Automation and Robotics in Construction XI
D.A. Chamberlain (Editor)

Comparison between industrial robotic manipulators, agricultural and construction plant and equipment

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Abstract

The use of robotics and automation technology in the manufacturing industry has become very much accepted. In recent years, interest on the use of robotics technology in agriculture and on-site construction has been on the increase with several working prototypes being actually deployed in farms and on construction sites. This paper presents a comparison between the equipment used in the manufacturing industry, construction sites and agricultural production. This is achieved by recognising their fundamental differences as well as common features. Results are then cross-fertilized so as to be included as part of the design considerations to be applied for the design of new construction robots.

1. INTRODUCTION

The deployment of mechanical aids for the production of food and the construction of lodgings has been undoubtedly one of the oldest human concerns. Consequently over the years, there has been a gradual progression from simple manual tools to complex automated systems. It is therefore natural to think of using robotic technology for on-site construction and agriculture.

Currently robotics together with information technology are changing the industrial sector as dramatically, as mechanical power did during the industrial revolution. However, this is not the case for on-site construction or agriculture, where there has been a much slower introduction of automation and robotics due to the levels of complexity found in the automation of both processes.

This paper presents a comparison between equipment used in the manufacturing industry, construction sites and agricultural production. It is perceived that construction and agriculture share common features. Thus, the mechanical devices used by both industries would have also common design characteristics. Examination of features found in industrial and on-site construction robots will enable us to recognize differences and similarities, and to select the most useful properties of each. As a result of this reflection, it is then viable to cross-fertilize the most useful properties and design features of each, and include them as part of the design considerations for future construction robots. This appraisal has resulted from the perception that several construction robots have employed directly robotic manipulators, devices which were designed to work in different conditions and with distinct work objects [1].

2. ROBOTICS AND AUTOMATION IN AGRICULTURE

As with other industries, there is also considerable pressure to improve productivity in agricultural processes. This issue is compounded by the migration of farmers onto city dwellings and the lack of interest in young people to work in field-related occupations. Recent apprehensions on the environment imply that many agricultural practices have to change. While reliance on agricultural machinery has augmented over the years, there has also been an increase in manufacturing costs. Hence, the motivation for improving their performance [2].

2.1 Features of Agricultural Production

Agriculture generally takes place in an unstructured environment. Although plants and animals may be similar in descriptive terms, they are all different in engineering terms. The work objects are located in environments subject to natural variations both from place to place and over time. In addition, there would always be the risk of disturbances in the form of farm animals and wildlife [3].

All tasks are performed outdoors, often in a harsh environment, the machinery is exposed to weather, corrosive chemicals and in proximity to large animals. Due to the unstructured work environment on which tasks are performed, agricultural machinery must work under a wide range of conditions.

2.2 Robotic Applications

Applications of robots in agriculture can be classified into four types: nursery, cultivation, harvesting and husbandry [2]. Of these, the most interesting ones from the construction automation perspective are those developed for cultivation and harvesting.

Considerable work has gone on the automation of tractors to pull cultivating implements. Tractors are currently evolving into "true data acquisition systems". The availability of field data means that the driver cab would become a decision centre capable of assisting with the driving and on the choice of implements [5]. Much interest exists also on the localisation and guidance of agricultural machinery. Applications range from simple driving aids to fully autonomous vehicles. The remote controlled tractors developed by Kone-Sampo Ltd. (Finland) are a good example. As the vehicle does not include a cockpit, the design of the device is extremely flexible. This device is projected to evolve into a fully automated navigation unit [6].

The plough is the traditional farmer tool used to lay seeds in the cultivation process. The slip of the tractor wheel could lead not only to wastage of power but would also damage the soil. Generally, wheel slip can be controlled by changing the plough depth. Changes in soil conditions imply that the force exerted by the plough would vary to maintain a constant depth and furrow width. Through the use of auxiliary motorisation and sensors, it is possible to fix the extra traction required at the plough as a function of the soil conditions [7], [8].

The harvesting of fruits, crops, vegetables has also attracted interest from mechanisation specialists. For example a machine has been developed for thinning forestry plantations. It consists of a conventional vehicle platform on top of which a manipulator arm has been mounted. Once the operative assigns the tree to be removed and approaches the robot, the manipulator arm removes the tree [3]. The automatic recollection of fruit has also attracted much interest [8].

It can be asserted that robotics technology in agriculture is still in its formative stage and that applications to farming have been minimal. Devices are found only in research laboratories [2].

