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Imaging technology for robot maintenance and calibration

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Abstract
Mature robots in the manufacturing industry, i.e. those which have been in operation for 10 to 15 years, start to show wear-out characteristics as the lives of individual components are exceeded. Studies in the automotive industry, for example, where robots have been used for mass production for over 15 years, show that robots fail from a vast range of component failure modes, including mechanical drive faults, electronic failures in drive and control, and control parametric failures. In automated plants, for example, the robots may account for 20% of lost production time and cost £ millions per year in lost production.. In the future, the construction industry will doubtless adopt more and more automation and robotic solutions for its processes, and will thus face similar problems. This is particularly so as the construction site presents a far more adverse environment for automation and robotics than generally found in the manufacturing industry.

1. INTRODUCTION

In the last decade the use of robots has proliferated. The concentration of research has been on the development of new applications and enhanced performance. To ensure good reliability, early-life failures are designed out. Robust systems are provided by redundant capacity, multi-loop feedback control and self diagnosis. It must be recognised, however, that robots work in dirty and dangerous environments, where the maintenance required for such precision machinery and electronics may not be present.

Mature robots, i.e. those which have been in operation for 10 to 15 years, start to show wear-out characteristics as the lives of individual components are exceeded. The failures cost £ millions per year in lost production. In automated plants the robots may account for 20% of lost production time, and this proportion will become higher as the level of automation progresses.

Existing maintenance methods are clearly inadequate because of the nature of the failures. Methods for predicting failure have therefore been considered, with the intention of reducing overall costs, i.e. minimizing the sum of maintenance costs and lost production. It is necessary to know the main modes of failure of the plant to aim at the most significant areas. Any method which predicts the failures must be capable of working in the industrial environment - it is not cost effective to transfer plant to a laboratory for testing. Portable instrumentation is likely to offer better pay back since the monitoring will not be continuous, and can therefore be used on many robots.

Optical methods were considered because they offer non-contact metrology techniques at long range. Digital processing of images for measurement is common in medicine and astronomy, and vision systems are now common in industrial automation. Vision is often used to enhance the capabilities of robots, but the system discussed here turns the camera on the robot to evaluate the robot's own performance.

2. MAINTENANCE METHODS AND FAILURE STATISTICS

The majority of maintenance techniques for robots are based on manufacturer's recommendations, and include only the basic requirements for mechanical and electrical plant (see table 1). The main function of a robot is to assume a programmed position, but this is rarely checked or calibrated.

Thorough testing and acceptance procedures were documented by Warnecke and Schraft [1]. These methods are largely adopted by the British and International standards for robot testing [2], and include:

- Geometric values;
- Kinematic values;
- Dynamic values;
- Power and noise values;
- Thermal values.

The methods suggested, however, intrude to the extent that they are, at least, likely to stop production, and at worst require installation in a test laboratory. Neither of these is suitable in the industrial environment.

Studies in the automotive industry [3], where robots have been used for mass production for over 15 years, show that robots fail from a vast range of component failure modes, including mechanical drive faults, electronic failures in drive and control, and control parametric failures. The sample of historical data included over 400 robots from five manufacturers performing tasks including:

i) Spot welding;
ii) Arc welding;
iii) Stud welding;
iv) Sealant application;
v) Component Handling.

The robots consisted mainly of two types of arm geometry: all revolute axes, and gantry (main axes prismatic, wrist axes revolute). Most of the robots were electrically powered, but two production lines were hydraulically powered.

Robot failures accounted for 20% of down time in automated production lines, of which 45% were positional failures and 25% were drive failures (see figure 1). The positional error is manifested by collisions, unscheduled reprogramming, scrap work and sequence stops. Drive faults include all aspects of the actuator mechanism - shafts, bearings, gears, belts, motors, couplings, motors, brakes and controls.

The historical data does not suggest common components which fail. In complicated actuating systems many different components and parameters in mechanical, electrical and control systems can cause similar symptoms, and a measure of overall system performance will be more effective at predicting failure.

