行政院國家科學委員會補助專題研究計畫成果報告

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※ 智慧型檢測與逆向工程系統 ----- 子計畫四 ※

※ 彈性座標及定位控制系統（第三年） ※

※ **Flexible Coordinate and Position Control System (Ⅲ)** ※

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計畫類別：□個別型計畫　　□∨整合型計畫

計畫編號：NSC 89－2218－E－002－049－

執行期間：89 年　8 月 01 日至 90 年 07 月 31 日

計畫主持人：黃漢邦

共同主持人：

研究人員：王志遠

本成果報告包括以下應繳交之附件：

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□國際合作研究計畫國外研究報告書一份

執行單位：國立台灣大學機械工程學系

中　華　民　國　90 年　08 月　01 日

行政院國家科學委員會專題研究計畫年度報告

彈性座標及定位控制系統 (第三年)

Flexible Coordinate and Position Control System (Ⅲ)

計畫編號：NSC 89-2218-E-002-049 or 010
執行期限：89年8月1日至90年7月31日

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執行機構：國立台灣大學機械工程學系

中文摘要

本文的主要目的在於研發一個具有即時三維曲面量測能力的雷射結構光量測系統和電腦間協同控制，應用於 3D 資料擷取。雷射結構光量測系統的機構部分是由兩個固定在六軸機器人夾具上的 CCD 攝影機和一個三十三條直條紋雷射結構光所構成。利用直接線性轉換法(direct linear transformation)尋找矯正塊座標和影像座標的對映函數完成攝影機校正，並同時計算雷射結構光在空間中的平面方程式。藉由雷射結構光平面方程式、影像射線(image ray)和極線(epipolar line)，量測出三維曲面的座標點。

此三維量測系統結合影像伺服(visual servoing)可自動偵測量測工件的輪廓。利用面雷射的特性決定出一條和物體輪廓等距的掃瞄路徑，避免景深問題和機器人軌跡控制完成工件量測作業，達到資料擷取自動化。另外藉由網頁控制及 ISDN 可使控制人員在遠端監看並操作此系統，並透過視訊會議和遠端客戶進行意見交換，了解客戶的需求，更改設計，縮減雙方時間和金錢，節省不必要的浪費。

關鍵詞：結構光、影像伺服、攝影機校正、直接線性轉換

Abstract

The purpose of this project is two folds. One is to develop a 3-D vision measurement system that is capable of measuring the spatial coordinate of an object, the other is to cooperate and control the 3-D vision measurement system through network. The 3-D vision system consists of two CCD cameras and thirty-three laser-structured lights. The direct linear transformation method is used to find the transformation matrix between rectification coordinate and image coordinate. The planar equation of laser-structured lights is calculated at the same time. By combining the image ray, planar equation of the structured lights, and epipolar line, the 3-D surface coordinates of an object can be identified.

The system uses visual servoing to automatically accomplish the profile tracking. Based on the feature of the multi-laser beams, a path can be determined. By keeping constant distance from the object's surface, the scene depth problem can be avoided. The robot is controlled to follow the planned path and the eye-on-hand vision sensors are used

to detect the range data automatically.

Then, the control operator can manipulate the 3-D vision measurement system through the web site and ISDN. Manufacturers can communicate with the customer immediately and understand the customer requirements. It can save time and resource, and hence manufacture products more efficiently.

Keywords: structured light, visual servoing, CCD calibration, direct linear transformation

Motivation and Purpose

The breakthrough in computer technology, computer graphics, and Internet technology have recently generated much interest in systems that may be used for imagining both the geometry and surface of an object.

In designing a system for recovering the object shape, different engineering tradeoffs are proposed by different applications. The main parameters are: cost, accuracy, ease of use and speed of acquisition. Reverse engineering provides an efficient solution. Thus, how to rapidly and accurately get object surface and geometry data becomes important.

This project aims to combine the ranging data acquisition, visual servoing and Internet technology to develop an internet-based 3D-vision Computer Supported Cooperative Work (CSCW) system.

Implementation and Results

(1) System design

In the third year, an Internet-based 3D-vision CSCW system is constructed, as shown in Fig.1. This system consists of multi-laser lights, two cameras, a six-axis industrial robot and a PC with ISDN equipment. The laser has thirty-three laser beams. Two cameras are used to capture the image of the laser stripes. The industrial robot provides accurate location and translation. The responsibility of a PC is analyzing images, estimating 3-D coordinates and controlling a robot through ISDN connection [1,2,4,5,6,8,15].