3. ROBOTICS AND AUTOMATION IN MANUFACTURING

The majority of work in robotics and automation has been centred on manufacturing applications. The introduction of robotics into the production line has been possible by modifying manufacturing practices and adapting production to suit the requirements of automation.

3.1 Features of Manufacturing Processes

In manufacturing, designers and fabrication specialists all work for, or are captive subcontractors of the same company. Thus, the project manager can dictate organizational and operational changes which would affect overall productivity. Most tasks are performed in an almost constant environment under controlled conditions; that is, the disposition of the manufacturing equipment, and work areas remain constant throughout the production of one item. That is, the product is moved from workcell to workcell and not vice versa.

Other features include the relative comfort of the work environment and a more or less stable work force.

3.2 Industrial Robotic Manipulators

The origins of industrial robots lies in the machine tool industry. For these machines the objective is to hold the position of a tool independent of the forces acting on it, thus allowing repetitive production of uniform parts despite differences in materials. The relationship between the machine tool and the majority of commercially-available, robotic manipulators can be traced to an extension of numerical control methods. Thus the emphasis remains on positional accuracy [9].

Industrial robots have bulky-rigid links where component stiffness is an all important property in obtaining accuracy and repeatability in machining and assembly. They have low payload-to-weight ratios [9]. The type of controllers used emphasize position accuracy rather than force with very few cases including force control. The nature of the manipulation tasks imply that these, in most cases are position control dependent rather than force.

4. ROBOTICS AND AUTOMATION FOR ON-SITE CONSTRUCTION

In recent years, the industry has been facing a number of significant challenges including: decreases in productivity, increases in costs and greater demands for a better built environment. As a response to these challenges, the use of automated systems and robotic tools for on-site operations has been proposed.

4.1 Features of on-site Construction

The type of tasks performed in construction sites are often dangerous, but normally dirty and unpleasant. The site-operative has to work in a hostile environment. Most tasks are labour intensive and operative dependent due to the precision and job uniqueness involved. In general, work objects are of different sizes, weights, and have to be manipulated into position within a 3-D space. Thus, the precision and dexterity required from operatives is very high and restricted by the limits of their physical abilities and available equipment [10].

The products of construction are more durable and used over longer periods of time that those of other industries [11]. In construction, the work place is continuously changing and dispersed amongst many temporary locations, resulting in an ill-structured and dynamic environment. This implies that the construction plant and equipment is relocated as work progresses [10]. On site-conditions are rugged and harsh, and there is a high turnover within the work force particularly at the operative level.

4.2 Construction Robots

To date most construction robots have been designed for single tasks, particularly for ground and inspection operations having limited decision making capabilities. These devices are generally tele-operated with the operative remaining as part of the control-loop. There has been emphasis on the use of the robotic concepts borrowed from the manufacturing industry. Designers have been concerned with navigational difficulties in an ill-structured environment, the load of the work object and the robot itself, and material logistics required for most traditional construction tasks. Current robots are semiautonomous that is, they rely on human guidance. Robots can be considered as part of a team which together with a human have strength, dexterity, speed and quality skills exceeding those of either acting individually. Most efforts have been directed towards automating tasks which have been designed and perfected for human operatives.

5. COMPARISONS

In this section two comparisons are presented, that of agricultural machinery with construction equipment, and that of industrial robots with construction equipment.

5.1 Agricultural Machinery with Construction Plant and Equipment

Agricultural and construction devices have similar origins and objectives. They began life with the desire to extend the reach and force of operatives rather than to add precision or dexterity. This signifies that equipment is designed for strength and fatigue considerations. Tasks performed with this type of equipment occur mainly in unstructured environments and are subject to weather conditions. As a result machinery relies on the guidance of operatives and has been designed to withstand adverse weather conditions. In construction, the work environment could be subject to disturbances due to the presence of operatives and machinery. In agriculture the problem is compounded by the proximity of large animals. Therefore, the design of any autonomous device has to consider the existence of these potential disturbances.

The devices used in both processes have to be displaced as the task progresses contrary to what occurs in manufacture. Ground related tasks for both types of machinery can be considered similar. For example, ground levelling using a grader [12] would be analogous to soil preparation or ploughing in the cultivation process [7].

The basic difference resides on the characteristics of the manipulated work objects. In agriculture, work objects are smaller, softer and are located next to the ground, while in construction these are larger, heavier and harder, and positioned within a 3-D space.

