scope of this research as to what specific technologies are the most popular and in what ways they can be applied to the construction sector of Australia. Also, it will provide a background knowledge of the information that will be needed to carry out the study. As a starting point, previous works in excavation technologies will be discussed to understand what technologies are being adopted by the construction industry.

2.1 Australian Construction and Excavation Industry Overview

The construction industry is a critical driver of the economy in Australia. Being Australia's third biggest industry, behind just finance and mining, it generates around 8% of country's Gross Domestic Product (GDP). It includes more than 330,000 organizations across the country and employs around 9% of the total workforce. It delivers the infrastructure that is vital to the operation of all different businesses, adds to the riches of the country and supports the infrastructure upgrades that are important to bolster Australia's future wealth and livelihoods. There are various factors that control the demand of construction activities throughout the country.

Construction industry's demand is driven by various factors that include growth in population and income, industry development, innovation, interest rates, commodity cycles and inflation. Other influences include policies that affect the residential and

commercial building, infrastructure development and pricing (including taxes, allocation of land and policies development). Moreover, accessibility, cost and area of assets, building equipment and material are other key determinants of the pace of development in the business. These determinants affect all the construction areas of activity.

Australian construction industry functions in both public and private sectors in three broad areas.

- Engineering construction (include infrastructure and industrial projects)
- Non-residential construction (include shops, offices, amenities, etc.)
- Residential construction (include houses, townhouses, and flats, etc.)

Earthworks and earthmoving also forms a significant part of the areas mentioned above of activity of construction industry. According to Yellowpages Australia, there are around 15230 excavator contractor and hire companies that support the construction industry's earthwork activities.

According to construction industry trends and forecast report 2015-2016, on a macroeconomic level, indications are strong that the global economy will grow over the period of next two years and the economic growth levels will reach closer the levels that were seen in the pre-global financial crisis levels. There is a strong likelihood that the commodity prices will fall as gold and iron ore prices are currently decreasing which will impact Australia's resource market. However, the Australian construction sector will see growth due to significant investments in the residential sector that are mainly driven by a substantial growth in foreign investments, especially in the property sector.

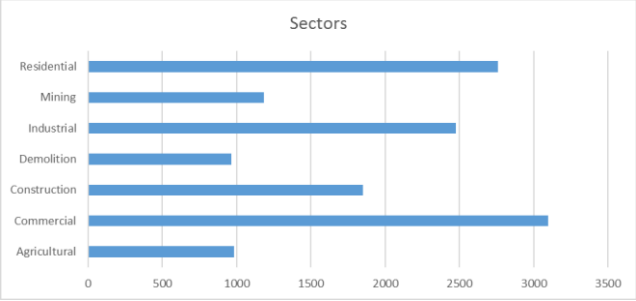

Figure 1. Excavation Companies according to Sectors

Figure 1 illustrates the excavation market scale in terms of different sectors. It is evident that residential and commercial sectors have the biggest excavation market. This is because of growth in these two sectors thought out Australia.

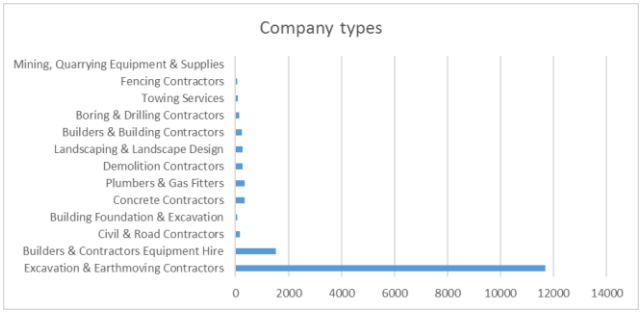

Figure 2. Excavation company types

Figure 2 illustrates that most of the excavation companies are independent excavation and earthmoving contractors. The type of smart technologies that these contractors use depends on the scale of their company and the type of construction contracts they take. Moreover, different states in the country have different market conditions.

