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Assembly Techniques For Large Construction Components

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This paper discusses some of the problems associated with positioning large components and shows how different joint designs may alleviate these problems. It will be necessary to define assembly methods and strategies for ensuring that the components can be joined successfully once they have been presented to each other by the erection system. The tolerances which are common on site mean that the joints must be able to accommodate errors in placement of parts by the lifting system and also errors in placement of the receiving assembly.

1.0 Introduction

In a robotised erection system, there are many problems associated with manoeuvring and docking large elements which have been fabricated from steel or concrete. Some of the problems involved in carrying components have already been investigated and solutions have been proposed for the phenomena which have been observed [1][2]. For example, at one research centre, experimental fixings have been developed and used on sites for such tasks as assembling grillages of structural steelwork and inserting load-bearing columns into place [3]. By contrast, this paper will discuss some of the problems associated with docking large cladding panels and fixing them in place on the outside of a building. It is intended to show how different joint designs may alleviate the problems which have been observed with cladding panels, particularly with regard to overcoming errors in component placement and geometry.

Because of the sizes and weights of the components to be carried by a construction robot, it is necessary to consider how to control the lifting equipment in order to minimise load sway, crabbing and overshoot. Previous work has shown that there are significant design differences between conventional robots and construction plant, which means that the nature of the control systems for construction robots will be different from those necessary for industrial robots [4]. However, the accuracies and repeatabilities of construction robots will be such that a reliable docking of components will not depend on the robot so much as on the strategies and methods adopted for assembly [5].

It will, therefore, be necessary to define assembly methods and strategies for ensuring that the components can be joined successfully once they have been presented to each other by the erection system. The tolerances which are common on site mean that the joints must be able to accommodate both errors in placement of parts by the lifting system and also errors in placement of the receiving assembly [6]. The implications of design for assembly for the joints between the components are crucial. In previous work, factors which would improve the likelihood of success in an automated construction assembly process were identified from similar research into manufacturing automation [7]. From this, several jointing methods are being investigated for potential use. In practice, this has meant a suitable scaling for the manufacturing process has had to be carried out in order to accommodate the loads and conditions found on site.

