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Multi-Sensor Intelligent Robot

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비구조적인 환경에서 평면패렛을 포크리프트로 로딩하거나 보조필드 재료운송시스템 로보트를 제안한다. 시스템은 패렛의 위치와 방향을 정의하고 패렛의 2개의 구멍의 위치를 결정하기 위해서 결합된 어쿠스틱과 비쥬얼 센싱 데이타를 사용한다. 그 결과 포크리프트를 패렛의 2개의 구멍에 접근하고 운송하기 위해서 패렛을 인게즈한다.

재료운송시스템의 복잡성을 줄이기 위해서 2차원 포라로이드 울트라소닉 센서와 2차원 압티컬 카메라 비쥬얼 센서데이타를 통합하는 시스템을 개발한다. 2개의 다른 소스에서 얻은 데이타는 서로서로 보완하고 재료운송 시스템로보트를 제어하기 위한 효율적인 알고리즘에 사용한다. 2개의 선형스캔닝으로 부터 얻은 레인지 데이타는 least-mean square 방법을 사용하여 패렛의 팬과 틸트 각도를 결정하기 위해서 사용한다. 그리고 에지탐지와 Hough 트랜스폼기술을 사용하여 스윙각도와 패렛의 인게이지먼트 위치를 결정하기 위해서 비쥬얼 데이타를 사용한다. 팬과 틸트각도를 결정하기 위해서 발생하는 제안을 논의한다. 개발된 시스템은 하드웨어와 소프트웨어 구현하여 평가하고 실험적인 결과도 나타낸다.

A robotically assisted field material handling system designed for loading and unloading of a planar pallet with a forklift in unstructured field environment is presented. The system uses combined acoustic/visual sensing data to define the position/orientation of the pallet and to determine the specific locations of the two slots of the pallet, so that the forklift can move close to the slot and engage it for transport.

In order to reduce the complexity of the material handling operation, we have developed a method based on the integration of 2-D range data of Poraloid ultrasonic sensor along with 2-D visual data of an optical camera. Data obtained from the two separate sources complements each other and is used in an efficient algorithm to control this robotically assisted field material handling system . Range data obtained from two linear scannings is used to determine the pan and tilt angles of a pallet using least mean square method. Then 2-D visual data is used to determine the swing angle and engagement location of a pallet by using edge detection and Hough transform techniques. The limitations of the pan and tilt orientation to be determined are discussed. The system developed is evaluated through the hardware and software implementation. The experimental results are presented.

Keywords : Robot, Vision, Acous GC sensor, Pallet, Forklift

1. Introduction

Typical tasks for a sensor based robotic system are to locate, recognize and transport a target object, load and unload a cargo, place its items into stock, and release or off-load the palletized cargo from line haul vehicles in field environment. The robotic system must be versatile and applicable to nuclear, biological, and chemical(NCB) circumstances in addition to a normal outdoor adverse condition in lighting, temperature, or precipitation. Currently, a typical robotic system whose main sensor is optical camera requires known patterns within field environment to reduce prohibitive amounts of processing time [1]. With such a system, difficulties can arise when system cannot detect known patterns due to the adverse environmental conditions. In this paper, a system equipped with acoustic sensor is presented to solve the inherent problems of optical camera in terms of processing time and illumination [2,3]. However, the acoustic sensing system has its own problems. The signal beam spread allows echoes to be obtained from more than one reflection source. But a pallet usually has the large planar surfaces. Therefore, the problems of the acoustic ranging system resulted from the measurement for the orientation of the planar surface of a pallet is eliminated. It is obviously desirable to design a system through the combination of more than one sensor data in such a way that increases system flexibility with improved reliability, accurancy, and speed. We have developed a robotically assisted field material handling system through the combination of acoustic and visual sensing.

A brief description of the overall system configuration is presented in section 2. Section 3 describes the distance measurement process of acoustic sensor. The procedure for computing the pan and tilt angles of the planar surface of a pallet using range data obtained from two linear scanning of an acoustic sensor is discussed in section 4. The determination of the swing and engagement point of the pallet planar surface is presented in sections 5 and 6. The experimental results are included in section 7. The conclusions are described in section 8.