3. SELECTION OF A MONITORING METHOD

There are a number of well established machine monitoring techniques, such as lubricant, vibration, and thermal analysis [4]. These are not appropriate to detect the deterioration of positioning. In selecting suitable methods for monitoring the condition of robots, it is necessary to consider the following points [5]:

i) the machine does not operate continuously, so it is difficult to obtain a consistent sample signal;
ii) failures are not restricted to a few known components;
iii) the machine moves considerably when operating; instrumentation fixed on axes other than the first must move with the robot; the instrumentation, whether on or off the robot, must not obstruct movement;
iv) the machine has many axes which require individual instrumentation for certain monitoring techniques.

The critical parameters depend on the application, and BS7228 [2] tabulates those which are appropriate. In some cases the path criteria are important (e.g. arc welding or sealant application) but for many applications the positional accuracy and repeatability of the robot at any programmed point is critical (e.g. component handling, assembly or spot welding). The majority of the applications considered were of the latter type.

Any method chosen to monitor condition or performance on the basis of accuracy and repeatability must take into account the practical problems associated with industrial robots:

i) Accessibility: the robot is usually guarded to avoid danger to personnel; measurement must not interrupt production;
ii) Conventional industrial instrumentation for the measurement of displacement requires the measurement probe to be very close to, if not touching, the moving object;
iii) Hard-wired instrumentation may be too expensive: permanent installation on many robots may not be cost effective, so the measurement system must be portable.

The factors above preclude the use of LVDTs, non-contact capacitive or inductive proximity probes, or the low cost laser probes. The accuracy required, however, is relatively low: errors which indicate the deterioration of a robot's positioning performance tend to be around a few millimetres. Laser techniques measuring to a wavelength of light are over-accurate and over-expensive. Other optical methods using visible light offer the accessibility, flexibility and portability required, while offering accuracy better than required.

4. THE MIDAS SYSTEM

A system called MIDAS (Measured Image Displacement Analysis System) was conceived to measure the accuracy and repeatability of robots and other mechanical handling equipment, without disrupting production and without gaining close access to the robot. The technique is essentially a development of simple photogrammetry techniques, where still photographs are compared to detect displacement [6].

4.1 Hardware

MIDAS uses images acquired from a video camera, which are digitized and stored on an image processing card fitted in a portable PC (see figure 2). The system was designed from the top down, with an architecture incorporating modular hardware and software, for rapid development and compatibility. The hardware is based on off-the-shelf components with industry standard platforms and interfaces; where possible software was chosen to complement the hardware. A proprietary image processing card accepts standard PAL video inputs, produces RGB output for a video screen. Data acquisition and subsequent processing is controlled by instructions from the PC's data bus.

CCD (charge-coupled device) video cameras are suitable for most industrial lighting conditions - a sensitivity down to 0.1 lux allows operation in low levels of indoor ambient light, and excellent performance in outdoor daylight. CCDs have excellent geometric stability and repeatability (particularly when compared to tube cameras) and are robust, light, and inexpensive. The optics are very important, because powerful magnification is required to obtain sufficient accuracy. Typically lenses of focal length up to 135 mm are used to obtain a resolution of 0.1 mm at a range of 2 - 3 m.

The image processing hardware consists of two image arrays which can store frames of resolution 512 x 512 monochrome pixels, each of 8-bit grey resolution (i.e. a contrast resolution about 4 times that of the human eye). The board digitizes images and displays at full video rate, i.e. 25 frames per second or 6.5 million pixels per second.

4.2 Measurement

The principle of measurement is that the camera remains steady, while the robot moves repeatedly away from and back to a programmed position. The measurement of accuracy and repeatability of a robot relies on the selection of a suitable feature on the robot itself. The requirements are:

- The feature must offer a recognizable edge, i.e. dark to light;
- A known distance should be in the image for calibration.

If necessary an edge can be artificially fixed to the robot, and the calibration can be calculated by other means. It is first necessary to focus the camera on the chosen edge. An image is recorded by the computer, and the features in the image are used by the operator to calibrate the system. The operator selects the direction in which the edge will move,and the system records the current position of the edge as a datum (see figure 3). Subsequent frames are triggered either manually or automatically after a cycle of the robot, when the edge returns to the measured position. Each frame is scanned to determine the new position of the edge relative to the datum. Following the recording of sufficient measurements, the software calculates peak-to-peak, standard deviation, maximum displacement and error.