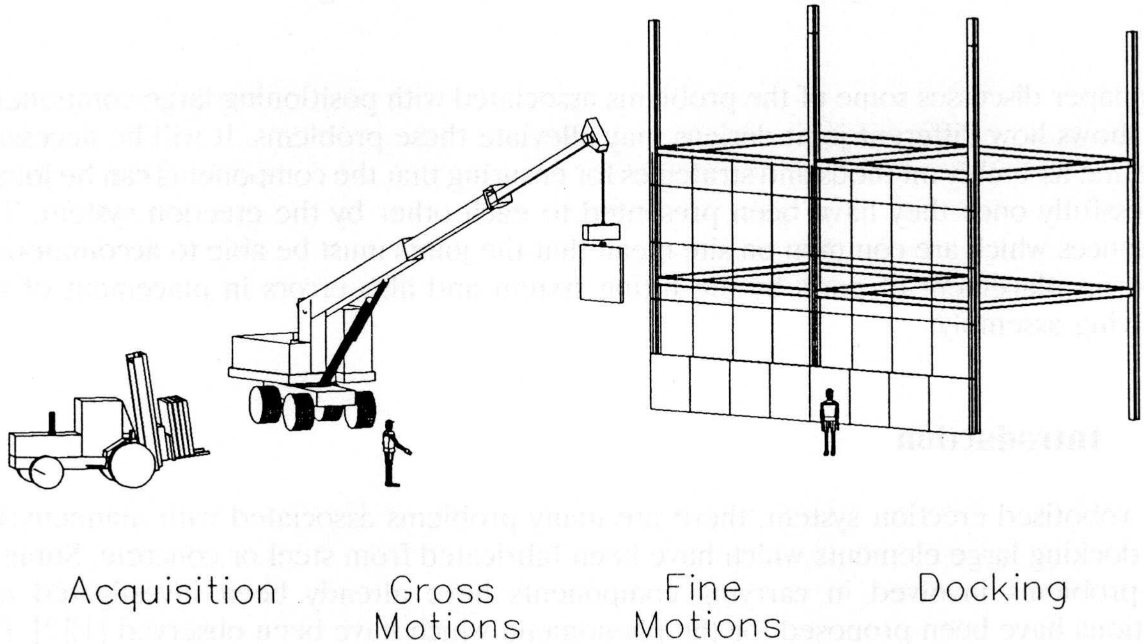

Figure 1 Four distinct phases of a lifting sequence

Furthermore, as illustrated in Figure 1, it was observed that there are four distinct phases of the lifting operation necessary to position a panel on the cladding frame. These may be described as the acquisition of the part in a loading area, the gross motions of the part en route to the assembly area, the fine motion of the component in order to enter the area of assembly in a safe manner, and lastly the docking of the part into the partiallycomplete assembly on the outside of the building [8]. Not all the problems to be discussed in this paper are present at every stage of the lifting operation, but some are more important at various times. It should be stressed that this paper is concerned principally with the docking and fixing of components rather than the gross motions or path-planning aspects of lifting operations.

2.0 Problems associated with heavy and bulky loads

From observation of how lifting operations are carried out, it is apparent that there are three main categories of problems with moving large and bulky masses. These problems arise because of (i) the motion of the component, (ii) the motion of the robot, and (iii) with errors and tolerances in the assembly into which the part is being fitted. An example of the kind of lifting operation being considered here is shown in Figure 1, where a cladding panel is being carried from a loading area to the building where it is to be installed.

2.1 Motion of the components

The most serious problem with component motions arises because of the inertia of the part while being carried by a flexible handling system. As the robot accelerations are transmitted to the part via flexible couplings, the part will sway from side to side along the direction of travel. If the point of suspension of the load is different from its centre of mass, sway movements will ensue which are perpendicular to the direction of motion. The frequency of these motions and their amplitudes may be estimated in advance and compensated for using non-linear acceleration profiles or gentle ramps. However, it is not possible to do so without an active feedback system to monitor the state of the load and to adjust the motor parameters accordingly.

One of the main disturbing forces comes from the wind loading. While the gross effects of wind are known and can be calculated in advance, the direction and magnitude of wind loadings are weakly-stationary and inherently unpredictable.

The principal conclusion is that the motion of the part on the end effector need not be the same as the commanded motion of the robot. While it may be possible to compute an approximate solution for the dynamics of the robot and load while they are moving, computing the exact solutions is not currently feasible in real time given the added complication of unpredictable external wind forces.

2.2 Motion of the lifting system

Most industrial robot controllers assume that the machine is infinitely rigid in all three planes and about all three axes. This assumption greatly simplifies the mathematics of controlling robots and so modern robots are designed to minimise position errors by eliminating deflections under load. Therefore, the accuracy and repeatability of an industrial robot depends on the speed at which it is driven and also on carrying a payload which is generally limited to one percent of self-weight. By contrast, construction plant is expected to carry loads which are up to twenty percent of self-weight. The higher loads cause the crane or excavator to experience deflections and inertial problems to which an industrial robot is not subject.

Furthermore, wear, backlash, and hysteresis in gear-trains and mechanical linkages add to the problems of trying to predict part motions following a set of joint rotations and translations. Problems also arise due to sinking supports when the construction robot is used on a deformable soil as opposed to the stiff floors that industrial robots require. Such problems may be alleviated by the addition of external sensors and using the information they supply in order to adjust the movements of the joints to position the load correctly. Lastly, the robot may be asked to place a component in a place that is either outside its working envelope or awkward to approach. In either case, it may not be possible to derive solutions to the equations which relate the joint movements to changes in position and orientation of the load.

