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

Robot control system for window cleaning

M. Farsi[a], K. Ratcliff[a], P. J. Johnson[b], C.R. Allen[a], K.Z. Karam[a], R. Pawson[b]

[a]Department of Electrical and Electronic Engineering, University of Newcastle Upon Tyne, Newcastle Upon Tyne, NE1 7RU, UK.

[b]OCS Group Limited, 79 Limpsfield Road, Sanderstead, Surrey CR2 9LB, UK.

Abstract

The paper describes the dedicated robot control system for a robot demonstrator for window cleaning by mimicking human actions. Human washing and wiping actions are carried out by a sophisticated cleaning head with a combined datuming and cleaning function.

1. INTRODUCTION

A two-stage process is performed by human operator for cleaning windows. The first being the application of cleaning fluid, which is usually achieved by using a wetted applicator. The aim of this task being to cover the whole window area in the shortest possible time. This depends on two parameters: the size of the applicator and the path which the applicator travels without significantly overlapping previously wetted area. The second is the removal of cleaning fluid by a squeegee blade without spillage on to other areas of the facade or previously cleaned areas of glass. This is particularly difficult for example if the window is located on the roof of a building and cleaning is performed from inside by the human window cleaner.

Simulation studies were conducted to demonstrate the feasibility of a robot system to act and mimic the human operator (1). Several points were considered: An end effector had to be designed to accommodate different tools such as applicator and squeegee; The pay load for tool handling; Sensory feedback requirements; Force and compliance control; And finally the cost of the overall system had to be feasible. Furthermore, the robot cleaner should be expected to clean as well as a human cleaner and to provide a near-continuous operation with minimal human interaction.

As a result of the simulation studies it was conceived that the end effector should contain a combined datuming/cleaning head. This arrangement eliminated the necessity for tool changes between the two datuming and wiping operation. It also has a further advantage being that of a limited form of on-line datum monitoring while the wiping process is being carried out. The arrangement would allow automatic datuming and location of the window pane relative to the robot using a specially designed and constructed compliant head (2). The robot used to demonstrate the window cleaning robot system (3) was a six-axis Staubli-Unimation PUMA 560 robot manipulator. After successful demonstration of the robot window cleaning task a dedicated

XYZR robot was designed. A dedicated hybrid controller structure based on an Industrial IBM PC connected to a DELTA - TAU systems PMAC card, was designed to drive this robot and to co-ordinate its actions with those of the OCS roof mounted gantry delivery carrier system (4).

2. ROBOT CONTROL SYSTEM

The general block diagram and the main components of the control system is illustrated in Figure 1.

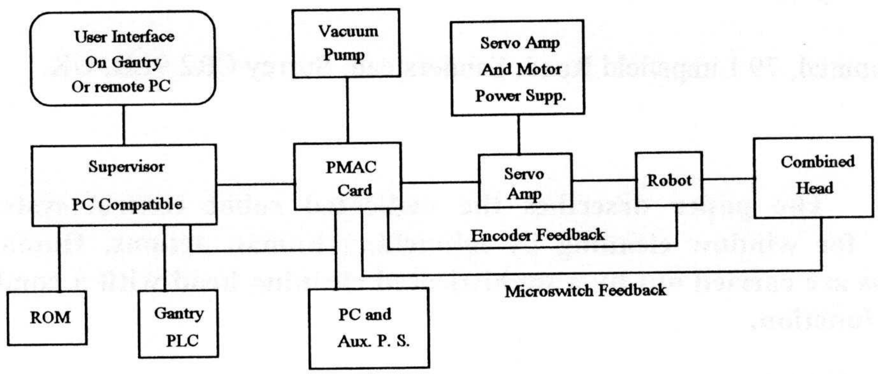

Figure 1; Block diagram of the control system

The role of the PC (Industrial grade) acting as the host supervisor for the gantry robot is to communicate with the gantry PLC system and also to communicate with the outside world i.e. the user interface diagnostics. It also control the gantry robot via the PMAC system. The PC used is diskless, all operating program and data being stored on ROM/RAM disks.

The PMAC card plugs directly into the supervisor back plane and is situated in the PC's memory map.

The robot system is a dedicated XYZR unit designed specifically for the window cleaning operations.