2. Overall system configuration

The overall system configuration of the sensor-based robotic system used in the experiments is shown in Fig. 1. The major components include a PUMA 560 robot, a Trapix real time image processor, Poraloid ultrasonic sensor, a wood pallet and a Micro Vax II computer. The working prototypes of the end-effector, multi-sensor based forklift, is shown in Fig. 2 to guide the robot and to perform the engagement tasks.

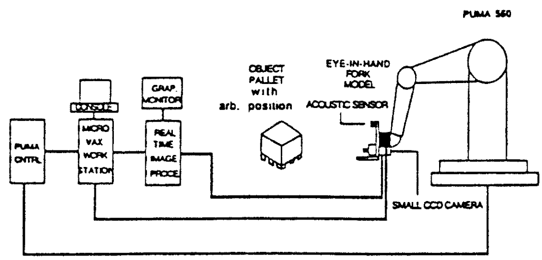

Fig. 1 Overall System Configuration

3. Ultrasonic transducer and ranging system

In acoustic ranging, a sinusoidal electrical pulse excites a piezoelectric transducer which, in turn, generates and transmits an acoustic pulse, through air, toward the target object (i.e. a pallet). A fraction of the incident acoustic energy is reflected back to the transducer and is detected. The time delay between the pulse transmission and the first echo detection is multiplied by onehalf the acoustic speed of the pulse to compute distance between the sensor and the object. Therefore, spatial distance from the object and the transducer is given by Eq. (1) [4]

$$r = C \times (T_r/2) \tag{1}$$

where r is distance, C is sound velocity, Tr is the time when amplitude of the echo first reaches to a prefixed threshold level. Polaroid ultrasonic ra-

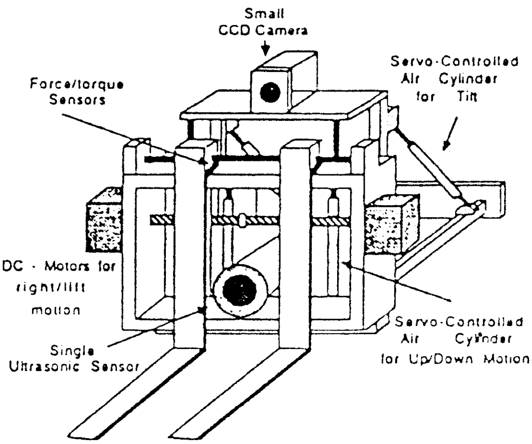

Fig. 2 Model of multi-sensor forklift system

nging sensor was used in our experiment.

4. Determination of the orientation by the ultrasonic range data

In general, the object has the three position and three orientation parameters that specify the object position and orientation relative to a fixed reference frame. We have chosen a convention to denote the object orientation using the pan, tilt, and swing angles. The pan, tilt, and swing angles of the object is denoted by θ, ϕ, and φ respectively. The rotated reference frame is then obtained from the original reference frame by a rotation of θ angle about the oz axis followed by a roation θ of angle about the rotated ox axis and finally a rotation of φ angle about the rotated oy axis.

Let us start with the relatively simple problem of finding the pan angle of the planar surface of pallet. As shown in Fig. 3, the reference frame is the xyz coordinate and the x,y, axes are the xy axes rotated by an angle of θ. Let the planar surface of a pallet be on the z,x, plane. The acoustic sensor is arragned at a point s_1 on the xy plane and radiates down in a direction of the line parallel to the y axis. The orientation of the planar surface can be determined by translating acoustic sensor to a point on a line parallel to the x axis through s_1 Two sampling points, s_1 and s_2 of acoustic sensor

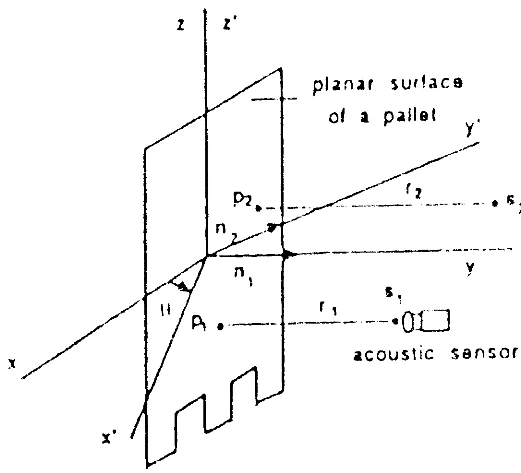

Fig. 3 Determination of the pan angle of the planar surface of a pallet

are represented by $s_1=[x_0\ y_0\ 0]$ and $s_2=[-x_0\ y_0\ 0]$ with range magnitudes r_1 and r_2 respectively. A unit vector, n_1 normal to the zx plane from the xyz reference frame is given by

$$n_1=[0\ 1\ 0] \tag{2}$$

The normal vector of the planar surface which is obtained by rotating the vector Subsoript 1 about th z axis by θ is given by

$$\begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} \sin\theta \\ \cos\theta \\ 0 \end{bmatrix} \tag{3}$$