2.3 Fit of components into the assembly

Having delivered the component to its intended destination in the building, there may be problems attaching the part to its fixings and mountings. This may be due to inaccuracies in the geometry of the part, inaccuracies in the geometry of the receiving assembly, or some combination of both of these factors. The problems associated with moving the components to fit the existing structure are such that there may be clashes with other parts in the assembly which would not occur had the various pieces been manufactured and assembled correctly. Accumulation of tolerances can mean that components have to be forced into place rather than eased in gently. If the rules of Design for Assembly are not followed, there may be ambiguities in the assembly sequence which will inevitably lead to errors on site. Repeating sections of work to correct previous mistakes will involve manipulation of components with fine precision and force control. Unfortunately, these requirements conflict with the need for closer tolerances in order to ensure better fits between components for sealing purposes. Ensuring the integrity of joints between cladding panels requires better manufacturing and so lower tolerances on sites [9].

3.0 Fixing methods for assisting assembly

Three of the jointing methods outlined in previous work have been developed further and will be discussed in this section with reference to their utility for assisting in the assembly of large and bulky components. These methods were among the more promising alternatives which arose from a study into how manufacturing industry uses different fastening techniques which are not commonly used in the construction industry [7].

3.1 Deformable fixings

Deformable fixings are non-reversible in that the attachment is achieved by a permanent deformation of part of the fixing. In general, they are of the *push-fit* variety and may be formed from aluminium or durable plastics. A simple arrangement of such a fixing system is shown in Figure 2. Since a force of known magnitude must be exerted in order to close the fixing, the force may be monitored and used to infer whether the fixing has been completed satisfactorily. This need not conflict with the load-bearing capacity of the fixings which should be adequate to resist shear loadings as well as wind suction. The play in the fixings can also be used to take up thermal expansions.

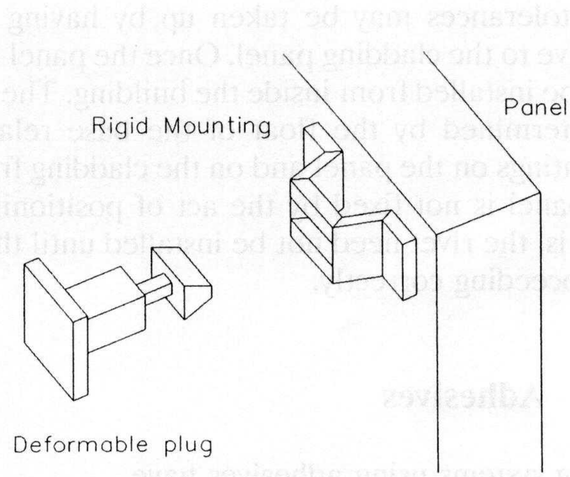

Figure 2 Deformable fixings

Tolerances can catered for by mounting the fixings on a base which is able to move relative to the panel. Once one fixing has been completed, the panel is constrained in its possible rotations and translations which then simplifies the problem of lining up the other fixing points. The tolerance that the fixing can cope with is determined by the float of the base relative to the frame and also the offsets achievable on the chamfered head of the fixing.

3.2 Rivets and adjustable mountings

As with deformable fixings, connections using rivets are not reversible. Normally, rivets require pre-drilled holes but more recent versions incorporate a drill-bit. The rivets are presented to the cladding panel and spun at high speed to drill holes in the mounting plates. A simplified view of such a fixing system is shown in Figure 3. Commercial systems are becoming available and it is only a matter of time before they are adapted for use by robots.