A report by Partnership (2015) outlines the market conditions of states within Australia. According to the report, there will be a significant amount of reduction of construction sector growth in Queensland and Western Australia. This is due to the fact that the mining and resource industry in these states have suffered. On the other hand, New South Wales will see a steady amount of growth in the coming 2 years. Reason being that this state has the most number of construction projects evenly spread across residential, non-residential and engineering sub-sectors, and there is very less reliance on a single subsector. South Australia's construction industry growth will remain stagnant, as many of the major projects have been delayed. Similarly, Tasmania will see an increase in construction of aged care facilities. However, forecasts show that there will be slow growth in this region. New South Wales, Queensland, and Vitoria, being the primary construction states, will see a significant amount of growth in the next 5 years, mostly due to growth in the residential sector. The excavation markets in different states also show similar trends.

3. Problem Statement and Research Objectives

Review of the smart technologies illustrated that excavation guidance technologies can be narrowed down to two broad categories, i.e., laser leveling technologies and GPS-based guidance technologies that are being used in the excavators throughout the world. The Australian construction industry is one of the biggest industries in the country. Forecasts show that this sector is going to grow even more in the coming years. Earthworks sector is closely related to the construction industry with around 15230 companies operating throughout the country. However, there is no

quantitative understanding of how much the Australian market has been able to adopt these smart technologies. A quantifiable review of the adoption of smart technologies will not only allow better strategy making for the Australian construction market but also provide a way forward to incorporate these smart technologies in the earthworks industry.

The main objectives of this research is to identify the types of technologies that are being used in the Australian excavation industry and gather a quantifiable amount of the status of the adoption of smart excavation guidance technologies. The sub-objectives include providing an understanding of the trend of adoption of smart technologies all over the country and state-by-state. In order to achieve these objectives a viable research method will have to be proposed.

4. Research Method

This research method involved, initially, a review of the previous works in excavation technologies. This analysis included various patents, inventions and researches. This investigation was done to identify key guidance technologies that are being used in excavators throughout the world.

Once the key technologies are identified, an analysis of Australian construction and excavation market was conducted. This examination was done to understand the market scale and to provide a better picture of the volume of the industry and the amount of earthworks that is being carried out throughout the country. This was done by investigating various industry forecasts and conducting a market survey of 15230 excavation companies state wise, activity wise and sector wise.

After the key technologies and the scale of the excavation market was identified. A research was conducted on how many companies have adopted these smart excavation technologies. Data collection strategy involved visiting sites for case study, internet search and phone interviews.

For case studies, various excavation sites were identified from Victoria and Western Australia and an inquiry was made on the following questions:

- What excavator are you using?
- What type of building it is?
- What smart technology are you using in your excavators?
- How is it used?
- Would you change to a better technology?
- What other technologies do you use?

After the inquiry was made, photos were taken of the site and the excavation technologies being used to understand how they work.

Apart from case studies, data was collected from the internet and phone interviews. For internet search, data was collected using search engines with keywords “excavator laser”, “excavator GPS”, “excavator Trimble”, “excavator TopCon” and “excavator machine control” were used with search parameters within Australia. Data collected from the internet also included searching from various journals, magazines and YouTube videos. For phone interviews, calls were made to various excavation companies and enquiry was made regarding what smart technology was being used in their excavation services. The inquiry was done by asking the same questions which were used during the case studies. Finally, all the data was collected from 162 sources in a spread sheet with the name of the company, contact details, technology used and the state in which they were operating. The data which was collected on the spread sheet was then interpreted into a table to gather the results in table format.

5. Investigation of Excavation Technologies Used in Australia

5.1 Investigation of Technologies from Web-Searching

Data was collected from the internet from 74 various sources. Investigation was made on what type of guidance technologies are being used by various companies. This internet search included identifying all the excavator companies working in Australia. Then company’s websites were accessed individually to find out what type of technologies they offer in their excavation services. Data collected from websites is summarized in a Table 1 and Figure 3, which show the number companies that are using either laser or GPS based guidance technologies.

