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Laser interferometry-based guidance methodology for high precision positioning of mechanisms and robots

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ABSTRACT

Laser interferometry-based sensing and measurement (LISM) technique was originally investigated to perform dynamic measurements of the end effector of a robot manipulator in motion. This technique can provide dynamic position measurements in real time and has high accuracy, large working space, high sampling rate and automatic target tracking. In this paper, a methodology using LISM technique is proposed to perform laser interferometry-based guidance (LIG) for accurate positioning of a robot manipulator in high precision manufacturing operations. The methodology utilizes the LISM apparatus to guide the robot's end effector to a desired location or along a desired path by directing the robot to follow the trajectory mapped by the laser beam. This is accomplished through the establishment of techniques for path generation, sensing and data acquisition and guidance error determination and compensation in the control algorithm. The algorithms for this methodology, together with the measurement and analysis techniques are described. A number of experiments are carried out to examine and validate the proposed LIG technique. Experimental results show that the established technique can effectively improve the positioning accuracy of the robot manipulator.

1. Introduction

The increase in the number of complex applications of robots in manufacturing and service industries has emphasised the need for robot manipulators with high positioning accuracy [1–5]. It is well known that the repeatability of today's industrial robot is at least an order of magnitude better than its absolute accuracy [6]. This is due to the fact that the position and orientation of a robot manipulator is described using a kinematic model in the controller. This kinematic model uses the joint positions determined from the axes encoders to provide the three-dimensional coordinates of the end effector. The accuracy of such model is generally low, as it is heavily dependent on the accuracy of the parameters used in the model [7]. These parameters include joint positions and link lengths, which in turn have non-linear uncertainties that are affected by the environmental factors (e.g. temperature), load conditions and inherent dynamic properties of the joints and links (e.g. joint backlash).

Different methods have been developed to improve the accuracy of robots [8–11]. These methods include static or dynamic calibration of the robot manipulator and neural network-based learning of the uncertainties. The most difficult aspect of kinematic calibration is that many measurements throughout the workplace are required to establish compensation values for the variations of kinematic parameters and to obtain accurate measurements of the end-effector position. Furthermore, kinematic calibration is time consuming and the compensation accuracy significantly depends on the knowledge of the operator. The convergence speed of the neural network training is one of the obstacles for the application of the learning of the uncertainties. Generally, the neural network training is also time consuming, and the prediction accuracy for the uncertainties relies on the amount and the representation of the training samples. Furthermore, the uncertainties resulted from the temperature are difficult to compensate by using the neural network.

In order to obtain a large number of position measurements required for kinematic calibration, laser interferometry-based sensing and measuring (LISM) technique was proposed to perform dynamic measurements of the robot's position to accurately determine the parameters in the kinematic model [12]. Further, a study was conducted to establish uncertainties in laser-based measurement technique [13]. The LISM technique can be divided into two categories: single- and multi-laser beam methodologies. The single-beam LISM technique uses the azimuth and elevation angular displacements of the steering mechanism to determine the position of the end effector of the robot manipulator [14]. It can also be used to obtain orientation measurements of robot's end effector by adopting dual position sensitive diodes (PSD). This technique can provide dynamic position measurements in real

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time and has high accuracy, large working space, high sampling rate and automatic target tracking [12–15]. The LISM technique has become indispensable for many experiments where position measurements are required. It has been used for position measurements for stiffness modelling and identification, and estimating positioning errors for error compensations [16–18]. In order to improve the positioning accuracy of the robot manipulator, a novel laser interferometry-based guidance (LIG) technique is proposed to direct the end effector of robot manipulator to a desired position in Cartesian space along a predefined trajectory by steering the laser beam.

This paper presents further development and experimental research of the methodology for laser interferometry-based guidance of the robot manipulator using LISM apparatus. The method is a control strategy whereby the LISM apparatus is used to guide the robot's end effector accurately to a desired point in Cartesian space along a predefined trajectory by directing the robot to follow the path mapped by the laser beam. The principle of the LISM technique is briefly described. The principle of the LIG technique and configuration of sub-systems are then developed. The kinematics of the LIG system is derived, and the control algorithm for this methodology, together with the measurement and analysis techniques are described. The experimental setup is described and the implementation of the methodology and experimental results for the proposed LIG technique are presented.