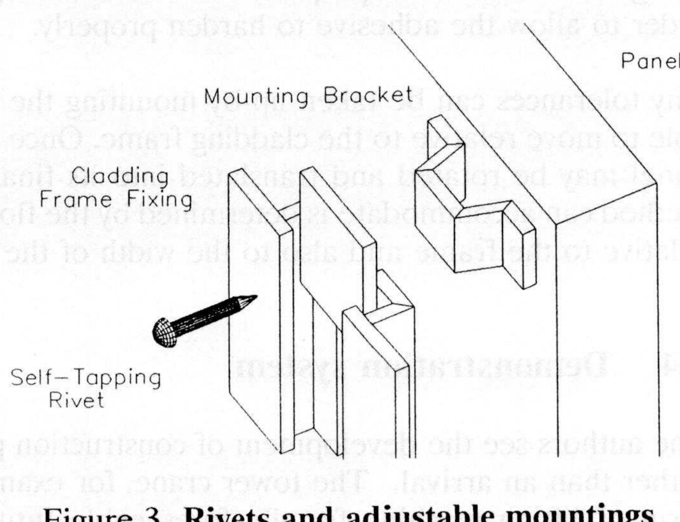

Figure 3 Rivets and adjustable mountings

Any tolerances may be taken up by having a mounting plate which is able to move relative to the cladding panel. Once the panel has been presented to this mounting a rivet may be installed from inside the building. The tolerance that the fixing can accommodate is determined by the float of the base relative to the frame and the offsets of the mountings on the panel and on the cladding frame. By contrast to the deformable fixings, the panel is not fixed by the act of positioning the panel next to the mounting frame. That is, the rivet need not be installed until the operators are satisfied that the assembly is proceeding correctly.

3.3 Adhesives

Fixing systems using adhesives have been available commercially for some time; they are non-reversible without the use of solvents. However, adjustments can be made while the glue has not yet hardened. Therefore, temporary fixings must be used to hold the panel in place while its final position and orientation are settled. A simple arrangement is shown in Figure 4. The beads of glue are protected by a cover which is broken when the panel is pressed against the cladding frame. As with the deformable fixings, the forces involved may be monitored and used to infer whether the temporary fixings have been made properly and whether the protective cover has been breached in order to allow the adhesive to harden properly.

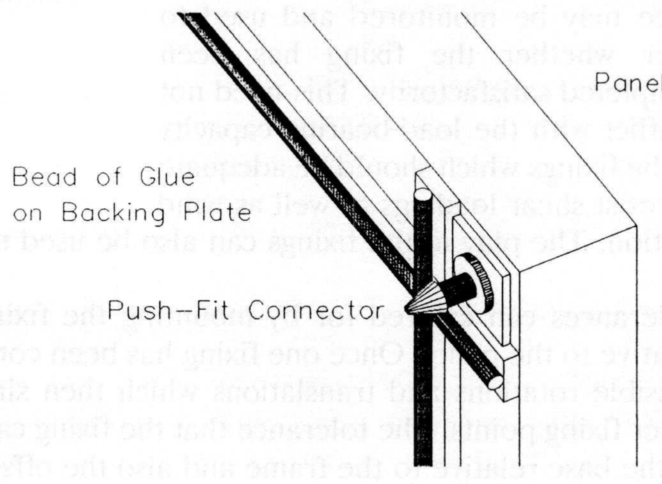

Figure 4 **Adhesive fixings**

Any tolerances can be taken up by mounting the temporary fixings on bases which are able to move relative to the cladding frame. Once the fixings have been compressed, the panel may be rotated and translated into its final place. The tolerance that the fixing method can accommodate is determined by the float of the base of the temporary fixings relative to the frame and also to the width of the frame that the panel is fixed to.

3.4 Demonstration system

The authors see the development of construction plant towards robotics as an evolution rather than an arrival. The tower crane, for example, is likely to remain the dominant form of lifting machine for the foreseeable future, although use of telescopic boom devices will increase as a solution to swinging load problems. The tower crane for use in the automated construction scenario will require two major developments:

i) precision load motion control - modern crane motor controllers are moving towards finer incremental control than hitherto, and the remaining development problems are now concerned with load sway.

ii) local sensors - crane operators will tele-operate such cranes from a point near the workpiece using radio or infra red links, and they will need various docking aids such as local video, edge detectors, proximity sensors, and absolute positioning systems.