5.2 Robotic Manipulators and Construction Plant and Equipment

Robotic manipulators and construction equipment come also from different traditions that have different objectives. These differences impede the use of industrial robots in construction and the use of construction technology in robotics [9]. The fundamental difference between construction manufacturing processes rests in the nature of the end-product delivered by both industries. The products of construction are more durable and used over longer periods of time, whilst products of manufacturing either become obsolete or worn over shorter periods. All those involved in manufacturing work for or are subcontractors of, the same company. Thus, the project manager can dictate organizational and operational changes which would affect overall productivity. By contrast in the construction industry all involved are often distant economic units with different objectives and long-term business policies [10].

On-site working conditions are also different. In manufacturing all tasks are performed in an almost constant environment under controlled conditions. Conversely in construction, the work place is continuously changing and dispersed amongst temporary locations. The work environment changes as each item is installed. This implies that construction plant and equipment is relocated as the work area changes.

The size of the work object in manufacturing is small compared with that handled on building sites. The manufacturing work force is relatively stable, while in construction there is a high turnover within the work force particularly at the operative level.

Another difference is that industrial robots have bulky rigid links where components stiffness is an all important property in obtaining accuracy and repeatability in machining and assembly. In construction, equipment is designed for strength and fatigue considerations rather than to meet stiffness standards. Construction plant and equipment does not have a rigid linkage from the work object through the base of the device, even if it was desirable. For example, in a backhoe excavator the operative makes adjustments continuously according to the hardness of the ground as well as the hole dimensions. The operative work is by feel with feedback information being sensed through his body and assisted by sight to tell him how hard to amplify the operator's physical force rather than to follow a prescribed path with each movement of the backhoe [11].

6. DESIGN RATIONALE

Examination of sample agricultural robots and those developed for on-site construction has shown that several prototypes have design concepts which can be applied to both of them. As an example, the laser assisted grading system developed for earth works [12] could be automated further by incorporating the technology applied to the automated guidance of agricultural tractors [4], [6]. In another example, the gripper and manipulator mechanism shown as part of the Column Positioning Robot in Figure 1 have been designed based on the manipulators used to handle large wood logs [10]. This robotic system would remove the operative from the vicinity of the column positioning task in conventional steel frame erection processes [1], [10]. Automation of this robot could be improved by applying some of the principles used in the robot developed for thinning forest plantations [3] and by using the system developed for remotely guiding agricultural tractors [6].

The principles applied towards the automation of the excavation process [11] are similar to the ones employed for automating the operation of the plough in the cultivation process [3], [7]. Therefore, the automation of the excavation process could benefit of the technology

