THE PROVISION OF A TASK SPECIFIC REFERENCE FRAMEWORK FOR ROBOTIC CONSTRUCTION PLANT

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SUMMARY

In order for an item of robotic construction plant to function it must be precisely located on site relative to its task. This can be achieved through the provision of a global or site reference framework and of a local or task specific reference framework.

In green field applications in the absence of obstructions to the line of site, both these objectives can be achieved by means of triangulation based on the use of lasers or video systems. However, as the work on site progresses line-of-sight techniques become increasingly disadvantaged by the presence of obstructions and other techniques will be required. Given the cost of systems of the accuracy required for many tasks and the difficulty of obtaining other than plan information by these means such global systems may well need to be supported by other, task specific, systems designed to provide the necessary information on location and attitude.

The paper considers a system under development in the Engineering Department at Lancaster University which is intended to provide all the necessary information to enable automatic operation of a range of robotic plant. The proposed system utilises a single laser source as reference and is capable of measuring all the degrees of freedom associated with the vehicle used to deploy an item of plant such as a robotic excavator arm.

1 INTRODUCTION

The introduction of automation technologies into manufacturing industry has been based around groups of computer numerically controlled (CNC) machine tools serviced by automated materials handling systems such as robots and automatic guided vehicles (AGVs). These 'Islands of Automation' are then interconnected by means of both local and factory wide communications systems to produced an integrated manufacturing environment. The design and layout of the individual machines and groups of machines within this environment is to a large degree dictated by the manufacturing processes involved in the production process. Each machine or group of machines therefore occupies a defined position. The workpiece is then transported between these individual locations, at each of which a defined task is carried out.

In a construction environment, the position is reversed. Here, it is the 'workpiece', in the form of the structure under construction, that is fixed in position and to which the item of plant must be transported. The problem is further complicated by the fact that a site environment is more dynamic than a factory and is in a state of continuous change. This not only creates problems in moving an item of plant within the site but also in locating it relative to a particular task.

In order to function an item of robotic construction plant must therefore be capable of being precisely located relative to its defined task. This in turn suggests the need for some form of global or site positioning system which can be used to navigate the vehicle deploying the item of plant about the site together with a local or task specific reference framework which defines the position of the plant relative to its task.

2 GLOBAL POSITIONING

In the case of a green fields site, global positioning can be, and indeed is, controlled by means of triangulation based on the use of either lasers or video systems [1,2]. These systems can be divided into two groups, ground mounted with targets on the vehicle as in figure 1 [3] or vehicle mounted with targets at fixed locations in the surrounding environment, as in figure 2 [4].