From the data gathered from the internet. It is evident that laser-levelling technology is the most prevalent technology in the Australian industry with 58% of the total technologies; there were a variety of laser levelling technologies that were being used. In some cases, laser levelling was done manually, in other cases laser receivers were mounted on the boom of the excavators. GPS based guidance technologies are slowly being adopted by the excavator companies with TopCon and Trimble as the most preferred brands. These brands offer various types of GPS based machine control systems with small differences in functionality. Moreover, advanced technologies such as remote excavator monitoring technologies, hybrid excavators and tilt rotators are still relatively new to the Australian market but these technologies are slowly getting popular. Data for a number of companies was gathered from the internet; those companies that did not have any information regarding technologies were contacted individually in order to further investigate.

Table 1 Summarized Data from the Internet

# of companies	GPS	Laser	Remote Monitoring	Hybrid Excavators	Tilt Rotators
74	23	43	3	4	1

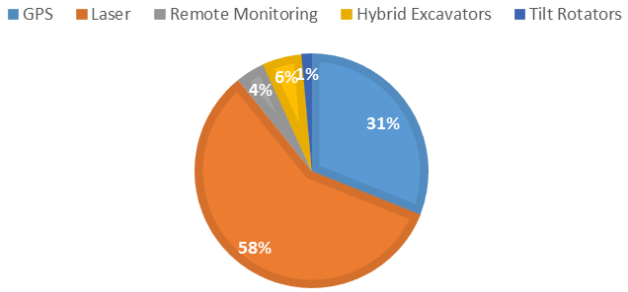

Figure 3. Pie Chart showing technologies used in terms of percentage

5.2 Investigation from Interviews

Phone interview were conducted to fill the gaps that were left by the internet search as there was a number of companies which did not provide information regarding technologies that were used in excavation. Data was gathered from 56 different companies and an inquiry was made regarding the technologies. This data is then summarized in Table 2 and Figure 4 to provide a picture of what type of technologies are being used currently.

Table 2 Summarized Data from Phone Interviews

# of companies	GPS	Laser	2D Grade Control
56	12	43	1

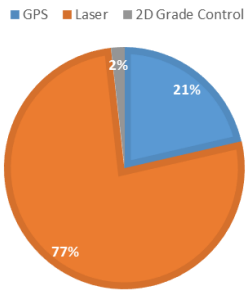

Figure 4. Chart Showing Technologies used in terms of Percentage

Data from the phone interviews also shows that there is a large number of companies using laser-levelling technologies. During the phone interviews, it was found out that most of the companies preferred TopCon and Trimble over any other brand as these two brands offer the best technologies. Moreover, 21% of the companies have started using advance GPS technologies and informed that their productivity increased by using such tools. Some companies were also using 2D grade control systems, which is an integration of laser levelling, machine control and display technologies. The overall trend, here, showed that most of the excavator users have not yet adopted smarter GPS-based machine control technologies which may change overtime as these companies get more exposure to these technologies.

5.3 Investigation through Case Studies

This section will discuss some case studies that were conducted during the research. These case studies were conducted in Victoria and Western Australia.

5.3.1 Excavation for a Small Residential Project

Initial inquiry was made by identifying excavation site within Victoria. Site selection was done on the basis that there would be an active excavation activity happening on the site. The first site that was chosen for case study was located at 77 Springvale Road, Nunawading VIC. It was a ground +2 apartment building construction site. Only one Zaxis 130k excavator shown in Figure 5 did excavation.

In terms of excavator technology, the excavator had basic hydraulic machine control system to keep the bucket parallel to the digging plane. Moreover, this excavator housed a LCD monitor with rotary dial to display and select work modes to do machine diagnostics, monitor maintenance intervals and make hydraulic flow adjustments as shown in Figure 5.

