Investigating the Use of Unmanned Plant Machinery on Construction Sites

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Abstract

The UK Construction Sector has been estimated to contribute 8% of the UK's GDP [1]. The worldwide recession has forced construction companies to introduce and adopt cost saving measures to increase productivity. Several robotic building systems are in development for the Construction Sector such as the PERI's Automatic Climbing System [2] and Brokk's remote-controlled demolition machines [3], but there has been little implementation on live sites. Construction sites by their very nature are dynamically changing environments, so if human input was removed entirely, a robot would need a high level of awareness of the current state of the building project in order to navigate and carry out its tasks.
Keywords: *Robots, Building Sites, Autonomy.*

Introduction

There has always been a need to make people safer while they do their job, and to help people do their jobs faster and with fewer mistakes. One field that has helped this most recently is the area of autonomous robotics. This is particularly apparent in the Military and Crime Prevention sectors, where an increasing number of autonomous vehicles are being introduced to carry out work that could be considered dangerous. Various Unmanned Ground Vehicles (UGV's), Unmanned Aerial Vehicles (UAV's) and Unmanned Surface Vehicles (USV's) have made it into the field and are taking place of humans in dangerous tasks such as bomb disposal and surveillance, potentially saving many lives. They are deployed with the philosophy that it is far better to lose a machine than a human life. Whilst people working in these sectors certainly warrant a high level of protection, there are also civilian industries that also claim a lot of lives. The most lethal of these is the construction industry where, in 2009-10, 28% of all fatal injuries occurred (see Figure 1) [4]. Whilst this high proportion of construction workers that are killed every year from being put into dangerous situations, the feasibility of designing robots to allow the work to be carried out from a safe distance has many challenges.

This paper will discuss the potential implementation and growth of unmanned autonomous machinery on construction sites. It will discuss the workings of a modern-day building site, and how the working conditions differ to those where autonomous robots are more commonly active. It will analyse current construction systems in production and how other technology used in other areas could be implemented on construction sites.

Modern Construction Sites

Construction sites are, on the whole, quite predictable in nature. The various stages of a construction project in the UK are set out by the Royal Institute of British Architects (RIBA) in the 'RIBA Plan of Work'. This document lays out the key points in the project from the initial briefing (RIBA Stage A) to the use of the building and feedback from the client (RIBA Stage M). Construction on site begins at Stage K, which means that prior to this, two preparation stages and six design stages have already taken place and the work schedule for the building is very carefully planned out [8].

