The Calibration of Parallel-CMM: Parallel-Coordinate Measuring Machine

O. Sato[1], M. Hiraki[2], K. Takamasu[1]

[1] The University of Tokyo, Japan; [2] Tokyo Denki University, Japan

Abstract:

The Coordinate Measuring Machine (CMM) is widely used for the 3D measurements of objects. Traditional CMM is based on a serial mechanism whose drawbacks are weakness against external forces and the accumulation of errors. We developed a new type of CMM based on a parallel mechanism. The advantages of this mechanism are its robustness against external force and error accumulation. On the other hand, this mechanism has disadvantages. One is its difficulty in its calibration. We make our prototype of parallel CMM to calibrate it easy by using unique joints. This paper deals with the calibration of our prototype of parallel CMM.

Introduction

The Coordinate Measuring Machine (CMM) is widely used for the 3D measurements of objects. Traditional CMM is based on a serial mechanism: the components from base unit to end-effecter i.e. base unit, ***x***-axis, ***y***-axis, ***z***-axis and measuring probe are connected serially. But some drawbacks of this mechanism are its weakness against external force and the accumulation of errors. Therefore CMM tends to become large and heavy in order to avoid the influence of the bending and twisting of its components and to decrease measurement errors. Because of its weight, it has been a very difficult problem to make large CMM capable of fast 3D measurement.

We develop a new type of CMM based on a parallel mechanism where the base unit and end-effecter are connected by six links parallel. The advantages of this mechanism are its robustness against external force and error accumulation[1]. Therefore we will able to make larger measuring machine that can measure large objects quickly. On the other hand, there are some disadvantages by using parallel mechanism for CMM. One is the difficulty in the calibration of CMM. Because of its difficulty in solving its forward kinematics and large number of parameters its geometrical model includes, it is hard to calibrate parallel mechanism efficiently.

To make the calibration of parallel CMM easy, we make our prototype by using unique spherical joint consists steel balls and magnets. That allows higher repeatability of positioning and setting-up.

At first, the prototype of parallel CMM that has been developed in our laboratory is introduces. Next we discuss about the parameters we should identify to calibrate parallel CMM and how to calibrate it. Lastly, we give the suggestion of the method to calibrate our prototype efficiently.

Prototype of parallel CMM

Fig. 1 shows the prototype of parallel CMM. This prototype has 3 DOF and its forward kinematics can be solved analytically.

This mechanism consists three linear actuators, three linear scales, six connecting rods, end-effecter and spherical joints. All heavy components, linear actuators and linear scales, are fixed on the base unit, so the upper part of this mechanism is very light and can move quickly. The end-effecter can move only ***x***, ***y*** and ***z*** axis and does not rotate. The repeatability of positioning of the end-effecter is about 2µm.

The end-effecter, connecting rods and carriers are connected by the spherical joints using steel balls and magnets shown by Fig. 2. This spherical joint consists a magnet and triangle hole and holds the steel ball at three points on its spherical surface. The advantage of the joint is high repeatability because of no gap between the housing and the ball.

Using this joint gives the high repeatability of the position of the end-effecter when we separate all connecting rods and end-effecter from the base plate and reset up them when each position of the carriers are not changed (Fig. 3, 4). This means we can choose each way of calibration for each component.

figure 1: Prototype of parallel CMM.

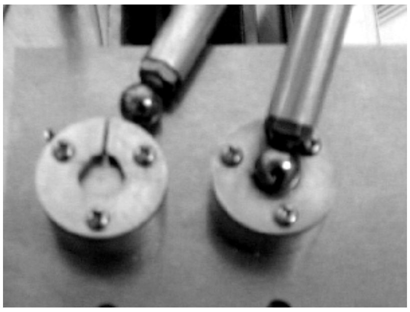

figure 2: Spherical joints using magnet.

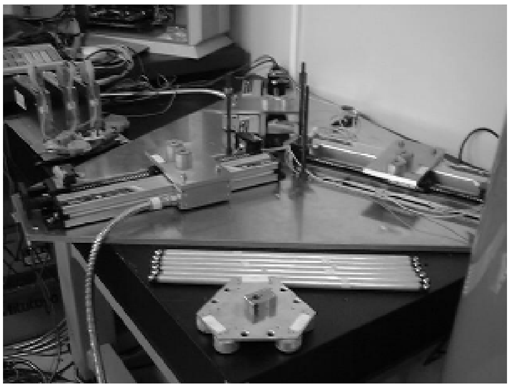

figure 3: Separating all components.

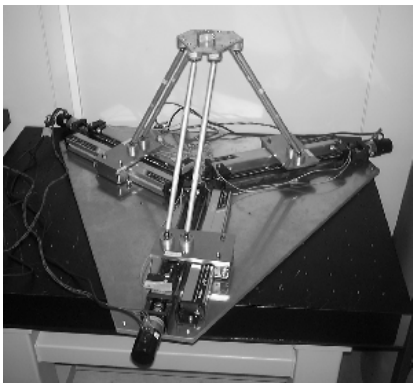

figure 4: Setting up all components.