2. Review of laser interferometry-based sensing and measurement

Laser interferometry-based sensing and measurement provides for dynamic acquisition of the three-dimensional position of a manipulator's end effector. The LISM system uses the angular and distance data, obtained from the beam steering mechanism and the interferometer, respectively, to provide the position of the target retroreflector attached to the end effector of the manipulator. It maintains tracking of the target by sensing the offset of the incident and reflected beam. It subsequently performs offset corrections by adjusting the angles of the beam steering mechanism. An experimental LISM apparatus has been developed for this study, and a functional layout of the overall design of the experimental LISM apparatus is provided in Fig. 1.

The laser interferometer utilized in this technique is a special variant of the Michelson laser interferometer employing the Zeeman split. A HeNe laser head generates the heterodyne laser beam consisting of two orthogonally polarised frequency components F_1 and F_2, offset by 20 MHz. The laser beam travels to the interferometer where it is split into a reference beam F_1 and a measurement beam F_2. The reference beam is directed to the reference retroreflector where it is reflected and directed to the measurement board in the laser interferometer controller via the fibre optic pickup. This beam will later be compared with the returning measurement beam, whose frequency will be Doppler shifted, to determine the displacement of the laser beam. The measurement beam travels through a 70–30% beam splitter and is directed to the target retroreflector mounted on the robot end effector by the beam steering mechanism. Once the beam hits the target, the beam is reflected through 180° and it travels back parallel with the incident beam. If the beam does not hit the centre of the retroreflector, it will be offset by an amount that constitutes the tracking error of the beam.

The reflected beam then travels through the mirror assembly and back to the 70–30% beam splitter. A 30% of the beam power is diverted to a PSD. The PSD detects the offset of the beam from the centre of the PSD sensor. This offset error is referred to as the tracking error. The remaining 70% of the beam power will be combined with the reference beam via the interferometer and the fibre optic pickup. As the end effector of robot manipulator carrying the retroreflector is moved, the frequency F_2 of the measurement beam shifts from the frequency of the previous measurement beam based on the Doppler principle, yielding a frequency change of ΔF_2. In the interferometer controller, F_1 and

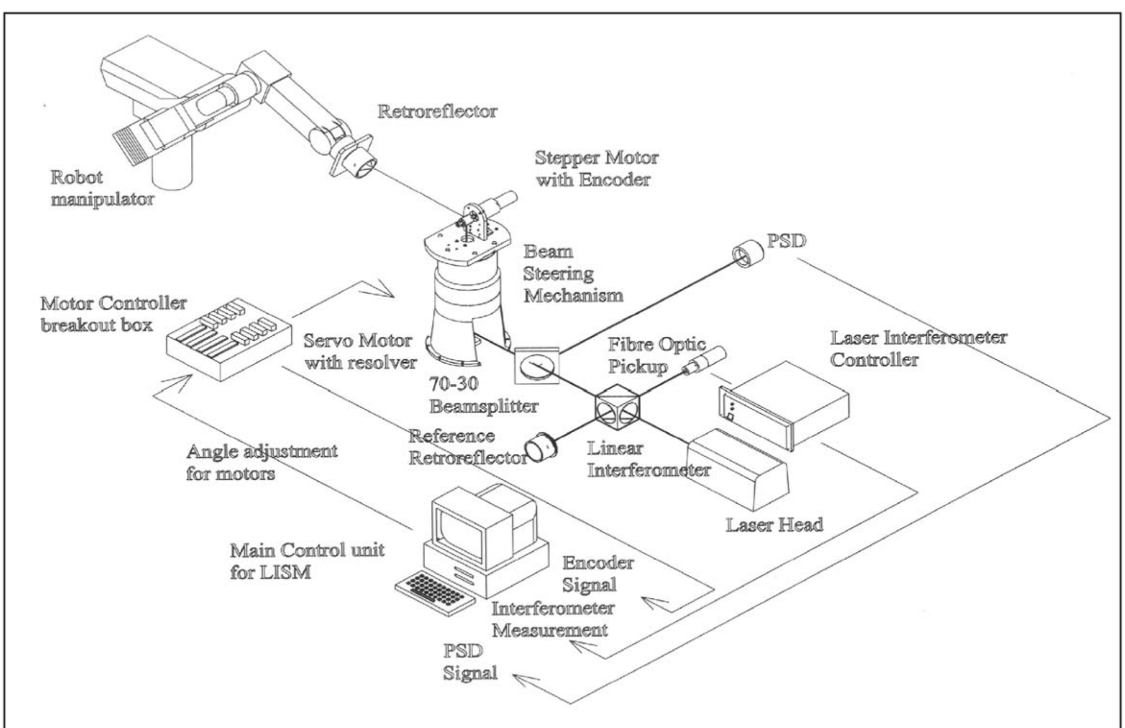

Fig. 1. Functional layout of experimental LISM apparatus.