A portable camera offers the lowest cost option for running MIDAS, but requires to be set up on each occasion, and cannot perform all measurements over a long period. Fixed cameras offer the advantage that all their set up parameters can be stored in software after initialization. Furthermore, a permanent datum is provided, which allows long term trends (e.g. drift) to be recorded. It is possible for the host computer to store the parameters for many fixed cameras, so improving performance while retaining a degree of portability. Clearly fixed cameras are a compromise on cost, but offer advantages to applications where the potential savings are sufficient.

The system was field tested on 4 sites over a year. Normally, production machines run satisfactorily, so extensive measurements were required before failures were detected. The results shown below were measured on gantry robots similar to that shown in figure 4, which had been in operation for approximately 15 years. The robot has 3 prismatic axes (X, Y and Z), and 3 rotational wrist axes (A, B, and C). The manufacturer's recommended tolerance was ± 0.35 mm, and the user required a tolerance up to ± 1 mm.

Typical results on a robot in normal operating condition showed a peak-to-peak error of less than 1 mm (see figure 5). This parameter, and other statistical values representing the spread of positioning and the drift, were recorded over extended periods for a group of similar robots. All the points on the graphs represent at least 10 robot cycles.

A poorer performance is shown in figure 6, where the maximum deviation from datum is recorded over one afternoon. The error gradually increases from about 2 mm to 3 mm, until a final reading approaches 10 mm - the robot failed at this point and further measurements were not possible.

The benefit of long-term measurements from a fixed camera is shown in figure 7, where a large offset is shown to be accidentally introduced and corrected by robot referencing procedures. This would not normally have been detected until scrap work was produced.

CONCLUSIONS

- Inaccuracy in position causes up to 45% of down time in robots studied.
- Measurement of accuracy and repeatability offers early warning of failure.
- MIDAS allows measurement of displacement without disrupting production, and without close access to the machine.
- The optics and image processing allow reasonable accuracy at a sufficient range.
- The software system allows flexibility in setting up and calibration.
- The portability of the equipment allows application to a great number of machines, thus improving cost effectiveness.

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- ✓ Visual inspection of equipment including:
  Gears, belts & chains
  Electrical cables
  Cleanliness
  Hoses, flexible joints and connecting devices.
- ✓ Regular checks on:
  Voltages
  Hydraulic fluid
  Filters
- ✓ Lubrication - slides, racks, ballscrews, bearings, gears, chains
- ✓ Servo adjustments
- ✓ Maintain a log on every robot to provide history and forecast requirements.
- ✓ Check quality of product. Check any trend towards defective products.
- ✓ Periodic replacement of critical components
- ✓ Actions prescribed by the manufacturers for specific assemblies