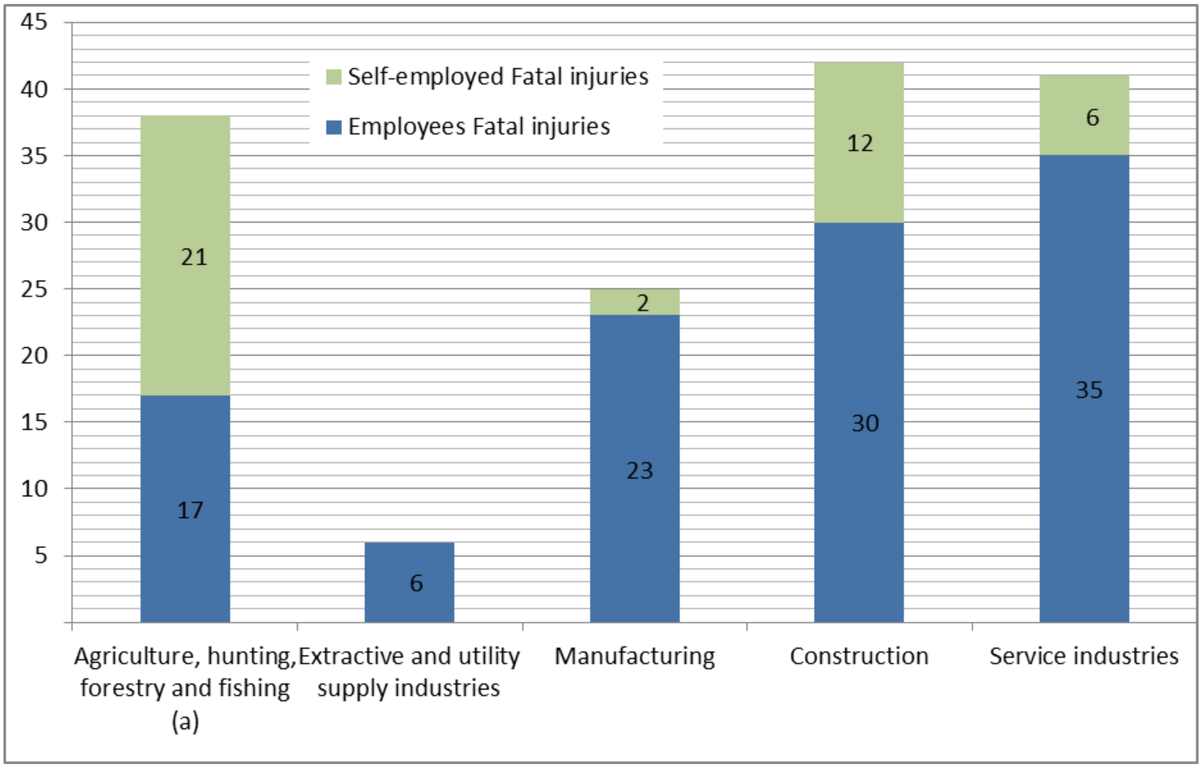

Figure 1: Fatal injuries in the UK 2009/10 for employed and self-employed workers by industry [4].

Therefore, if a robotic system had a real-time knowledge of the current work programme, it would already have a reasonably accurate awareness of the larger obstacles in its surroundings. This differs somewhat to other applications for robots such as on a battlefield, where the surroundings for a UGV, for example, are constantly changing in an unpredictable manor, and the level of intelligence needed to predict this is extremely high.

One less predictable aspect of a construction site is the terrain during the early stages of construction, particularly when ground works are taking place. Vehicles tracking over bare earth create ruts which results in a constantly changing topography, which would be extremely difficult to forecast by a robot. Therefore in order to manoeuvre on site, the robots would either have to be intelligent enough sense and adapt to changes in the landscape, or have a drive platform that can work on any terrain without disrupting its localisation.

Current Plant Machinery

Plant machinery or 'Heavy Equipment' describes pieces of machinery designed to carry out construction tasks, and covers most large machines commonly found on a building site including tractors, bulldozers, excavators, cranes and pile-drivers [5]. Perhaps one of the greatest technological advances in construction machinery to date is the JCB Backhoe Loader (see Figure 2). This was invented by Joseph Cyril Bamford in 1953 and has made the name "JCB" a synonym for "digger" [6].

This machine was originally based on a tractor with a bucket added to the front and a 'backhoe' on the back, and can be used to carry out a multitude of different tasks on site, from excavation, landscaping and breaking asphalt, to small demolitions and road paving. The hoe itself is removable and allows powered tools to be added to further its capabilities.

Figure 2: JCB backhoe loader [7].

Current Robotic Construction Systems

One example of a very large unintelligent system used construction sites is the PERI Automatic Climbing System (ACS) (see Figure 3) as used on the United Tower, Sharq, Kuwait Sweden [2]. This system is designed to provide a safe working platform and support for concrete formwork to allow construction of a section of a skyscraper. During construction of the walls, anchors are built into the concrete. Once the concrete has cured, the ACS climbs up the new structure using these anchors, ready for construction of the next floor. Previous to this, scaffolding would need to be manually fixed in place using a crane, which is not only more time consuming, but is also more dangerous for the workers.

An example of a smaller unmanned machine can be seen in figure 4. Brokk's demolition robots have been in development since 1972 and are remote-controlled, which allows the operator to keep a safer distance from the building being demolished [3]. Although these machines are still man-operated, the process of moving the man out of the machine to operate them from a distance shows that the machine can operate by mechatronics, and therefore all that is needed is the correct sense and control systems to make them fully autonomous.