Parameter identification

To make high accuracy parallel CMM, it needs to calibrate parallel CMM. The first step of calibration is parameters identification of its geometrical parameters[2]. The geometrical model of parallel CMM includes 39 geometrical parameters. When we make a parallel CMM of large size, some parameters can be identified directly with high accuracy. Because of using spherical joints shown in Fig.2, we assures that each geometrical value of parameter measured by other way does not change after setting up. Here we classify into four categories depending on the way of parameter identification.

End-effecter

The geometrical parameters of the end-effecter are on the relative position between the probing sensor and each spherical joint. These parameters are three dimensional data. We can make a small end-effecter when we make parallel CMM of large size. Therefore it is good to get the values of the parameters of end-effecter by measuring by another CMM.

Connecting rods

The geometrical parameters of connecting rods are the length between two balls joined at the each end of connecting rods. These parameters are one dimensional data. And they can be measured easily when the connecting rods become longer.

Carrier

The parameters of the carriers are the height of the joints and the distance between two joints on the carrier. These parameters are three dimensional data. And we can make small carriers when we make parallel CMM of large size. Therefore it is good to get the values of the parameters of carriers by measuring by another CMM.

By measuring each value of above parameters and use their values to solve forward kinematics of parallel CMM, we can reduce number of parameters to calibrate.

figure 5: End-effecter.

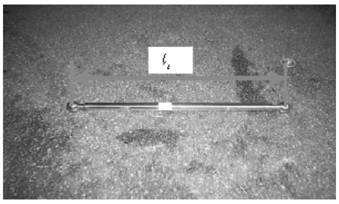

figure 6: Connecting rods.

figure 7: Carrier.

Geometrical model of base plate

Differently from above parameters, the geometrical parameters of linear actuators and linear scales change their values by separating/resetting. And it becomes hard to measure their values directly when the parallel CMM gets larger or regardless of the size of the parallel CMM.

The parameters of linear actuators are the arrangements of them on the base plate. The ones of linear scales are the arrangements of them on it and the initial origin of each scale. We calculate them with the least squares method. Fig. 8 shows the geometrical model of base plate. Geometrical parameters including in this model are the arranged position of each actuator, $\theta 1$, θ 2, ϕ, r, and the initial origin of each scale, $\delta q1$, $\delta q2$, $\delta q3$.

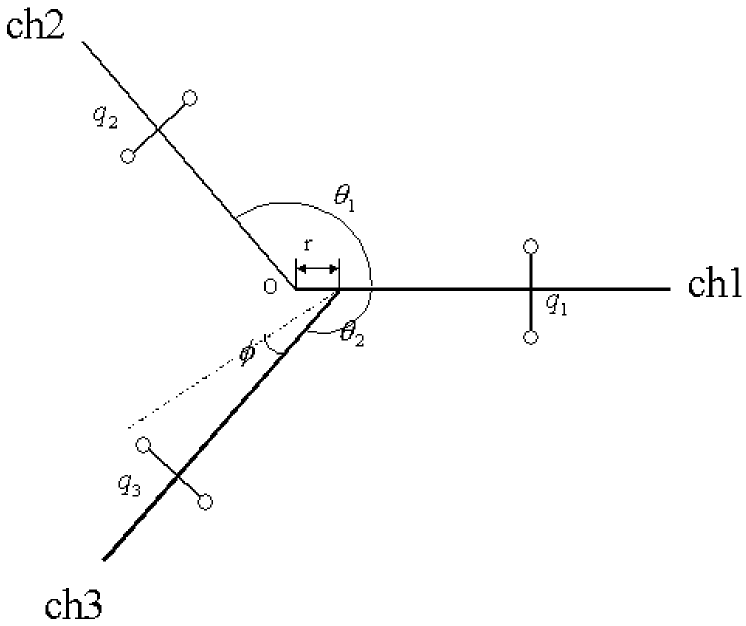

figure 8: Geometrical model of base plate.

Calibration of parallel CMM

We did the experiment of parameter identification for our prototype. Geometrical parameters of end-effecter, connecting rods and carriers are measured by the CMM. And those of base plate are calculated using the result of measuring by the CMM and the signal from each linear scale.

We put a steel ball on the end-effecter. Then we move the end-effecter at 64 points in the workspace and measured the centre of the ball by CMM.

All geometrical parameters including in Fig.8 and the initial origin of each scales are identified with high accuracy. The result of our experiment, the positioning error after calibration reduced from 500µm to 7µm.

Conclusion

In this paper, the prototype of parallel CMM is introduced. Using unique spherical joints, this prototype has the high repeatability of the position of the end-effecter when we separate all connecting rods and end-effecter from the base plate and reset up them. Then we suggested to calibrate each component of parallel CMM by each method.

We classified the geometrical parameters of each component into four categories depending on the way of parameter identification, and decided each method to calibrate each component. We calibrated the parameters of the end-effecter, the connecting rods and the carriers by measuring directly with CMM, and the parameters of the base plate by the least squares method.

We calibrated our prototype of parallel CMM. The result of our experiment, the positioning error after calibration reduced to 7µm.

References

[1] O. Sato, M. Hiraki, K. Takamasu and S. Ozono: Calibration of 2-DOF parallel mechanism, Initiatives of precision engineering at the beginning of a millennium, Kluwer academic publishers, 2001, pp. 734-7738.

[2] Merlet, J.-P.: “Parallel Robots”, Kluwer academic publishers, 2000.