Let n_2 be expressed by $n_2=[-\sin\theta\ \cos\theta\ 0]$ The planar surface can be expressed by

$$[x\ y\ z] \begin{bmatrix} -\sin\theta \\ \cos\theta \\ 0 \end{bmatrix} = 0 \tag{4}$$

Let the signal reflection points on the planar surface of a pallet from the acoustic sensor at s_1 and s_2 be p_1 and p_2 respectively. The locations of p_1 and p_2 are given by

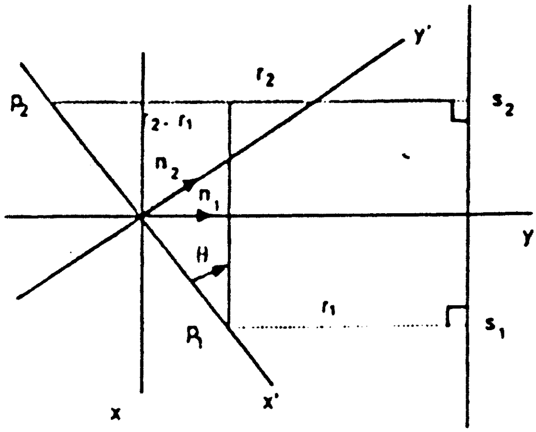

Fig. 4 Geometry of a simplified 2-D pan angle defermination.

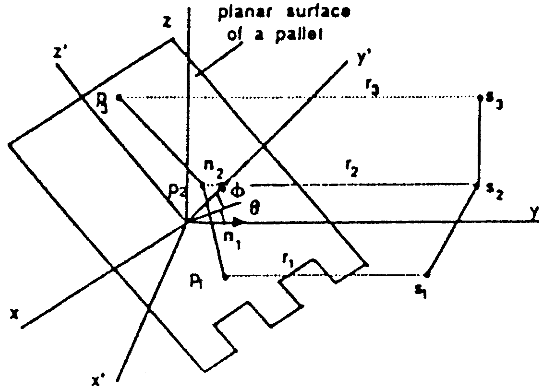

Fig. 5 Determination of the pan and tilt angles of planer surface a pallet.

$$p_1=[x_0\ x_0\tan\theta\ 0] \quad p_2=[-x_0\ -x_0\tan\theta\ 0] \qquad (5)$$

The problems of finding the orientation of the planar surface can be simplified by recognizing the x,y, plane as shown in Fig. 4. A right triangle can be formed by drawing a line parallel to the y axis through p_1. Range magnitude, r_2 is subdivided into two range magnitude, r_1 and (r_2-r_1). The pan angle θ of the planar surface is given by

$$\tan\theta=(r_2-r_1)/D_1 \qquad (6)$$

where D_1 is sampling distance between the two consecutive sampling points along the line parallel to the x axis.

Fig. 5 illustrates a more complex example for determining the pan and tilt angle simultaneously. An acoustic sensor lies at a point, s_1 on the xy plane and radiates to a direction of the line parallel to the y axis. This acoustic sensor is translated horizontally to the next sampling point, s_2 for measuring the pan angle and then translated vertically to the third sampling point, s_3 for measuring the tilt angle. The location of the three points are $s_1=[x_0\ y_0\ 0]$, $s_2=[-x_0\ y_0\ 0]$, and $s_3=[-x_0\ y_0\ z0]$ with range magnitudes r_1, r_2, and r_3 respectively.

