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ANALYSIS OF PRINCIPLES AND SOLUTIONS FOR THE MULTI-COORDINATE POSITION DETERMINATION IN A LARGE INDOOR WORK SPACE

There are several applications where planar drive systems consisting of more than one planar drive unit are needed. In order to control the planar drive system, the position of the planar drive units on the work surface should be determined. This paper provides an overview of available positioning principles and solutions for the position determining of the planar drive units with large range of motion (up to 10 m) on the work surface. The advantages and disadvantages of the typical topologies and measurement methods for position determination are analyzed. State-of-the-art systems which provide accuracy of positioning better than 1 mm are considered.

Keywords: *planar drive, large work space, multi-coordinate position determination system.*

Introduction

There are applications where planar drive systems are needed. But the development of the planar drive systems have been often constrained by unavailability of the appropriate multi-coordinate position measurement systems. Recently, some solutions were developed which allow determining the position and orientation of the object in space. The aim of this paper is the analysis of the applicability of available solutions for the position determination of the planar drive units in large indoor work space. First of all the planar drive system and its components have to be described.

The planar drive system consists of planar drive units located on the work surface. The planar drive unit has three degrees of freedom: two translational and one rotation. An overview of existing solutions to construct planar drive units is given in [1]. The work surface which is the part of the work space has square about 100 m^2 (10x10 m). Target accuracy of the planar drive unit position determination is about 1 mm.

By means of the two points coordinates it is possible to calculate the angle of rotation of the planar drive unit. The position determination on large work surface only for one point is considered in current paper.

For each position determination system the coordinate system of work surface must be designed. In this paper the position of the planar drive unit is determined by coordinates in designed coordinate system. The scheme of the planar drive system is shown on Fig. 1.

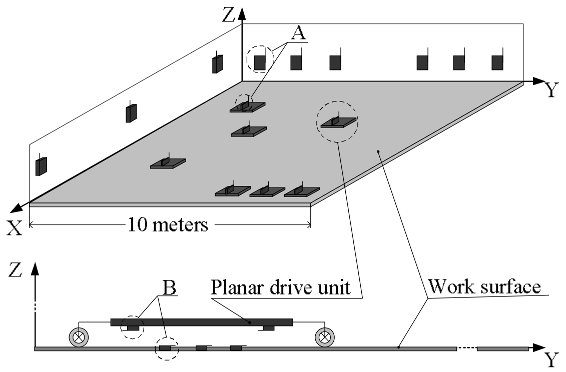

Fig. 1. Scheme of the planar drive system

Classification

Before analyzing the possible topologies of the systems for the position determination of the planar drive units it is necessary to classify them. All topologies separated on two groups: internal and external. On Fig. 1 location of the system elements for both groups of topologies is shown.

The Internal topology includes solutions in which the elements of the measurement system for position determination are located in space between planar drive unit and work surface (B on Fig. 1). The main work principles of such systems are scanning of the work surface or interaction of the system elements located in planar drive unit and work surface (in general, such systems have a work principle similar to principle of incremental encoders). Before using such solution it is necessary to create coordinate system of the work surface.

In general representation, internal topology consists of two methods for the position determination. The first is based on distance measurement. There are a number of non-contact optical and magnetic encoders. The measurand for such devices is distance. Some models allow to measure the distance in both directions (X,Y). So, such encoder can be fixed on the bottom of the planar drive unit to measure its displacement. Special tags, located on the work surface, should be used in case of magnetic encoder application. Important requirement for such encoders is that planar drive unit must have calibration points with known coordinates. The position of it can be determined by coordinates of the calibration points and measured distance.

The second method is based on using a grid of sensitive elements fixed in work surface. And the signal source for such grid must be fixed on planar drive unit. So, the coordinate system of the work surface can be designed in accordance with grid of sensitive elements (with the grid pitch acceptable to obtain target accuracy of the positioning). Such solutions described in [2].

The External topology includes solutions in which the elements of the measurement system for position determination are located on planar drive units and in the work space (A on Fig.1). Such location of the elements is traditional for number of wireless position determination systems. These systems use radio-frequency and optical signals. And some of them use magnetic field. In [3 – 5] classification and description of the measurement approaches and algorithms for wireless position determination systems are presented. In this paper the classification of the approaches and methods for the position determination systems with external topology is shown.

Generally, there are two approaches for position determination of a point in space: triangulation and trilateration approaches. Both approaches are shown schematically on Fig. 2. A lot of different methods can be applied to implement both approaches.

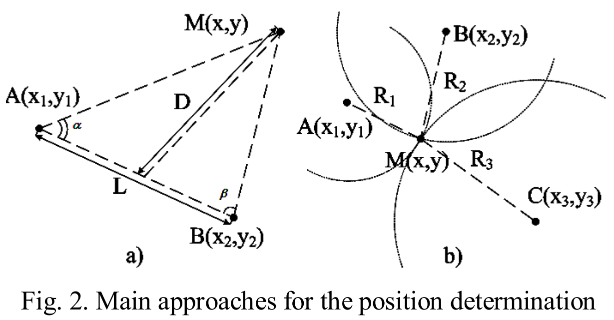

Fig. 2. Main approaches for the position determination

Triangulation approach is based on measurements of the directional angles in respect to the planar drive unit position (Fig. 2 (a)). It is easy to calculate the position of point M(x,y), when $A(x_1,y_1)$ and $B(x_2,y_2)$ are points with known coordinates. Distance L and angles α, β are known too.