As it was a small scale and relatively simple excavation activity, laser-levelling technology was used to conduct the digging operations. TopCon laser levelling transmitter and receiver were used. The site supervisor initially marked the boundaries using pegs and tapeline. There was a laser transmitter on one end and a receiver on the other end. The receiver was attached to a straight metal rod with a scale. The excavator operator was given a site plan with level markings on it. The operator would move to different points on the site and adjust the height of the receiver. When the right height of the receiver is achieved, then it would beep which would tell the operator how much height to cut or fill. He would then mark the height and excavate accordingly.

The excavator LCD panel only had basic controls related to the excavator. When compared to the latest LCD panel control technologies. The laser levelling system was inefficient as well as compared to the current grade control systems, which are integrated with the LCD panels in the excavators. The operator had to stop the excavator and then mark the levels that increased the excavation time considerably. The investigation for excavation technology was carried out on a similar project but with a larger scale.

Figure 5. Excavator in Stationary Position; Cabin with LCD Control Panel; TopCon Laser Trasmitter

5.3.2 Excavation for a Medium Sized Residential Project

This project was a larger scale project as compared to the last case study. The location of this site was 555 Glenferrie Road, VIC. The contractor for this project was Lloyd Group Pty Ltd. It was a residential townhouse project with ground +2 construction. The excavator used here was bigger and the levelling technology used was similar but a bit different in its working.

They were using a CASE CX300C excavator. The excavator was fitted with a LCD panel that provided basic excavation controls. The excavator had a relatively advanced hydraulic system that saved fuel by identifying the work cycle activities.

Regarding smart technologies, GPS-guidance based excavator was used only during the site set-up phase. For marking levels, TopCon laser transmitters and receivers were used shown in Figure 6. The receiver was mounted on the excavator arm that was visible to the operator. The levelling details were put into the receiver control panel. When the excavation was conducted, the receiver would turn green when the digging level was within the allowable depth limit. The control panel would change color and indicate to the operator when the grade level was achieved.

This laser levelling system was more efficient as compared to the system discussed in the previous case study, as it only required one person to conduct the excavation activity who was not required to stop the excavator and mark the levels from time to time. However, as compared to GPS-based guidance technologies this system was still less efficient. With GPS-based technology, the operator only has to input the site data once, but in this case, the operator was still dependent on his skills to conduct the excavation operations. The excavator contractor was aware of advanced guidance technologies but depending on the excavation size, they preferred to use laser-levelling technology. Investigation was carried out from Western Australia on excavation projects of different scales.

Figure 6. TopCon Laser transmitter with string line in view

An investigation regarding use of smart technologies in excavators was carried out from a project in Western Australia. The project name was Roy Hill Iron Ore project. This project involved various defective works along the rail line. The investigation was done from works at the Hillside Woodstock level crossing, Roy Hill borrow pit, and works at chainage 75, 146.1, and 323.2 km respectively.

5.3.3 Repair Work at Hillside Woodstock Road

At Hillside Woodstock Road (chainage 146.1km), a small repair project to rectify damaged approach seals and pavements for level crossing. The works included:

1. Saw cut and removing existing soil.
2. Removing base course
3. Applying Bitumen tape to T beam.
4. Asphalt resurfacing and line marking.

A small Hitachi Zaxis 30u excavator was used for excavation works. Two joysticks controlled the excavator's hydraulic system. The bucket used had a capacity of 0.09 cubic meters Tons and the excavator could dig up to 3.19 meters. As the excavation activity involved removal of the top 150mm of the exposed base course. The choice of excavator had to be around 3-5 Tons. Moreover, levelling was done by using laser transmitters and receivers. Figure 7 shows that the workers are measuring levels using a levelling stick. Laser levelling technology is cost-effective for such types of small works, however, more advanced level of technologies might be more feasible for complex digging activities where the whole site has to be

prepared.