2.1 KINEMATICS OF THE ROBOT WINDOW CLEANER

The kinematics of the robot window cleaner are made simple due to the fact that the robot is cartesian. The only complication is the rotary joint (joint 4) and the offsets to each end of the cleaning head and it is these ends which must follow in a straight line, the edges of the window. In fact, during cleaning only three of the four axes of the robot are in motion as the in/out axis (Y axis) remains fixed. Figure 2 shows the definitions for kinematics of the cleaning head. The tool tips are defined as the ends of the cleaning blade. The blade itself has a length 'L' and is offset from the end of the robot by a distance 'D'. The co-ordinate system for each of the joints on the PMAC card are set up so that the angle of inclination of the blade is exactly the same as the rotary position of joint 4 (U axis). Therefore, in order to calculate the joint positions for the X and Z axes the following equations may be used:

$$X_r = X_{t1} + D\cos(U) + \frac{L}{2}\sin(U)$$

$$Z_r = Z_{t1} + D\sin(U) - \frac{L}{2}\cos(U)$$

and,

$$X_r = X_{t2} + D\cos(U) - \frac{L}{2}\sin(U)$$

$$Z_r = Z_{t2} + D\sin(U) + \frac{L}{2}\cos(U)$$

where (X_{t1}, Z_{t1}) are the co-ordinates for tool tip 1 and (X_{t2}, Z_{t2}) are the co-ordinates for tool tip 2, (X_r, Z_r) are the joint values for the X and Z axis of the robot and U is the angle of blade inclination.

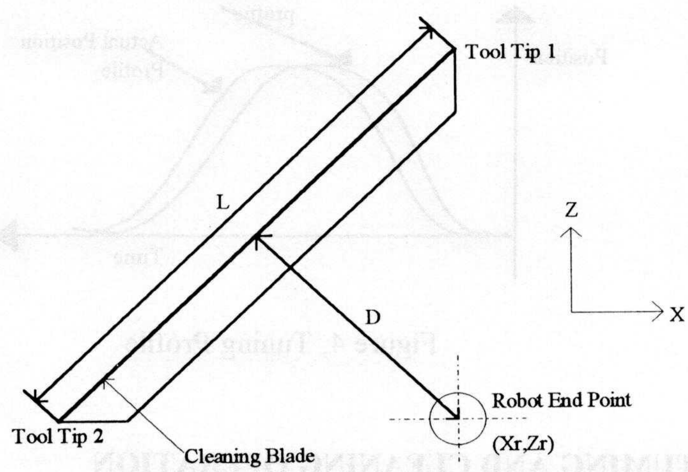

Figure 2, Definitions for robot kinematics

2.2 THE CONTROL STRATEGY AND TUNING

The controller uses a PID Plus control in order to control the robot axes. This is simply an enhanced PID form of control with velocity and acceleration feed forward terms in order to help overcome the effects of stiction and inertia. In run-time these velocity and acceleration feed-forward signals are applied temporarily for a period determined during the tuning procedure. The block diagram of the PID Plus and the velocity and acceleration feed-forward profile are illustrated in figure 3 and 4.

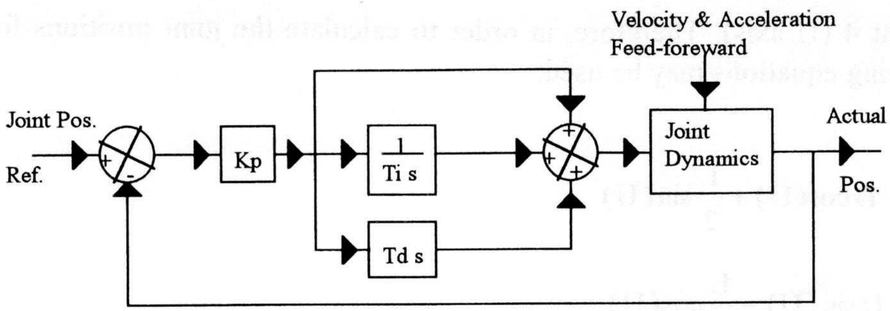

Figure 3, Block diagram of a PID Plus Controller

By connecting a monitor and keyboard to the robot, the in built robot software can be used to graphically analyse and tune each joint of the robot. This is done by first monitoring each joints response to a step input and tuning the proportional, integral and derivative gains in order to get the best performance. Once this has been done each joints response to a parabolic input can be measured and displayed (actual versus demanded) and the feed forward terms adjusted accordingly.