The unit vector, n_1 normal to the zx plane from the xyz reference frame is given by $n_1=[0\ 1\ 0]$. The unit vector, n_2 normal to the z,x, plane is given by

$$\begin{bmatrix}1 & 0 & 0\\ 0 & \cos\varphi & -\sin\varphi\\ 0 & \sin\varphi & \cos\varphi\end{bmatrix}\begin{bmatrix}\cos\theta & -\sin\theta & 0\\ \sin\theta & \cos\theta & 0\\ 0 & 0 & 0\end{bmatrix}\begin{bmatrix}0\\1\\0\end{bmatrix}=\begin{bmatrix}-\sin\theta\cos\varphi\\ \cos\theta\cos\varphi\\ \sin\varphi\end{bmatrix} \qquad (7)$$

n2 can be represented by $n_2=[-\sin\ \cos\ \cos\ \cos\ \sin\ ]$. Thus, the planar surface can be expressed by

$$[x\ y\ z]\begin{bmatrix}-\sin\theta\cos\varphi\\ \cos\theta\cos\varphi\\ \sin\theta\end{bmatrix}=0 \qquad (8)$$

Let the signal reflection points on the planar surface from acoustic sensor s_1, s_2, and s_3 be p_1, p_2, and p_3 respectively. The locations of p_1, p_2, and p_3 can be given by

$$p_1=[x_0\ p_{1y}\ 0] \quad p_2=[-x_0\ p_{2y}\ 0] \quad p_3=[-x_0\ p_{3y}\ 0] \qquad (9)$$

where $p_{1y}=x_0\sin\theta/\cos\theta$, $p_{2y}=-x_0\sin\theta/\cos\theta$, and $p_{3y}=-(\sin\theta\cos\varphi\times x_0+\sin\varphi\ z_0)/\cos\varphi\cos\theta$

Using the components of p_1, p_2, and p_3, the slopes of the lines passing through p_1 and p_2 and through p_2 and p_3 can be obtained as follows.

$$k_1 = \tan\theta \tag{10}$$

$$k_2 = \tan\varphi / \cos\theta \tag{11}$$

where k_1 is the slope of the line passing through p_1 and p_2. k_2 is the slope of the line passing through p_2 and p_3. Thus, the pan and tilt angles can be solved by the equations (10) and (11).

The acoustic ranging system suffers from random interference and random noise. The sensor may have the electronic timing errors and acoustic amplitude fluctuations. Other sources of noise are changes in medium properties that affect the velocity of sound, such as air temperature, gaseous composition, etc. These are the sources of the range error. In order to perform the task precisely it is necessary to reduce the data error of the range magnitudes. The error can be decreased by increasing the number of measurements along linear scanning paths as shown in Fig. 6.

If there are no errors of range data, the range data from the linear scanning along the line parallel to the x axis through s_1 and s_2 should lie on a line. This line equation can be described by Eq. (12).

$$r = \alpha + KT \tag{12}$$

where r is the range magnitude at each sampling point. α is a value on an axis intersected with the line slope of range magnitudes. K is the slope of the line of range data. T is sampling time.

Since the system is subject to the errors, linear equation, Eq. (12) is not satisfied exactly by the range magnitudes of r and T [5]. If we denote the range data of r measured at a time $T=T_i$ by r_i, the range magnitude, r_i lines randomly approximated on a straight line due to the inherent range error. The relation between r_i and T_i can be written as

$$r_i = \alpha + K\,T_i + e_i \tag{13}$$

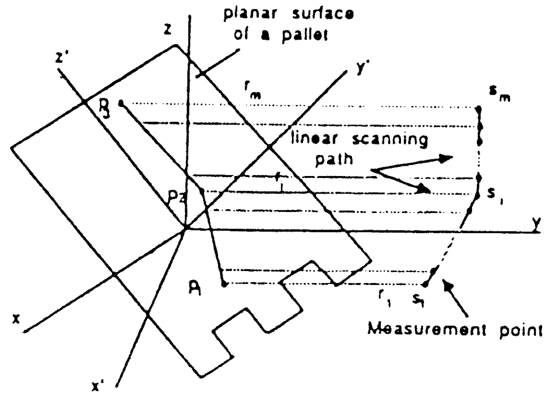

Fig.6 Linear Scauning of acoustic Sensor

where ei represents an inherent range error resulting from acoustic ranging system.