Autonomy

When discussing the concept of autonomous machines, it is important to define the meaning of autonomy. Sanz et al propose that a system is autonomous if it can fulfil a task within its context [9]. In the context of a building site, therefore, a fully autonomous system would be one that can carry out a complete construction task by itself without human supervision.

There are, however, different levels of autonomy that can be applied to such machines, which would vary depending on the amount of intelligence given to the machine. Frampton summarises these when classifying Unmanned Combat Aerial Vehicles (UAV's) (see Figure 5) [10].

Engineering firm, QinetiQ have developed the Appliqué Robotic Kit (ARK) system that is designed to add remote control capabilities to existing machinery. This system was originally developed for the UK Ministry of Defence and has been successfully implemented into the JCB 4CXM and CAT 320B vehicles.

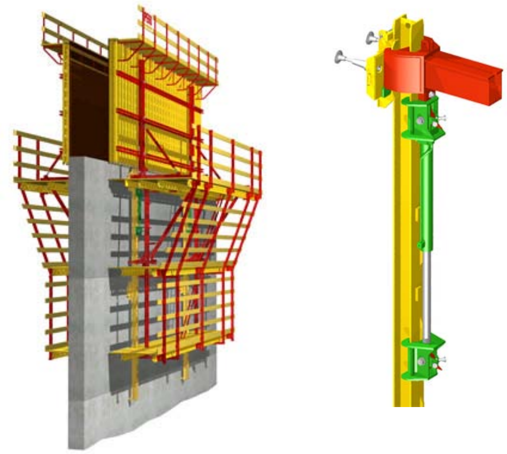

Figure 3: The PERI Automatic Climbing System (ACS) [2].

Figure 4: Brokk 330 demolition robot [3].

Level	UCAV Authority	UCAV Status	
0	None	Commanded	Supervisor full control
1	Advice, only if requested	At call	
2	Advice	Advisory	
3	Advice and, if authorised, action	In support	
4	Action unless revoked	Direct support	
5	Full UCAV authority	Fully autonomous	UCAV authority

Figure 5: UCAV autonomy "levels" (based on MOD Pilot Authority Control of Tasks interpreted by QinetiQ) [10].

It comprises of an Operator Command Unit (OCU) Vehicle Mounted Control Modules (VCMs), host feedback interface and vehicle specific electro-hydraulic system (see Figure 6). These components can be fitted and removed in 12 hours and provide a control range of up to 1 km non-line of sight [11].

Such a system still relies on the intelligence of the operator and so does not add full autonomy to the plant however, due to the distance between the operator and machine, the plant itself can be considered to be functioning autonomously whilst being sent commands by a human.

Robot Intelligence

The previous sections in this paper have identified that the main issues that will affect an autonomous machine working on a construction site are awareness of the obstacles in its surroundings, and localisation within the site. As mentioned previously, a starting point would be to assume that construction progress is running to schedule, and a three-dimensional map could be generated from the design team's CAD drawings.

A robot could therefore be programmed with an internal map of the current 'world' in which it is working. This primary knowledge of the site could be combined with a Probabilistic On-Line Mapping System, where a team of robots on site are fitted with two perpendicularly mounted laser range-finders and work together to follow and update a three-dimensional map of their surroundings (see Figure 7). This map would be stored on a central control computer and accessed and updated by other robots on site.

This real-time feedback would allow the robots to not only avoid obstacles, but also to localise themselves within the construction site, which will overcome any odometry errors that would occur from traversing the difficult terrain [12].

Future Systems

There are two main reasons why autonomous machines might be used on building sites. The first is for cost saving. As the machine would be carrying out very labour-intensive jobs, it would save money for the construction industry. The costs saved by completing tasks in a shorter time would outweigh the initial outlay and maintenance costs. With the right engineering, almost any task that already involves machinery would be suitable for automation in this way.

Figure 6: QinetiQ ARK [11].