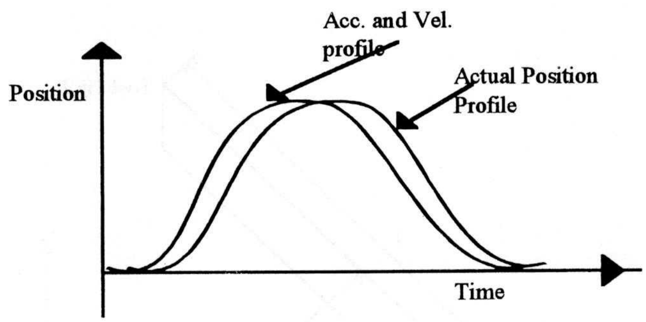

Figure 4, Tuning Profile

2.3. WINDOW DATUMING AND CLEANING OPERATION

The datuming stage can be programmed by moving single joints. That is, the controller can be programmed so that the robot performs joint interpolated motion where only the end joint values, velocities and accelerations have to be specified. The exact height, width, centre and the depth of the window pane with respect to the zero position of the robot is calculated in this stage by the PMAC card.

Once the datuming phase has been completed, the PMAC card can then use data found during the datuming to calculate the cleaning trajectory required to clean the window. An example of trajectory is shown in Figure 5. Due to the manner in which the PMAC card operates, the trajectory for each joint is calculated on-line as the robot is moving through the cleaning path. This means the moves are smooth and continuous throughout the entire cleaning process.

The job of the supervisory PC is to download the configuration of the windows and gantry level, etc. into PMAC card for calculating the cleaning trajectories using the data obtained from the datuming stage. A window configuration is defined as a set of one or more windows for any one gantry delivery position. It interrogates the PMAC for proper and safe operation during the window cleaning operation. Safety checks are performed automatically by the controller hardware during robot motion. For example if the robot fails to find one edge of the window during the datuming operation or the head is too close to window micro switches are activated. The controller is capable of reverting to manual control should a major fault occurs. These events are also brought to the attention of the operator of the building services control system.

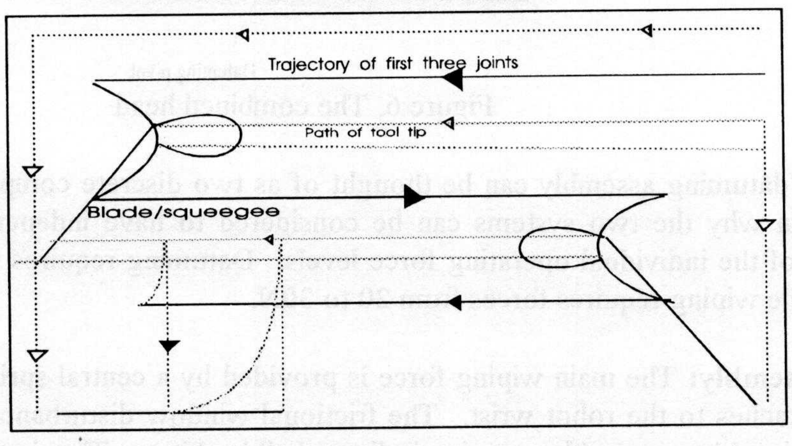

Figure 5; Example of Cleaning Path

3. THE COMBINED HEAD

The advantages of a combined head are obvious; no tool changes required between the two operations of datuming and wiping. Combining both functions reduces the mechanical and control complexity whilst providing the further advantage of being able to perform limited on-line datum monitoring while the wiping process is carried out.

Considerable attention was initially devoted to a pneumatic solution - providing ideal force control characteristics. But this had the drawback of requiring an air supply which would add weight to the gantry payload and was subsequently rejected. It was then decided to use passive compliance eliminating the pneumatic requirement. The outline of such a design using springs is shown in figure 6.

Spring Based System: After preliminary tests, typical wiping forces were found to be in the range of 20N for a 12 inch blade. The compliance was therefore designed such that a force of up to 30N could be tolerated, within the 25mm compression range.

