TECHNICAL REPORT

ISO TR 13309

First edition
1995-05-15

Manipulating industrial robots — Informative guide on test equipment and metrology methods of operation for robot performance evaluation in accordance with ISO 9283

Robots manipulateurs industriels — Guide informatif sur l'appareillage d'essai et les méthodes métrologiques opératoires pour l'évaluation de la performance d'un robot conformément à l'ISO 9283

Reference number
ISO/TR 13309:1995(E)

CONTENTS

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented in that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of ISO technical committees is to prepare International Standards. In exceptional circumstances a technical committee or sub-committee may propose the publication of Technical Report of one of following types:

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee or sub-committee has collected data of a different kind from that which is normally published as an International Standard ("state-of-the-art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13309, which is a Technical Report of type 3, was prepared by Working Group 2 - Performance criteria and related testing methods - of ISO/TC 184/SC 2 - Robots for manufacturing environment.

This document is being published in the form of a Technical Report because it is intended to provide an overview on technically feasible metrology methods and the current state-of-the-art of test equipment when evaluating robot motion performances in accordance with ISO 9283:1990 - Manipulating industrial robots - Performance criteria and related test methods.

Introduction

The International Standards ISO 9283 and ISO 9946 were published in 1990 and 1991 in order to meet the needs of industries. For the purpose of supplementing these standards some amendments are being investigated for real applications.

It is important to clarify the kind and performance level of existing measurement systems applicable to robots in relation to ISO 9283 and establishing additional standards or reports.

This Technical Report contains an attempt to classify the measurement techniques and methods applicable to the robot characteristics testing, and describes the principles of operation and accuracies of the current state-of-the-art, and as much as possible, currently available measurement systems.

Manipulating industrial robots — Informative guide on test equipment and metrology methods of operation for robot performance evaluation in accordance with ISO 9283

1. Scope

This report supplies information on the state-of-the-art of test equipment operating principles. Additional information is provided that describes the applications of current test equipment technology to ISO 9283.

2. Major categories of performance measuring methods

There are several methods which are used for characterizing robot performance in accordance with ISO 9283. These methods are classified as follows:

1. Positioning test probe methods
2. Path comparison methods
3. Trilateration methods
4. Polar coordinate measuring methods
5. Triangulation method
6. Inertial measuring method
7. Coordinate measuring methods
8. Path drawing method

Brief discussion of these methods is given in Section 4. Detailed description of these systems can be found in documents provided in Library list (Annex C).

3. Recommended robot performance measuring methods

Table 1 presents a list of the recommended methods for measuring the performance criteria in accordance with ISO 9283. The methods that are categorized into eight categories in Section 2 are itemized into a total of 16 individual methods. Each method's capabilities are also provided. Although some methods can be used to measure the characteristics of both the pose and the path, some of the methods have limitations. Some of the limitations are:

- (1) Only position (or orientation) can be measured in pose characteristics testing.
- (2) Path characteristics (linear or circular) can be measured only along restricted command paths.
- (3) Only robots with limited overshoot can be tested.
- (4) The performance of the test equipment may not provide sufficient accuracy or uncertainty of measurement for particular characteristics.

- (5) Measuring is limited to the number of freedom of the test equipment.
- (6) The test equipment may provide limited measurement volume compared to the test cube defined in ISO 9283.
- (7) The sampling frequency of the test equipment may not fit for the top frequency of the robot movement to be measured.

The tester should discuss the limitations with the test equipment manufacturer when planning performance measurement.
Table 2 is a summary of typical performance characteristics and capabilities of the recommended methods. It is advised that before testing a robot, the tester should understand the performance levels of the robot and select the appropriate testing methods.

4. Robot performance measuring methods

This section is a descriptive presentation and schematic configurations of the methods listed in Table 1.

4.1 Positioning test probe methods

The attained pose characteristics can be measured using a probe containing sufficient number of displacement or proximity sensors which are positioned by the robot to slowly touch a precision artifact located at a prescribed position or to stay in the air to measure possible overshoot. A typical set up is shown in Figure 1. Figure 2 shows some alternative applications of the method. Several types of test artifacts and probes can be combined, depending on the number of pose parameters required.