(2) Epipolar geometry

Epipolar geometry has been employed in three dimensional computer vision [7,10,11,12,13,14]. The points at which the line through the centers of projection intersects the image planes are called epipoles. In Fig. 2, the left and right epipoles are denoted by e_l and e_r. The left epipole is the image of the projection center of the left camera, and vice versa. P, O_l and O_r constitute a plane, called epipolar plane. Epipolar plane intersects each image in a line, called epipolar line. The condition that the corresponding points must lie on conjugated epipolar line is called epipolar constraint. The search for corresponding points is reduced to a 1D problem. It is the most effective procedure to reject false matches due to occlusions.

- The Essential Matrix

In Fig. 2, we can get vectors P_l, P_r and $T = O_r - O_l$. The relation among those vectors is $(P_l - T)^T T \times P_l = 0$ like dot product of two orthogonal vectors. This function is substituted into $P_r = R(P_l - T)$, and we get $(R^T P_r)^T T \times P_l = 0$. Since a vector product can be written as a multiplication of a rank-deficient matrix, we can get

$$T \times P_l = SP_l \qquad (1)$$

where matrix S is given as

$$S = \begin{bmatrix} 0 & -T_z & T_y \\ T_z & 0 & -T_x \\ -T_y & T_x & 0 \end{bmatrix} \qquad (2)$$

Therefore, the original function is obtained as

$$(R^T P_r)^T SP_l = 0 \qquad P_r^T R \ SP_l = 0$$

$$P_r^T EP_l = 0 \qquad (3)$$

where $E = RS$, and S is always rank 2.

The matrix E is called the essential matrix from two orthogonal vectors' relation. It establishes a link between the epipolar constraint and the extrinsic parameters of the stereo system. Eq.(3) can be rewritten in terms of the image coordinates as $p_r^T F p_l = 0$, and $u_r = Fp_l$. The essential matrix is the mapping between the points and the epipolar lines we are looking for in the camera reference coordinates.

(3) CSCW

CSCW [3,9] is concerned with the design of computer-based systems to support and improve the work of groups of users engaged in common tasks of objectives, and the understanding of the effects of using such systems. CSCW can improve computer-based group communication, such as modern multimedia applications and conventional monomedia systems, as shown in Fig. 3. CSCW has been studied since the early 1980s. Major contributions to the field come from Scandinavian researchers.

(4) Development of the CSCW system

This system is designed for collaborative works between local user (*Local*) and remote users (*Far end*). The main issue is to make sure of establishing connection for T.120 protocol. The following describes the setting in the collaborative system, and procedure for establishing T.120 data conference. Local and far end mean active local side and passive remote side in collaboration, respectively.

1. *Local*

(1) Determine whether the *Far end* supports T.120. If it does, then execute next step, otherwise exit program. If *Far end* supports T.120, then local prepares the local data mode for MLP.

(2) Set data request mode in MLP (Multiple Layer Protocol) and set serial port (toggle ON) preparing for T.120 connection. Open T.123 data channel using Q.922.

(3) Launch local NetMeeting, prepare application and data sharing standby.

(4) Send MCI (Media Control Interface) string command to notify both *Far*

end and Local to prepare for T.120 channel.

(5) Initialize T.120

(6) *Local* and *Far end*: Start the collaboration of data-conferencing in T.120

2. *Far end*

When *Far end* has received the MCI string command in preparing for T.120 channel connection, *Far end* must react. *Far end* must set data request mode in smart mode (MLP) and set serial port (toggle ON) for T.120, then initialize T.120 immediately.

Discussion and Conclusion

(1) The limitation of the proposed 3-D vision measurement system

For the proposed system, there are still some drawbacks that can be further improved. The 3-D measuring accuracy is limited due to the view angle between CCD and the object. The resolution of the system is 0.84 mm/pixel. If the view angle is big, then the CCD resolution can be better.

The ISDN online discussion and data conferencing works well in this system. For fast transfer speed, bandwidth should be improved.

(2) Evaluation of the results

Basically, the proposed project goal has been achieved. The 3D vision CSCW system has been constructed and the associated theory has been developed. Moreover, the system automatically scans the object and starts the scanning program, then remaining procedures, including rough outline estimation, path planning, robot control, coordinate transformation, etc., are calculated and executed by a host computer. Based on ISDN, videoconference and data conference can work well. Connection with NCKU and MEAS Lab. works well. Far end client can control the system to measure the object's surface.