For simplicity purpose, it is convenient to express the following analysis in matrix notation, Eq. (13) can be rewritten as

$$R = AX - E \tag{14}$$

$$R = \begin{bmatrix} r_1 \\ \cdot \\ \cdot \\ \cdot \\ r_m \end{bmatrix} A = \begin{bmatrix} 1 & T_1 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ 1 & T_m \end{bmatrix} X = \begin{bmatrix} \alpha \\ K \end{bmatrix} E = \begin{bmatrix} \varepsilon_1 \\ \cdot \\ \cdot \\ \cdot \\ \varepsilon_m \end{bmatrix}$$

m is the number of the measurements.
The error vector is $E=R-AX$. The criterion we use to find the best straight line is that we minimize the sum of squares of the errors of the range data. The solution for the least squares is

$$X = (A^T A)^{-1} A_T R \tag{15}$$

Using the Eq. (15), we obtain the more precise value of slope of the lines on the planar surface passing through p_1 and p_2 and passing through p_2 and p_3. Let k_1 and k_2 be the more precise values of slopes from Eq. (15) using several measurements along each two linear scanning paths respectively. Substition of k_1 and k_2 into (10) and (11), we can obtain the pan and tilt angles and θ and φ.

where $\theta=\tan^{-1}(k_1)$ and $\varphi=\tan^{-1}(k_2\cos\theta)$

5. Vision System

In the previous section, the pan and tilt angles were found by the use of the acoustic range data. The swing angle and engagement point of the planar surface of a pallet must be determined to perform engagement task. A way is the use of vision system. Vision system can easily obtain the information about edges and features once camera is orthogonal to the planar surface. The vision system can provide a 2-D description of the scene in the plane of the workspace which is incident to the optical axis of the camera [6].

6. Determination of the pallet swing angle and its 3-D location

Edges are detected between regions of light intensity. The gradient or edge magnitude is calculated using Sobol operator [7]. The edge magnitude of the planar surface of a pallet was obtained by applying this operation at every pixel of the gray-level image. Since centroid of the image taken at a certain distance is invariant to the rotation, the normal distance from the centroid to an edge of the planar surface of the pallet is constant. The swing angle which is a feature of an object involves the transformation of a line edge in Cartesian space to a point in polar coordinate space. A straight line from the centroid with the appropriate(d,∪) parameters fits an edge. In our case, d is not variable and ∪ is incremented by +/− degrees.

7. Experimentation and Results

The first experiment was the investigation of the accuracy of the acoustic-sensor. The distance between the acoustic sensor and the pallet is about 45cm. A height and width of the pallet are about 23cm and 17cm respectively. The resolution of the horizontal and vertical scanning is 1cm. To reduce the effects of dispersion of the acoustic signal around edges of a pallet. range data obtained near edges of the pallet planar surface is neglected. Based on this experiment, the results showed errors between the actual and measured orientation of approximately 10% if the pallet planar surface has less than +/− 15 degrees of the pan and tilt angles. The vision system was used to measure the swing angle and engagement points of the pallet. The results showed average errors between the actual and measured swing angle of approximately 4% and an average error between the actual and measured engagement point is approximately 5%. Fig. 7 shows a functional diagram of the forklift pallet engagement process.

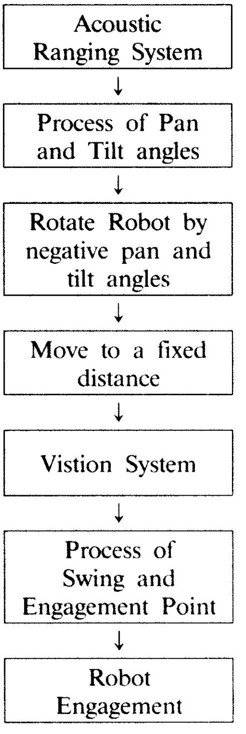

Fig.7 Functional diagram of the forklift pallet engagement process

8. Conclusion

We have described a mehtod that uses both acoustic range data and visual intensity data to locate a planar object and perform a specific task. The range data were used to find the pan and tilt angles of a planar object (i.e. pallet). The pan and tilt angles were computed with a least mean square mehtod. The intensity data were analyzed to obtain the swing angle and the engagement point at the pallet. The combination of the acoustic data with the visual data provides new opportunities for the simple and rapid location of the object in the 3-D space while the location of object in 3-D space would be difficult and time-consuming to obtain from visual data or range data alone.

The overall experimental results demonstrate that the system can operate in real time. Also the system has proven the robust in an unstructured environment as would be found in a real world application.

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