Figure 7. Worker Measuring Levels with a Levelling Stick

5.3.4 Excavation Works in a Borrow Pit

Another case where laser levelling was used was during excavation works at SCT Rail where rectification works were carried out in a borrow pit at chainage 75 km. The excavation works involved:

1. Site setup
2. Movement of materials
3. Rectification works e.g. drainage works
4. Survey; and
5. Demobilization/ rehabilitation.

Before the work commenced, the operator and the supervisor had to complete a walkthrough of the site in order to be aware of the work boundaries. Afterwards, the operator had to commence work of removing materials from the current drain into adjacent existing creek. The material to be removed would allow the water to drain into the existing creek.

This activity was carried out by a Volvo Vostok digger with a load of 34.3 - 38.7 Tonnes and a small Hitachi ZX30u excavator shown in Figure 8. The Volvo excavator housed an advanced screen that provided information regarding the excavator components. The control panel in the screen allowed the operator to monitor and activate machine functions in a convenient way. Moreover, this excavator came with a Roll Over Protection System (ROPS) which would keep the excavator safe at steeper angles. However, the Hitachi excavator was a standard small excavator with basic excavation functions. Regarding the levelling system, a laser system was used in this case. The excavator operator was assisted by another worker who attached the laser receiver on a shovel to check grade level and marked the boundaries and regularly. In the same project, at chainage 323.2 km, defective works were being carried out where the same excavator (Volvo Vostok Digger) was being used with the same laser levelling technology. After the investigations from the internet, phone interviews and case studies was done, all the data was summarized to discuss the findings.

Figure 8. Operator Assisted, Laser Receiver mounted on Shovel

6. Summarised Research Findings

Data was gathered from 162 excavator contracting companies which use guidance technologies for excavation throughout Australia. This data is summarized in the table below.

Table 3 Summarized Data from the Internet

Australia						
# of companies	GPS + Laser	Laser	Remote Monitoring	Hybrid Excavators	Tilt Rotators	2D Grade Control
128	37	82	3	4	1	2
New South Wales						
17	10	2	3	2	0	0
Queensland						
11	10	1	0	0	0	0
Victoria						
100	15	79	0	2	1	2
Western Australia						
	2					

There were various equipment guidance technologies being used in which laser and GPS technologies were the main technologies that were used in the excavators. The most popular brand for equipment guidance technology were Trimble and Topcon technologies. There was a variety of models in equipment with small upgrades, however the basic principal behind the equipment was based on either GPS or Laser sensing technology as discussed in the literature review. Moreover, it was found out that almost all of the contractors used laser-levelling technology for excavation; however, earthworks on large-scale projects were done using GPS guidance technologies. In some of the excavators, the laser sensors were fitted in the boom to let the excavator operator know the grade levels, in others, levelling was done manually. On smaller construction sites, the operator himself did laser levelling, but on bigger site, a worker assisted the operator.

7. Conclusion and Discussion

Overall, this research aimed at quantifying the status of smart technologies that are being adopted by the Australian construction industry. Data was collected from 128 sources that included site visits, phone interviews, and web search. The summarized results showed that 64% of the total companies used laser guided excavation technology. However, 29% of the companies have started to use advanced GPS-based excavation technologies that show that there is a trend of companies adopting advanced technologies. A small fraction of companies was using technologies such as 2D grade control, tilt rotator control, hybrid excavators and remote monitoring. The usage of technologies depended much on the type of excavation services the excavation companies were providing. Specialized big companies offered state-of-the-art technologies with advanced GPS-guidance machine control system, whereas smaller companies only used laser-levelling technologies. State by state analysis showed similar trends with 15% and 12% of the companies using advanced GPS-based technologies in Victoria and New South Wales respectively with other states also starting to use these technologies. This research was limited as it narrowed down the technologies in two major guidance technologies. If these categories are researched individually and then a collective report is made; it would give a better understanding of the status of guidance technologies used in excavators in Australia.

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