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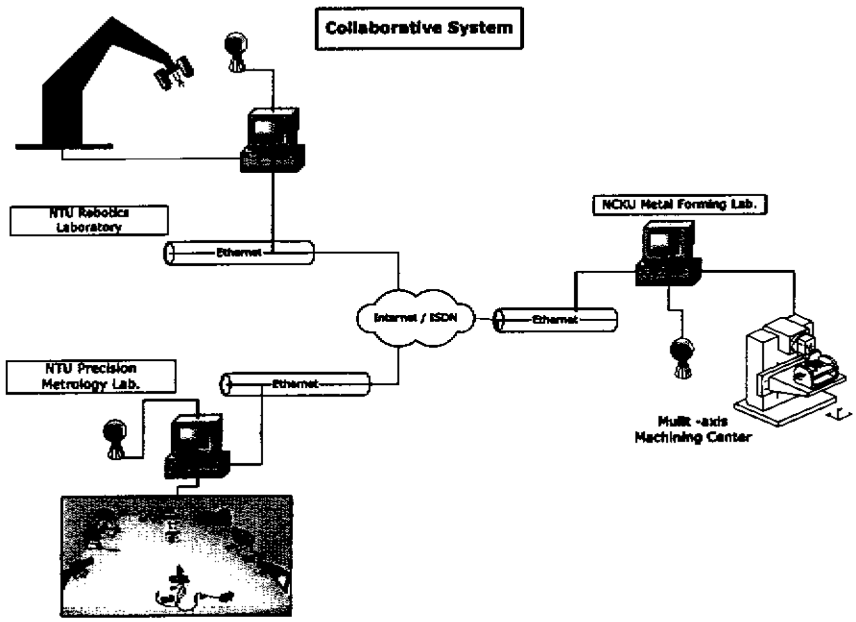