Mechanical systems naturally lend themselves to

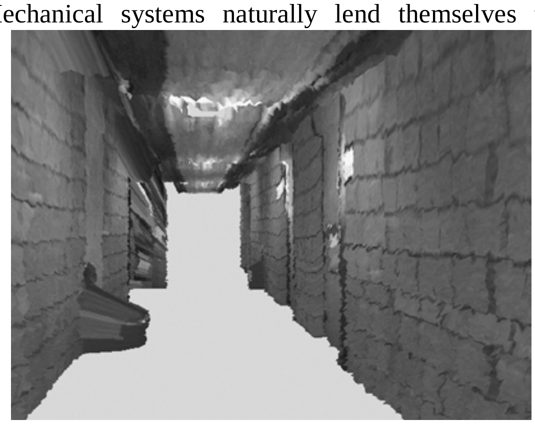

Figure 7: A corridor mapped using the Probabilistic On-Line Mapping system [12].

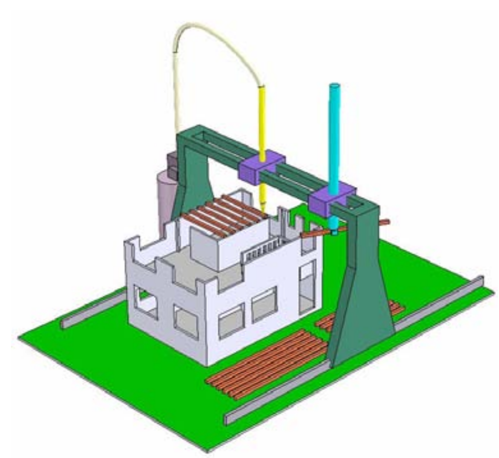

Figure 8: Construction of conventional buildings using CC [13].

repetition and so tasks such as roof tiling and bricklaying could be taken on by robots. This would have advantages over using human workers as a machine does not tire like a labourer is likely to. This would mean fewer mistakes and potential accidents, and a potentially faster, more accurate result.

This philosophy has led Dr Behrokh Khoshnevis of the University of Southern California to develop Contour Crafting (CC) (see Figure 8). The concept of this system is to use a layering technology similar to Rapid Prototyping to construct entire buildings in concrete, simultaneously inserting reinforcement and utilities:

"Construction machines built for Contour Crafting may be fully electric and hence emission free. Because of its accurate additive fabrication approach Contour Crafting could result in little or no material waste. The CC method will be capable of completing the construction of an entire house in a matter of few hours (e.g., less than two days for a 200 m^2 two story building) instead of several months as commonly practiced" [13].

Another construction task that has already had research applied is piling. This is where a piling rig is used to drive metal or concrete columns into soft ground to reach firmer strata below. Setting-out of these piles would be done by GPS, with the piling rig automatically driving to the required locations and installing piles [14].

Arguably the most significant reason for implementing construction robots, as mentioned earlier in this paper, would be to take over dangerous jobs. These could include jobs at a height, such as assembling steel frames and pouring concrete for skyscraper floors and walls.

Conclusions

This paper has highlighted some key research areas in construction robotics that could lead to the implementation of such machines on an increasing number of building sites over the coming years.

Companies like JCB Ltd have spent many years developing mechanisms for digging and moving earth. Systems developed by Brokk and QinetiQ prove that these mechanisms and drive platforms have the potential to be transferred to fully autonomous machines.Technologies such as GPS and Probabilistic On-Line Mapping have been around for many years and could be implemented, along with the CAD building plans that have to be generated before construction takes place, to give the machines given enough intelligence to know exactly where they are, and where to dig, could carry out ground work tasks without the need to employ labourers for what is a very time consuming part of a building project.

The paper has shown the key benefits of construction robots to be:

- Cost-saving
- Safety
- Speed, accuracy and repeatability

As long as the human race continues to reproduce, the construction of new dwellings and work places will be required. The quick, accurate work of autonomous machines could help to meet this ever-increasing demand, whilst reducing the alarmingly high accident rates associated with the construction industry.

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