In order to evaluate the utility of some of these new technologies and the approaches to fixing outlined previously, it is intended to use an overhead gantry crane to assemble sections of cladding panels on a test rig. The proposed test facility is illustrated in Figure 5 and will comprise a gantry crane with remote operation capabilities, a gripper for carrying and placing the panels, specially-designed aids for the human operator, and the novel fixings outlined in this paper. The panels are commercial systems which are to be modified to suit the fixing methods detailed above.

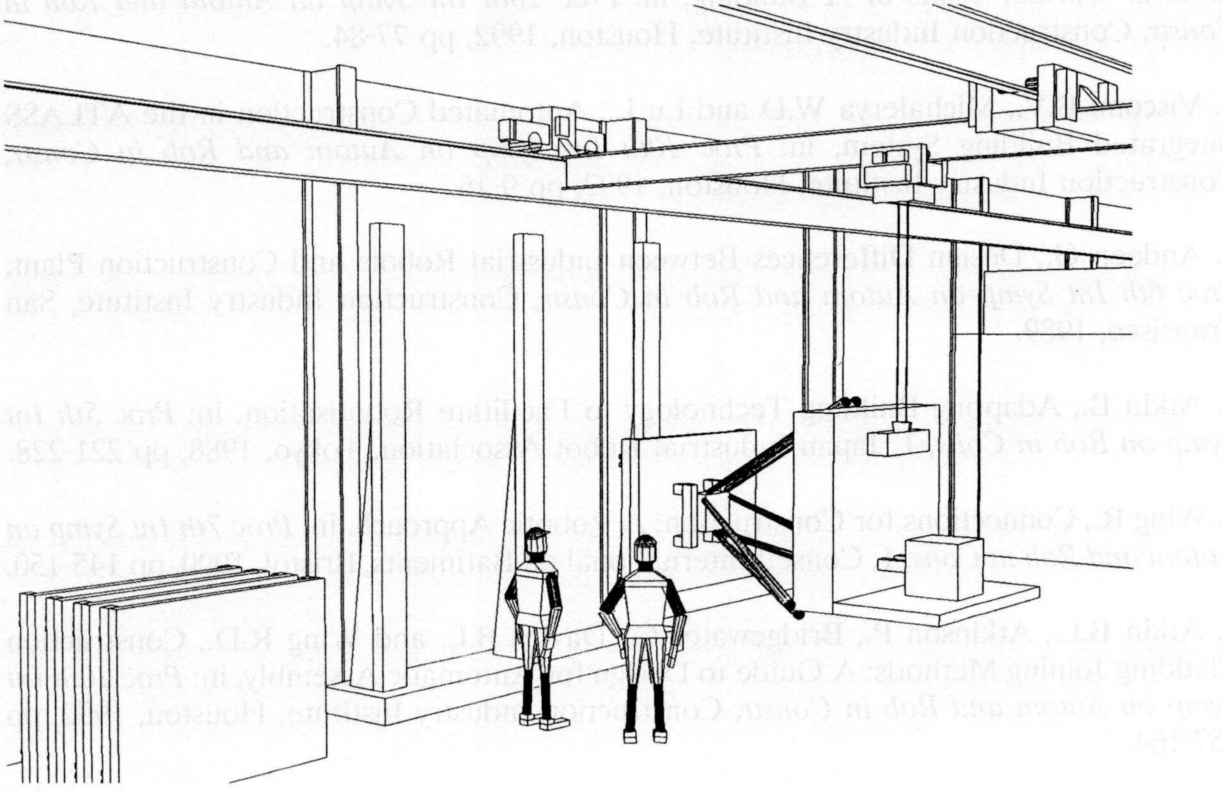

Figure 5 Cladding positioning demonstrator

4.0 Conclusions

The placement and fixing of large construction components is a focal point for many of the technical problems required to bring robots onto construction sites. The motion control of large flexible lifting devices requires a totally different approach to robotics, whereby the problem must be broken down into gross and fine motion stages, each having different sensing and control requirements. The paper shows how the authors are using specially engineered fixing designs to minimise the problems of fine motion control and component docking.

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