Fig. 1 CSCW 3D vision measurement system

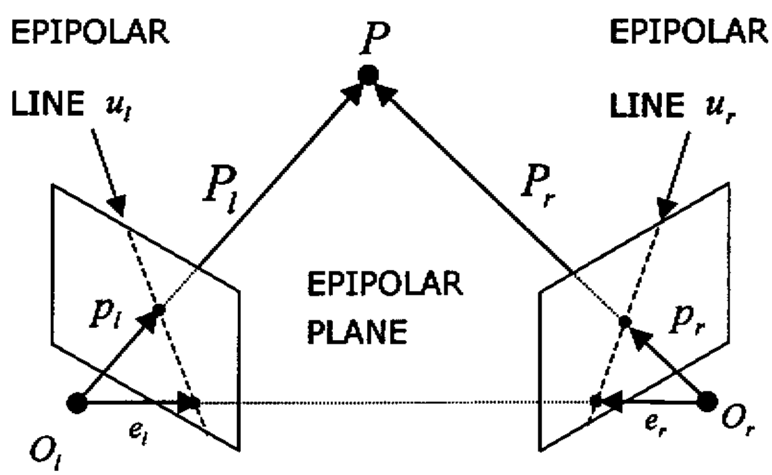

Fig. 2 Epipolar geometry

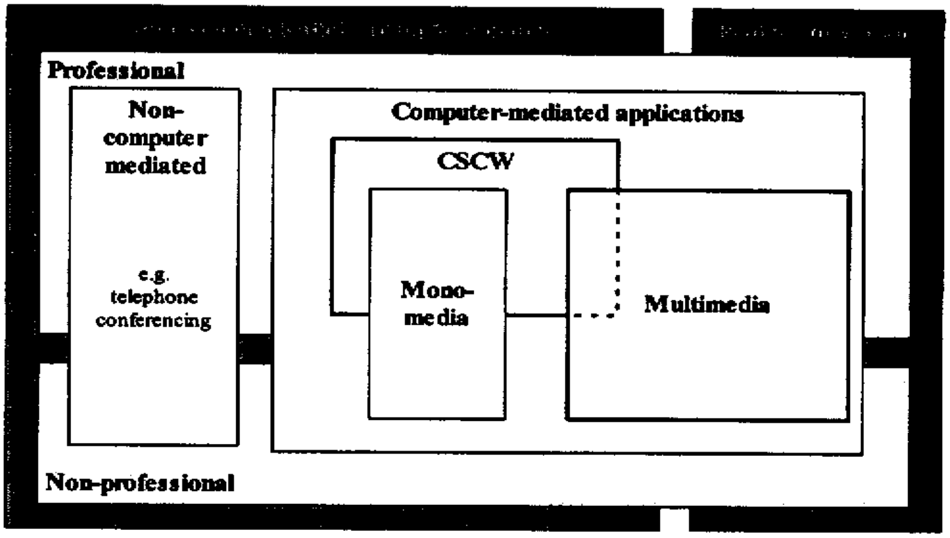

Fig. 3 CSCW field and multimedia field

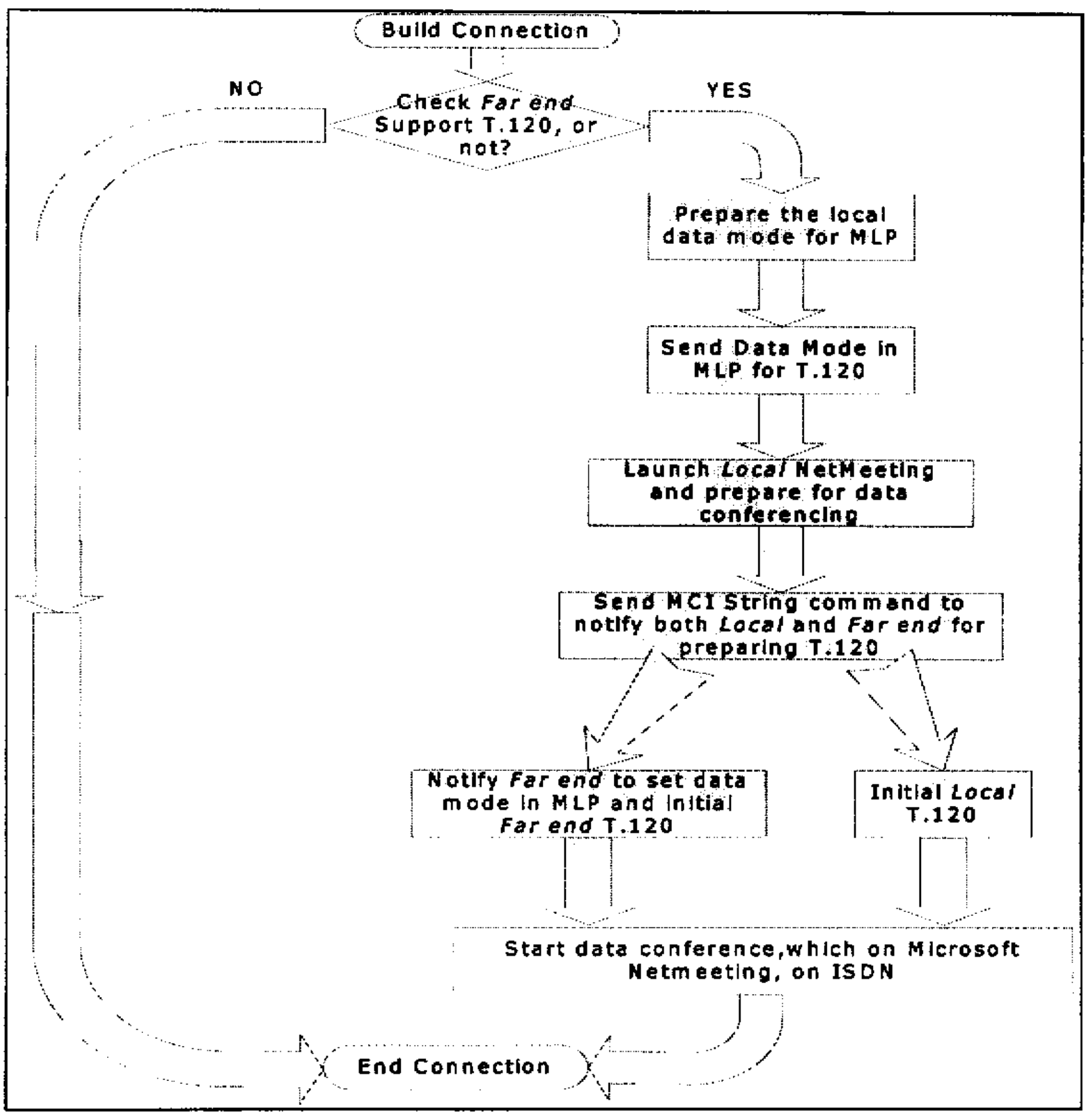