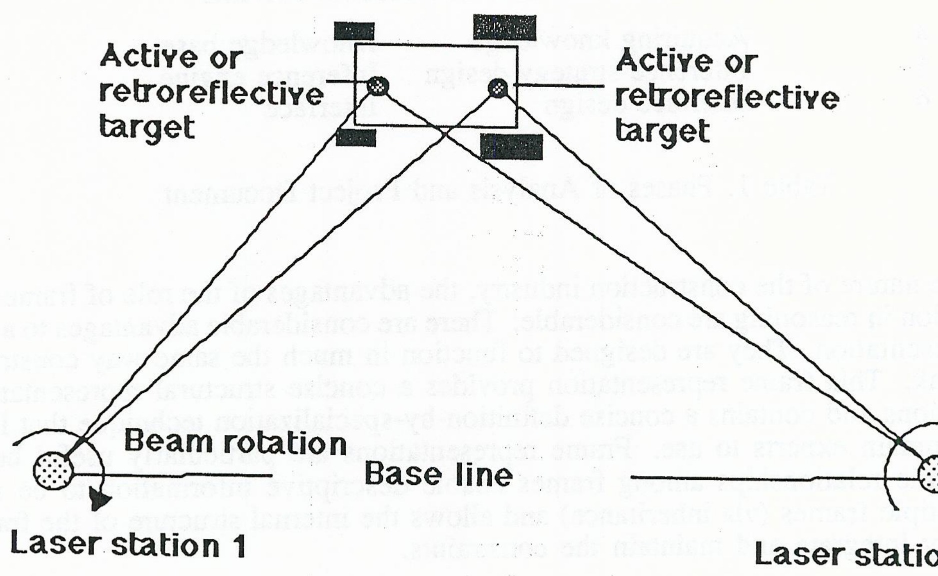

Figure 1: Triangulation with a ground mounted system

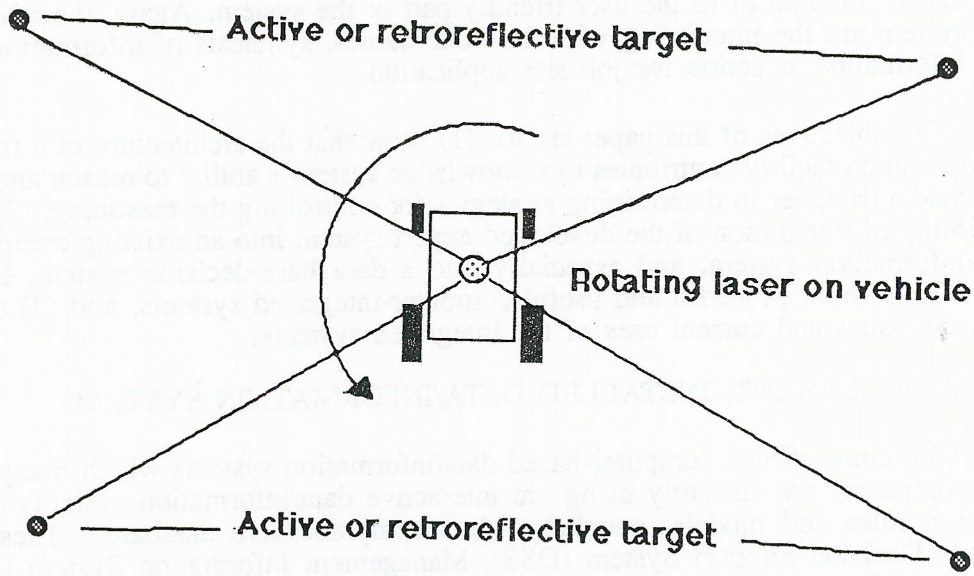

Figure 2: Triangulation using a vehicle mounted system

Satellite navigation systems also present a possible means of obtaining positional information a global basis. Though it is possible to obtain high positional accuracies by this means, these are often only attainable for short periods in the course of a day and at high cost.

Other possibilities such as the use of vision operating in conjunction with a fully autonomous mobile robotic system remain a research tool and are unlikely to reach a point of commercial application for general site use within the next few years.

Thus, for all sites other than those where unobstructed lines of site can be guaranteed by some means, it is suggested that for the foreseeable future, global positioning will be achieved by means of an operator 'driving' the plant vehicle into position. This operator will also be responsible for safety aspects associated with the operation of the plant, something which will be a major factor in determining the deployment of such plant.

3 A TASK SPECIFIC REFERENCE FRAMEWORK

3.1 The Problem

Consider the operation of a robot excavator. The excavator arm itself has the general form of an anthropomorphic robot and may be treated kinematically as such. As shown in figure 3 such an arm will typically have at least 4 degrees of freedom and possibly 5. Even so, the problems of controlling such an excavator arm are significantly different from those of controlling a conventional robot of similar geometry because of the problems of reach, flexibility and variable inertia associated with its operation. Once the arm is mounted on a mobile base, the control problem is further compounded by the introduction of the 6 additional degrees of freedom represented by the base as in figure 4.