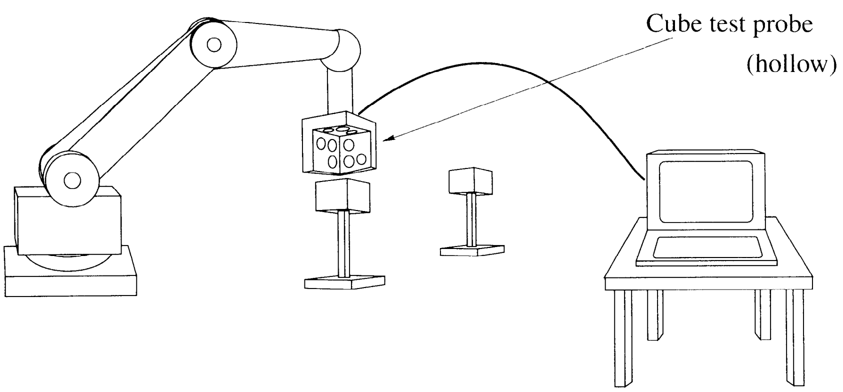

Figure 1 Positioning test probe method (cube artifact)

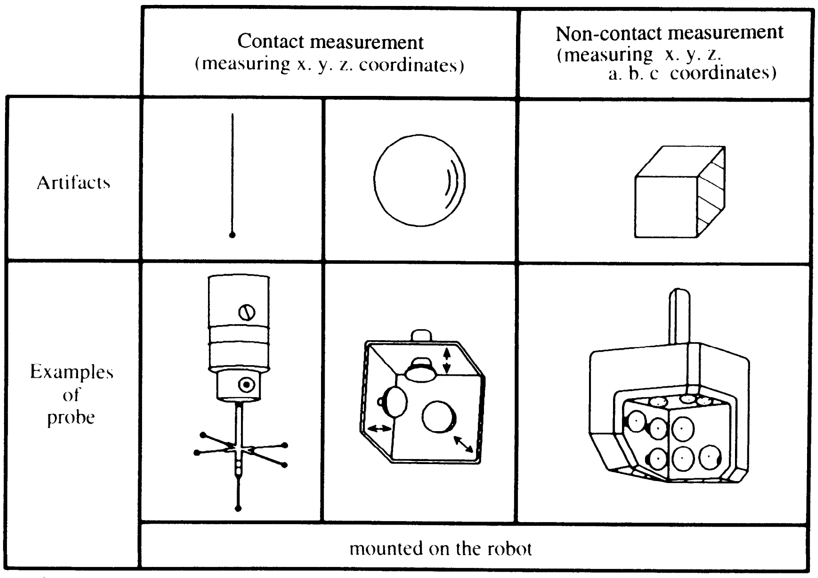

Figure 2 Artifacts of positioning test probe method

4.2 Path comparison methods

4.2.1 Mechanical gage comparison

This methods is based on comparing an attained path with a command path which could be composed of linear or circular path segments. The path is constructed using a precision mechanical gage or other position reference structure. Figure 3 shows a set up for the method where the proximity sensors are fitted on a cube probe and the artifact is a straight edge representing the command path. Deviations occurring during the execution of the path are sensed by appropriate number of sensors and used to determine characteristic parameters (accuracy and repeatability) of the attained path. Complete pose deviations (position and orientation) can also be determined when sufficient sensors are used.

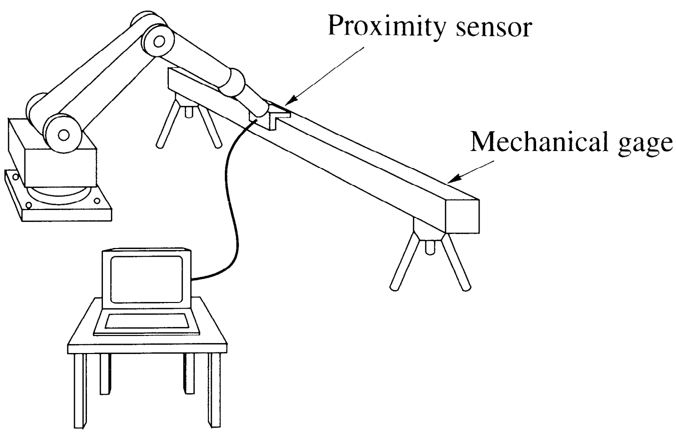

Figure 3 Mechanical gage comparison

4.2.2 Laser beam path comparison

Path accuracy/repeatability along a laser beam can be measured with a photosensitive transducer which has the capability of detecting the position error of incident beam from the centre of the transducer. System set up is shown in Figure 4.