Table 1: Traditional maintenance for robots

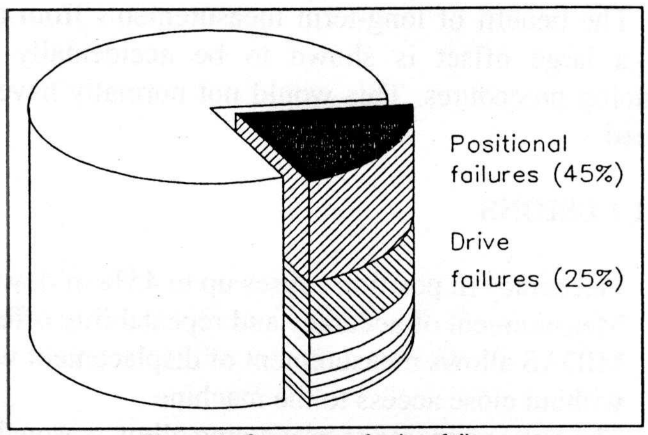

Figure 1: Summary of robot failures

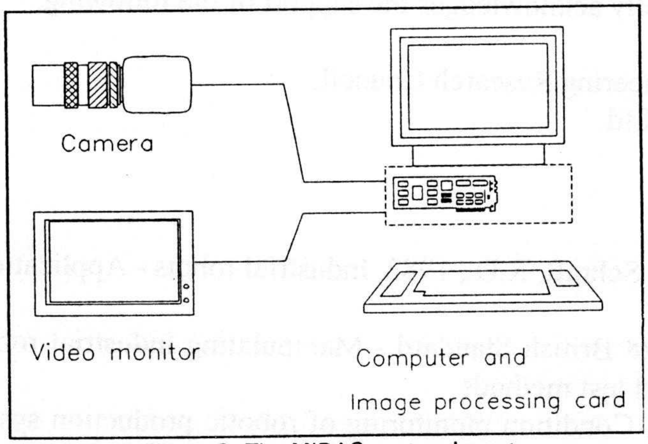

Figure 2: The MIDAS system layout

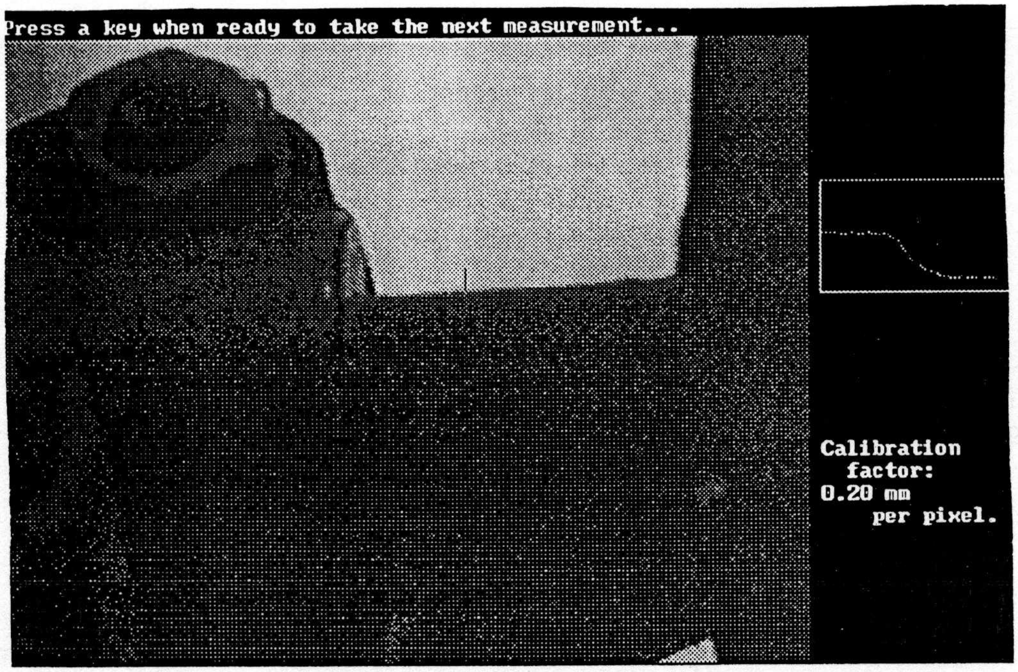

Figure 3: Edge selection on a captured image