Fig 4 Communication block diagram

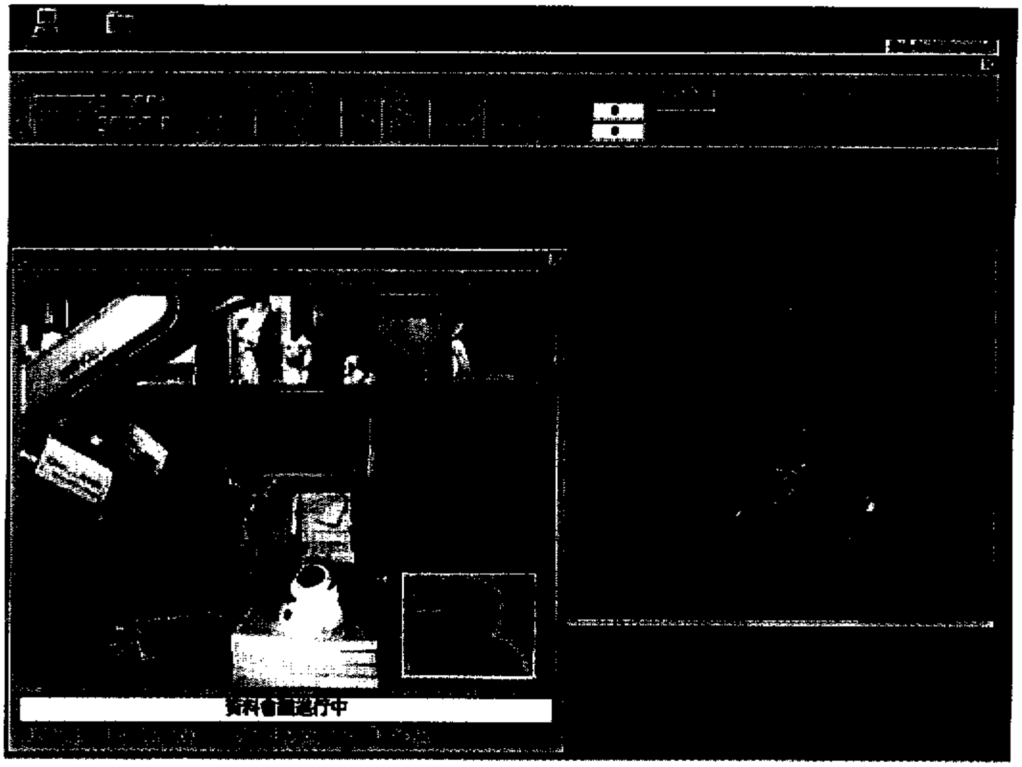

Fig. 5 Online scanning (NTU Meas Lab.)

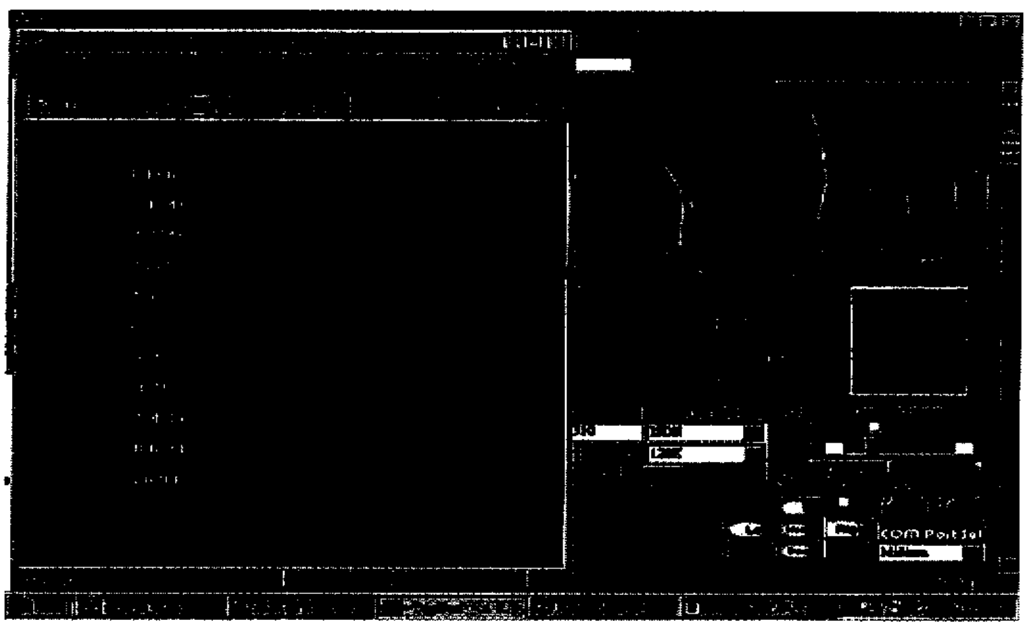

Fig. 6 Online Discussion (NCKU Metal Forming Lab.)