The robot's pose along the beam can be calculated as a function of time if the laser source is replaced by a laser interferometer and the photosensitive transducer has light reflecting capability.

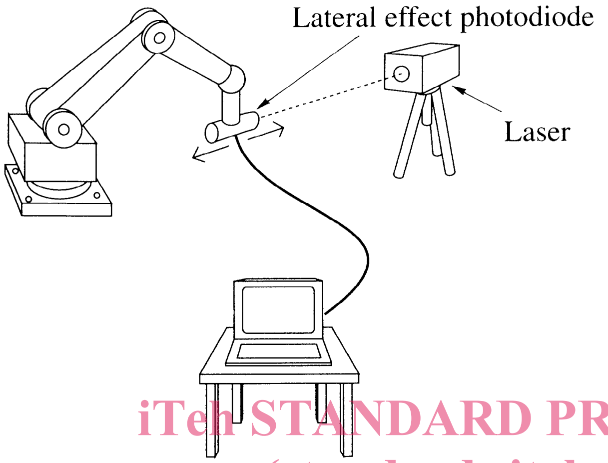

Figure 4 Laser beam path comparison

4.3 Trilateration Methods

Trilateration (meaning "using three sides") is a method of determining the Cartesian coordinate (x, y, z) of a point P in three-dimensional space with three distance values between the point P and the three observation stations, and the base lengths between three fixed stations. Figure 5 explains the principle of trilateration in two-dimensional representation.

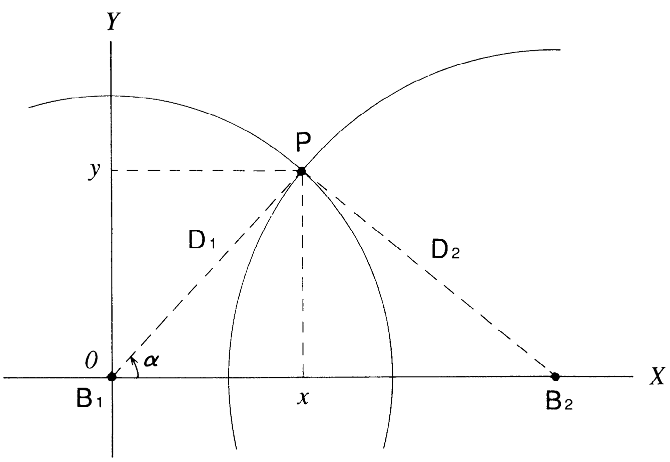

Figure 5 Measuring principle of trilateration
(two-dimensional representation)

4.3.1 Multi-laser tracking interferometry

This method is based on using three laser beams produced from three laser interferometers with two-axis servo controlled tracking aimed at a common target located on the robot's wrist. System set up is shown in Figure 6. The Robot pose characteristic in three-dimensional space can be determined based on distance data obtained from the three interferometers. The orientation can be measured if six interferometers are used in a set up in which the six beams are aimed at three independent targets on the robot.

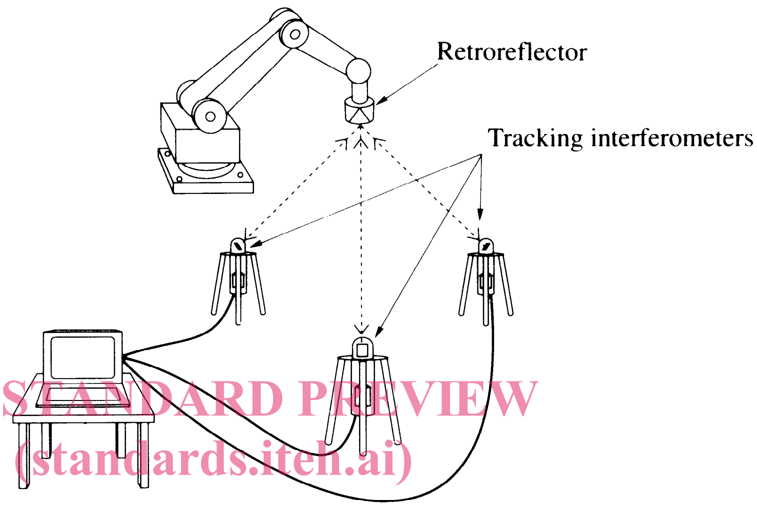

Figure 6 Multi-laser tracking interferometry

4.3.2 Ultrasonic trilateration

The robot's position in three-dimensional space can be calculated with distance data from three stationary ultrasonic microphones which receive ultrasonic pulse trains from a sound source mounted on the robot. System set up is shown in Figure 7.