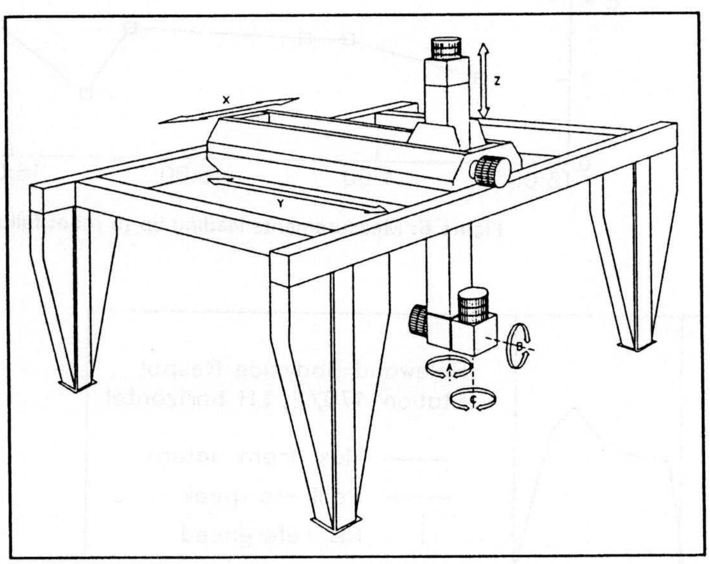

Figure 4: Gantry robot

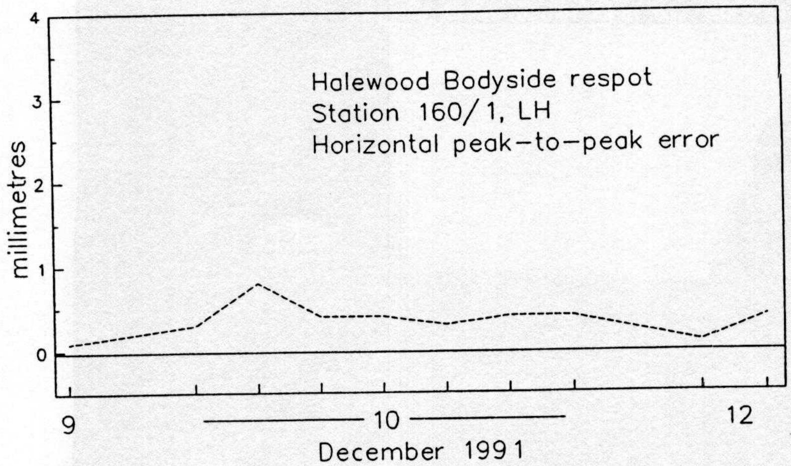

Figure 5: Typical robot performance

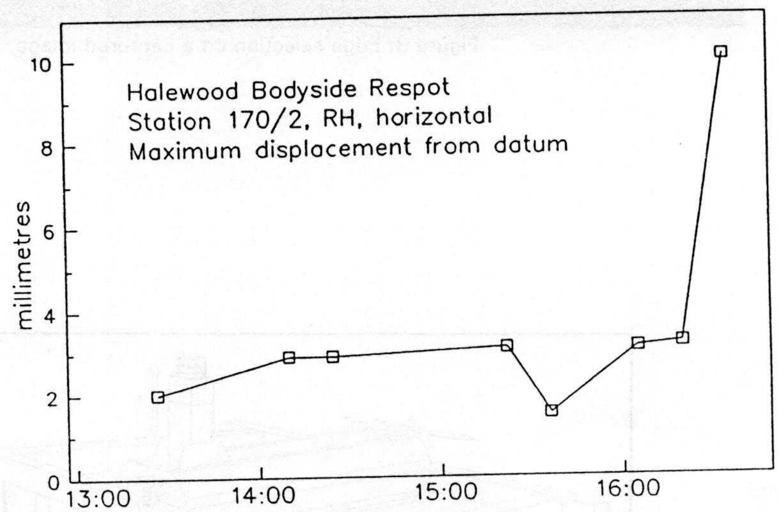

Figure 6: Measurements leading up to robot failure

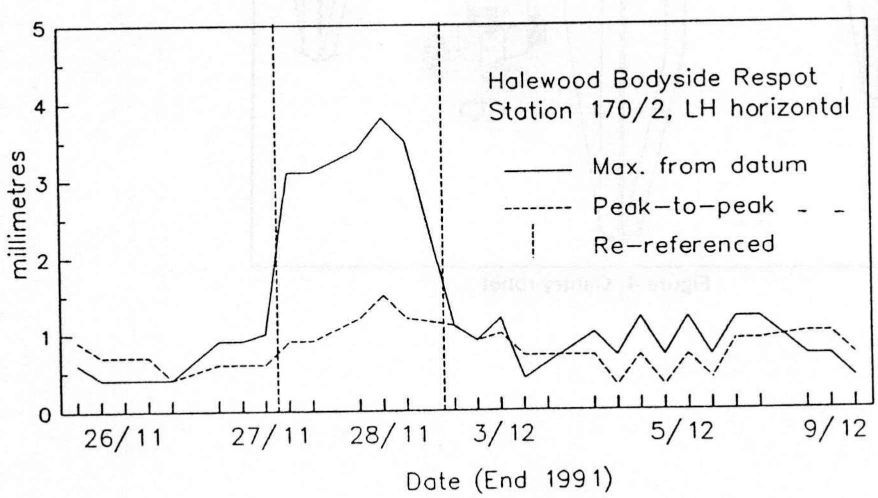

Figure 7: Re-referencing offsets