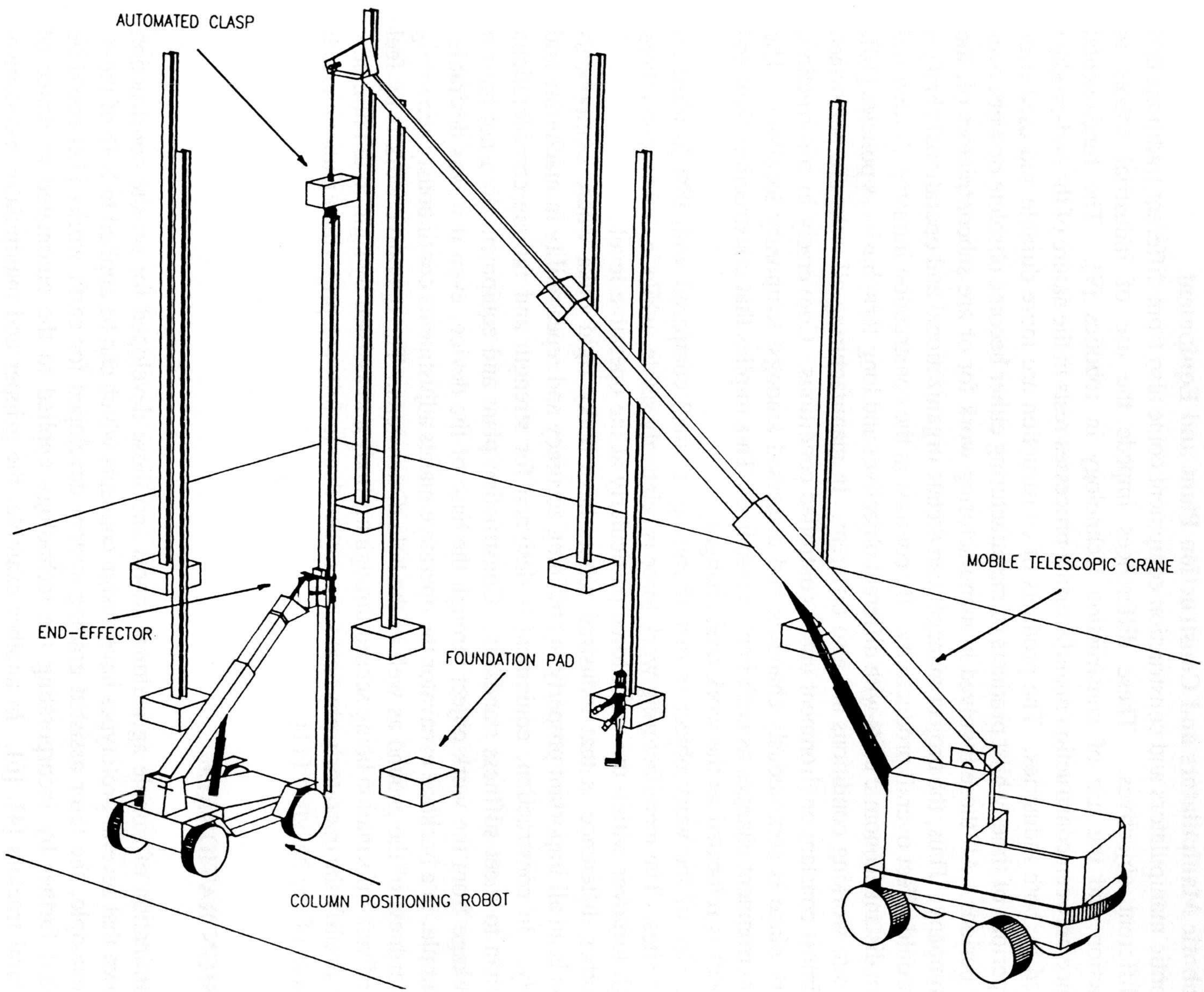

Figure 1. Column Positioning System

developed for the implementation of the active plough mechanism [7].

There are many fundamental differences between manufacturing and construction which make it inappropriate to apply manufacturing automation/robotics concepts directly to the design of automated construction equipment. In construction, on-site conditions (ill-structured) impose considerable limitations on the technology and require mobility for the construction plant and equipment used. Thus, any autonomous robot working in such an environment will need to have sophisticated navigation capabilities. A fully autonomous robot working in such an environment will need to be driven by sensor-based control systems.

Construction tasks, apart from being distributed over a large area, rely on the dexterity of operatives. Manufacturing tasks are more confined and rely on plant machinery. Consequently, the absence of the technology required to emulate human operatives in a construction site precludes full- scale automation of existing construction process. A design response to this issue is that construction robots should be designed in conjunction with the building, so that they could be developed using present day technology [10].

In a similar manner to developments in agricultural robots, construction robots would need to combine sensory capabilities, intelligence and adaptability of the operative, with machine features such as speed, strength and repeatability. In other words, the perception and judgement of an operative are superior to anything with which a device could be equipped and a machine (robot) could manipulate loads/tools far greater than a person is capable of moving. The aim would be therefore to design robotic tools rather than fully automated solutions which would use sophisticated sensor-based systems. Coarse manipulations of a work object could be made under robot control, while finer motions could be achieved by the use of joystick controls.

While it is still not possible to effect a well-structured factory-like environment, it is possible to create a factory in microcosm or workcell in which a specialist robotic manipulator arm can work within a confined area before being moved onto its next work position. This could be achieved by adapting currently-available construction plant and equipment as in the case of the cladding positioning robotic system described in [1], [10].

7. CONCLUSIONS

This paper has presented a reflection on the design features found in robots developed for agriculture, construction and manufacturing tasks. By identifying the differences and similarities between processes and machines, it was possible to cross-fertilize the most useful design concepts of each. The fundamental difference rests in the nature of the end-product delivered by the manufacturing and construction industries and the origins of the machinery employed.

It is felt that a profound examination of agricultural equipment in general, would enable the enrichment of the design concepts that can be applied towards the design of new construction robots. The initial comparison presented in this paper has enabled us to identify by analogy that the technologies being developed for the automation of *in-situ* construction are very similar to those being included in the automation of agriculture equipment. This is an image of the fact that there are more common features between agricultural related processes and on-site construction than between manufacturing and construction processes.

The function of a construction robot is to amplify the physical force and reach of the operatives or to eliminate them altogether. Construction robots should combine human perception and judgement with machine features such as speed, strength and repeatability. By including the operator as part of the control loop, it would be possible to design robotic tools rather than fully automated solutions.

It is perceived that advances in industrial robots as they seek to move out from the factory floor, would benefit from the designs being developed for the automation of agricultural and construction tasks.

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