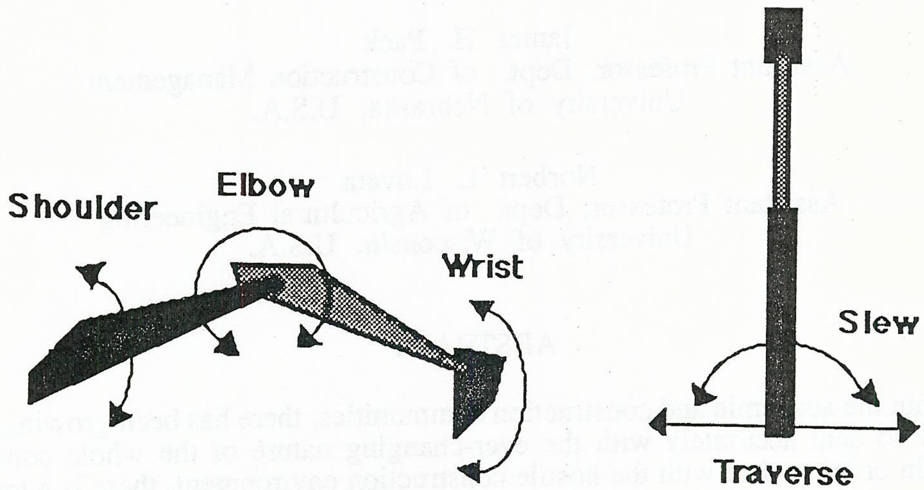

Figure 3: Degrees of freedom of an excavator arm

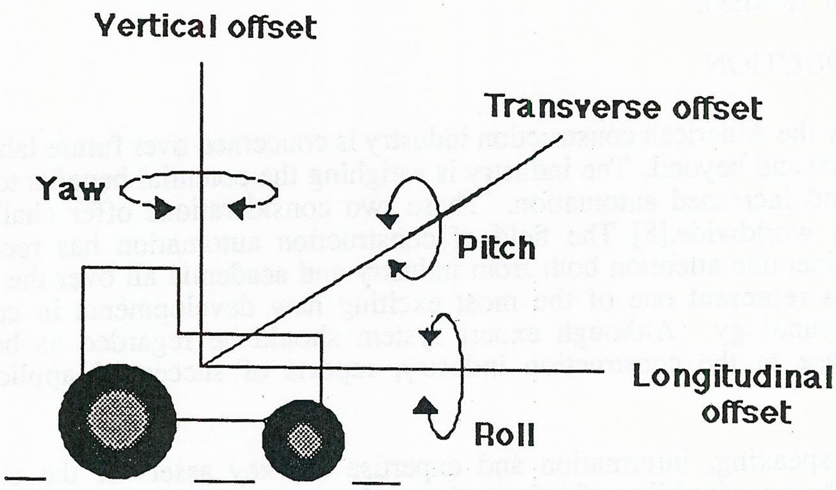

Figure 4: Degrees of freedom of mobile base

It must also be remembered that the mobile base once deployed may still be subject to motion. For example, in the case of an excavator the presence of an obstacle may result in the base being lifted rather than the bucket penetrating the ground. To simply assume that the base once positioned formed a fixed reference would introduce errors into the controller. Hence, the positioning of the base must be continuously monitored to provided information which can be utilised by the control algorithms to determine the position and operation of the head of the controlled robotic arm.

3.2 Options

In the absence of obstructions it would be possible to use a global positioning system based on the use of triangulation to provide not only general positional data but also information about vehicle attitude. Consider the case of a ground mounted triangulation system. The use of three targets on the vehicle will enable the roll, pitch and yaw of the mobile base to be obtained well as its position, provided all targets are visible. In order to ensure the availability of this information in respect of the possibility of the obstruction of a target by the vehicle itself, extra targets or sources may be required, increasing the cost and complexity of the system.

However, it was envisaged that for many applications it would not be possible to obtain either a suitable baseline for a ground mounted triangulation system or adequate secure reference points for an equivalent vehicle mounted system. A vehicle mounted system based on the use of a single laser line source as reference has therefore been devised which is capable of providing in its basic form a measurement of 5 out of the 6 degrees of freedom of the mobile base. The final degree of freedom can then be obtained by the addition of an additional sensor if required.

4 THE MEASUREMENT SYSTEM

The general configuration of the system showing the relationship between the vehicle and the laser source for a trenching operation is shown in figure 5. In this application, the laser line would be directed so that it was parallel to the bottom of the trench and to one side of the trench centre line. In this mode, the roll, pitch and yaw errors in vehicle position would be recorded together with the lateral and vertical offsets from the trench centre line and base respectively.

4.1 System operation

The basic system is shown in schematic form by figure 6 and consists of a damped gimballed base which carries a tracking semi-silvered mirror and associated drive train. On the reverse of the mirror at its mid-point is mounted a linear photodiode array. A second such array is mounted on the side of carriage. Drive is provided by means of stepper motors. Light from the laser source would enter through an aperture at the front of the system. Operation is then as follows:

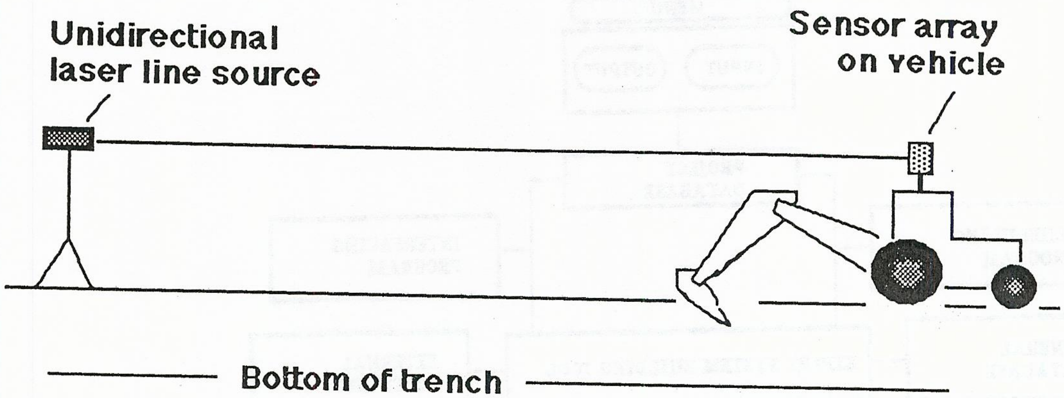

Figure 5: Measurement system, general configuration for trenching

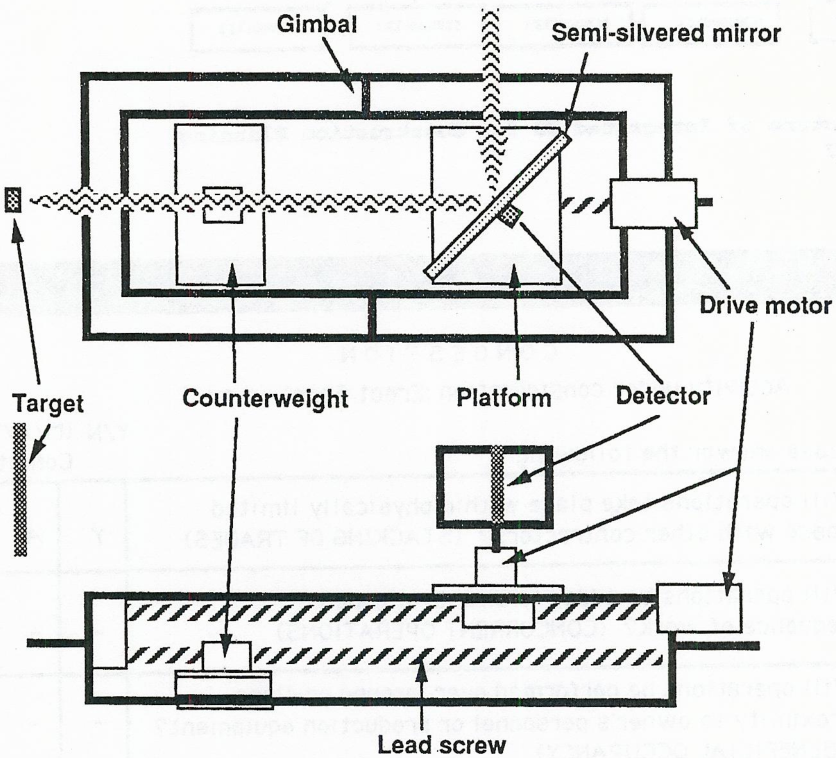

Figure 6: The measuring system, schematic layout

. The sensors on the gimbal base measure the gimbal angles to provide information on the current pitch and roll of the vehicle base. The damping on the gimbals is adjusted to compensate for minor movements and a dead band could also be incorporated if required.

. The semi-silvered mirror is then tracked from side-to-side on its mounting while the position of the counterweight is correspondingly adjusted to maintain equilibrium. The tracking continues until the incoming laser light is detected by the linear photodiode array mounted on the rear of the mirror. The distance through which the mirror has been displaced from its central position then gives the lateral offset of the centre of the sensor array from the line of the laser.

. Once the incoming laser light has been detected by the mirror the tracking motion is halted and the mirror rotated about its vertical axis to reflect the laser light onto the vertical reference array. The amount through which the mirror must be rotated to achieve this provides a measure of the heading error or yaw of the mobile base.

. The vertical displacement of the sensor array relative to the laser reference can be obtained by recording the point on the photodiode array at which the laser light is received.

The sensor array can thus be seen to provide a means of measuring 5 of the 6 degrees of freedom of the mobile base. The measurement of the sixth, in the example considered the offset distance down the line of the trench, can be obtained by mounting a retro-reflecting prism on the vehicle and using time-of-flight techniques as used in surveying.

A prototype system based on the above has been developed and tested in the laboratories of the Engineering Department at Lancaster University and has been shown to function in the manner described above. The next stage of the development is to reproduce the operation of the prototype in a form capable of being deployed on a real vehicle and to integrate its operation with other sensing systems to develop a sensor based controller for the robot arm. Once this has been achieved then operation can be integrated with high level functions used to determine the operational tactics and strategies to be deployed against a range of tasks [5,6].

5 CONCLUSIONS

It is considered that autonomously mobile robots capable of navigating around the unstructured environment presented by a construction site with the requisite accuracy will not become available for several years. As a result, the deployment of items of robotic plant will, with the possible exception of operations on green field sites or applications such as open cast mining, depend upon them being manually delivered to the point of use.

Once the robotic plant has been delivered to its point of use by its driver/controller it must then be free to operate automatically, freeing the driver/controller to perform other tasks on site. In order to function, the robotic plant will require information not only about the geometry and kinematics of the arm and manipulator being deployed but also on the effects of operation on its base. This requires the provision of a local or task specific reference framework which the system can use to monitor changes in the attitude of the base in the course of operation.

The paper discusses the requirements for the operation of such task specific reference frameworks and describes a simple system which has been developed in prototype form in the laboratory.

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