The robot's orientation can be measured if the robot has three independent sound sources and each stationary microphone can detect pulse trains from all three sound sources.

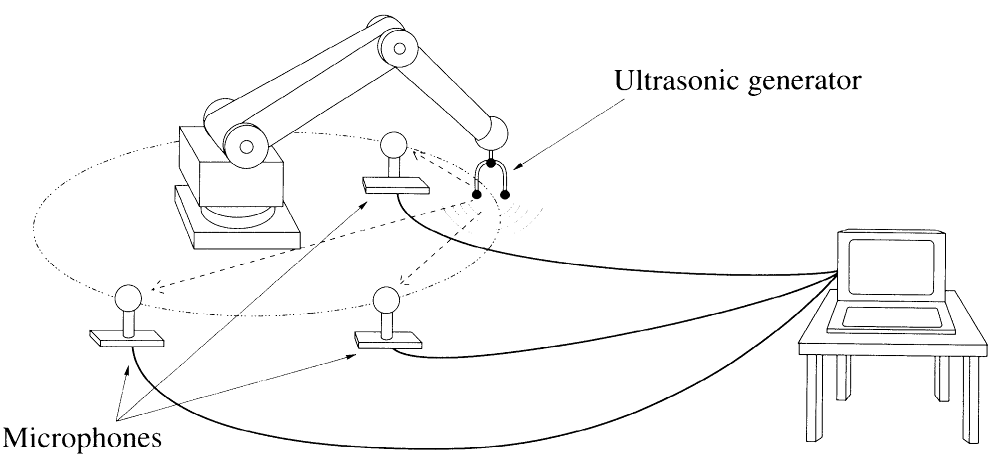

Figure 7 Ultrasonic trilateration

4.3.3 Mechanical cable trilateration

This methods is based on connecting three cables originated from three fixed cable-feeding devices to the robot's end point as shown in Figure 8. By evaluating the length of each cable, such as using potentiometers or encoders on the cable feeding devices which maintain the cables under tension, the position of the robot's end point can be determined.

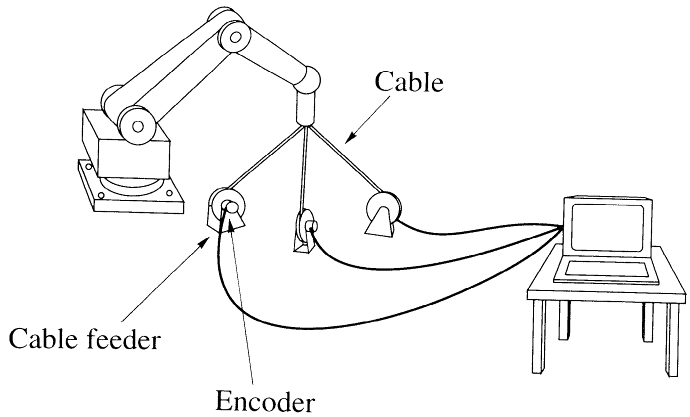

Figure 8 Mechanical cable trilateration

4.4 Polar coordinate measuring methods

Polar coordinate measuring methods can be used to determine the Cartesian coordinate (x, y, z) of a point in space by measuring a distance D, azimuth (α) and elevation (β) values as shown in Figure 9.