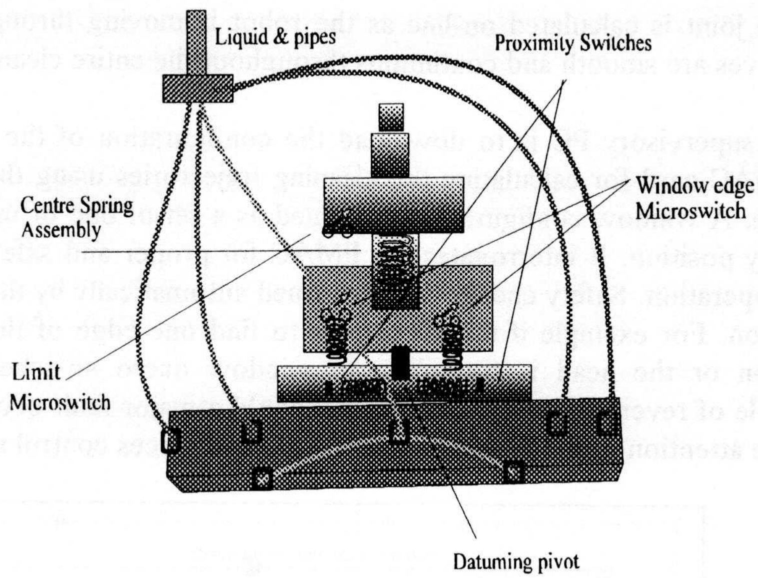

Figure 6, The combined head

The wiping/datuming assembly can be thought of as two discrete components combined. The principle reason why the two systems can be considered to have independent operation is the different level of the individual operating force levels. Datuming requires very light force levels, up to 10N, while wiping requires forces from 20 to 30N.

Wiping Assembly: The main wiping force is provided by a central spring located in the main body which attaches to the robot wrist. The frictional window disturbance forces of the wiping process are resisted by two guides running in linear ball bushings. That is the wiping spring force assembly only has a single axial degree of compliance, it is rigid in all other degrees of freedom. The central spring is pre-loaded to the minimum wiping force, 20N. Therefore no further spring compression or movement will occur until this limit is exceeded. So for force levels below 20N, i.e. when datuming, this provides an effectively rigid platform for the datuming head.

Datuming Assembly: As discussed above, the datuming assembly operates at force levels below 10N. Its main advantage is that the actual wiping blade assembly is used as the datuming probe. Apart from mechanical simplicity this approach should also display higher accuracy than achievable by using a separate datuming probe.

In the wiping position, when the force levels are higher than 10N, the datuming wiper blade assembly is pressed hard into its pivot pin stop. This prevents all movement apart from rocking about the pivot pin. This rocking motion is monitored by two micro switches.

During the initial datuming operation, where the blade does not make contact with the window, force levels are very low and certainly less than 10N and should be near zero. In this condition the two datuming head springs, repel the wiper blade assembly until the pivot pin is out of the pivot

stop and is relatively free to move within its movement envelope under only datuming spring restraint.

There are two proximity switches, in addition to the two micro switches monitoring rocking motion, mounted rear to the rocking pin to detect lateral translation of the wiper blade assembly. This latter facility is used to detect the window frame boundary using the two tips of the wiper blade.

CONCLUSION

A window cleaning robot system has been designed and developed which is capable of datuming and wiping clean general window panes. The combined head allows measurement of the window geometry, application of cleaning agent and wiping action in a single motion. The controller is developed such that it can be extended for cleaning variable size windows at any angle or inclination.

REFERENCES

1. Robot Simulation Study, an interim report written for OCS Group Limited, July 1990, Department of Electrical and Electronic, University of Newcastle Upon Tyne, UK.

2. Robotics window cleaning demonstrator, an internal report written for OCS Group Limited, an. 1991, Department of Electrical and Electronic, University of Newcastle Upon Tyne, UK.

3. Robot control system outline, an internal report written for OCS Group Limited, Jan. 1992, Department of Electrical and Electronic, University of Newcastle Upon Tyne, UK.

4. OCS robot controller, an internal report written for OCS Group Limited, Dec. 1992, Department of Electrical and Electronic, University of Newcastle Upon Tyne, UK.

ACKNOWLEDGEMENT

The authors wish to acknowledge the financial and technical support received from OCS Group Limited, United Kingdom. Any correspondence regarding publications listed in the reference section should be referred to the OCS Group Limited, 79 Limpsfield Road, Sanderstead, Surrey, CR2 9LB, UK.