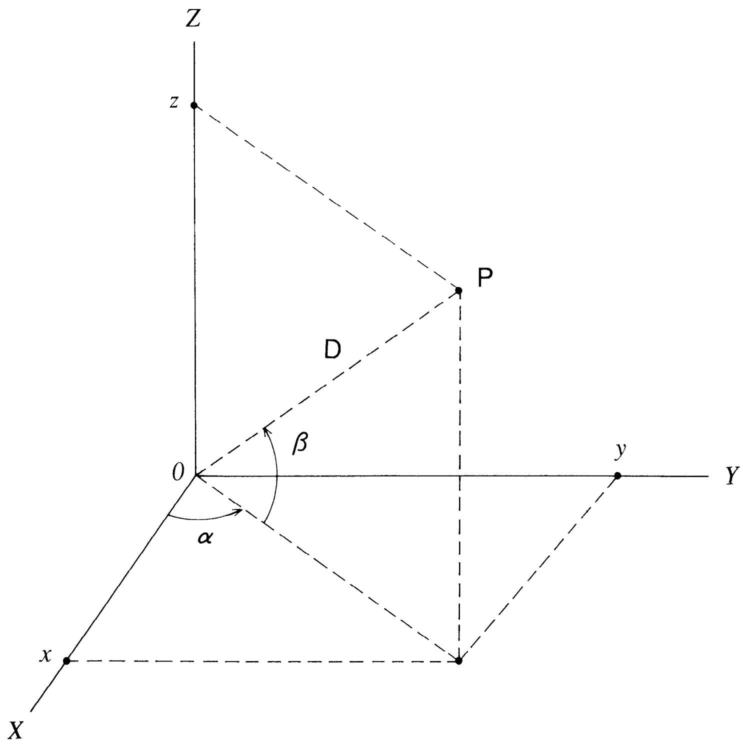

Figure 9 Principle of three-dimensional polar coordinate measuring

4.4.1 Single laser tracking interferometry

Laser tracking interferometry method can be used to measure robot's position or orientation. Figure 10 shows a typical setup of a single laser interferometer for position measurement. The robot's position can be calculated with distance data from the laser interferometer and azimuth/elevation data which is obtained from a stationary tracking system aimed at a retroreflector mirror mounted on the robot's end point.

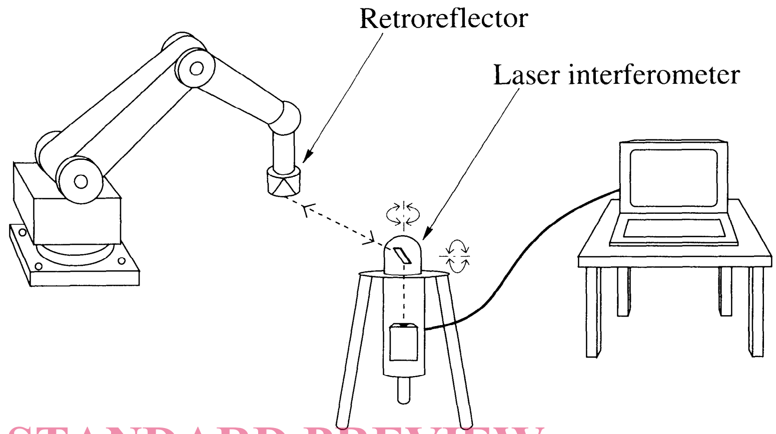

Figure 10 Single laser tracking interferometry for position measurement

The robot's orientation (pitch and yaw) can also be measured using the same system (Figure 11), if the retroreflector mirror system has the capability of keeping its optical axis pointed to the stationary tracking system, or if the stationary tracking system can analyze the diffracted image reflected by the retroreflector. This method can test 6 DOF (degree of freedom) robots.

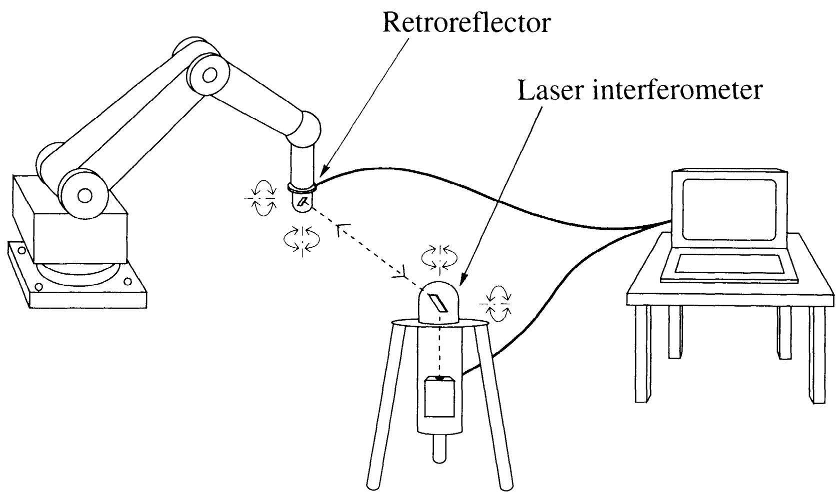

Figure 11 Single laser tracking interferometry for pose measurement