Trilateration approach is based on measurements of three distances to the planar drive unit. By means of measured distances the position can be calculated (Fig.2 (b)). In order to calculate the position of point M(x,y) it is necessary to solve a system of three non-linear algebraic equations where $A(x_1,y_1)$, $B(x_2,y_2)$, $C(x_3,y_3)$ are points with known coordinates. Distances R_1, R_2, R_3 are known too.

Methods for the triangulation approach realization are based on the measurement of directional angles between the signal source and receiver. Commonly such methods are usable in the radio-frequency position determination systems. But there are solutions which use influence of the magnetic field on sensitive elements of the measuring system.

Angle of arrival (AoA) method can be realized by using of the antenna arrays. The distance between two sensitive elements of an antenna array is known. The signals which reached the surface of the antenna array will be measured by sensitive elements with different phase and with time delay. Time delay and phase shift can be measured and the angle of arrival of the signal can be calculated [6].

Method of the magnetic compass can be implemented by means of the magneto-resistive sensors. Magneto-resistive sensors use the principle of a magnetic compass. The angles with respect to the source of the magnetic field can be determined. The source of the magnetic field can be used as marker the position of which can be calculated.

Methods for the trilateration approach realization are applicable in radio-frequency position determination systems. The most usable methods for determining the distance to the planar drive unit are following:

In *Time of Arrival (TOA)* method measurand is the time of signal propagation from transmitter to receiver (one direction) and the distance to the object can be calculated.

In *Time Difference of Arrival (TDOA)* method the measurand is the time delay between pairs of the receivers during receiving the signal from the source. Time delay is proportional to the difference between distances from one signal source to several receivers. Hyperboloid is the surface on which signal source can be located. Intersection of surfaces for different pairs of the receivers gives the coordinates of the positioning object (signal source for this method).

Round Time of Flight (RTOF) method is similar to TOA. The measurand is the time of signal propagation from transmitter to receiver and back.

In *Received Signal Strength (RSS)* method the measurand is the signal attenuation during propagation.

The method is based on prior data about signal power and attenuating properties of the working space. The distance to the object can be calculated through the measured attenuation of the signal.

Described approaches and methods are applicable for 2D and 3D position determination. These methods most applicable in radio-frequency position determination systems. An optical positioning systems use the same approaches for the position determination but another methods of their realization. In some cases combination of different methods and approaches leads to better results.

Comparative analysis

The most position determination systems are based on using radio-frequency (RF) and optical signals. In current section shown comparative analysis of the position determination approaches, methods, developed systems and prototypes. As was mentioned above, target standard uncertainty for the position determination of the planar drive unit is 1 mm.

At first the main advantages and disadvantages are considered.

The triangulation approach is applied in systems which use RF as well as optical signals. Normally, in case of optical signals the directional angles can be measured more precise. There are a number of photogrammetry based systems that use the triangulation approach. Such systems are base on infrared sensors (IR) or on the algorithms for the image processing. Measurement of the directional angels by means of current available RF techniques is not precise enough to use such combinations in indoor positioning. Realization of the AOA method requires high-quality antenna arrays and complicated data processing.

The trilateration approach is more commonly used for optical and RF position determination systems.

Distance to the planar drive unit by means of optical instruments can be measured very precise (e.g. principle of the optical interferometer). Traditional measurement instruments for large scale meteorology are laser trackers and laser tracers. Such instruments have very high accuracy of measurement. The standard uncertainty of the position determination for laser trackers is about 0.02 mm. Laser tracers are more precise because they measure only the distance. There is a necessary requirement for all optical systems: direct line of sight. Laser trackers and tracers should not be associated with position determination of planar drive systems. But these instruments are based on approaches and methods described in current paper.

All methods for the trilateration approach realization are usable for development of RF position determination systems. Such systems which are developed last year's generally use high frequency signals. A number of the positioning systems which use technologies like ZigBee, RFID, Wi-Fi are not enough precise. Some of the systems based on UWB (ultra-wide band) technology can achieve required accuracy. The most part of the RF systems can provide the position determination of the object with standard uncertainty 5 mm – 20 cm for the work distance above 2 m in accordance with [7]. In order to obtain target accuracy the work distance must be less than 2 m.

Table 1 provides an overview of applicable systems and solutions for the position determination of the planar drive units. All in the Table 1 specified accuracy parameters are valid for static mode.

Table 1

Comparison of the systems and solutions

System name/ link	Approach/ Method	Work range	σ*	Features
iGPS/[8]	Triangulation	up to 55 m	about 0.1 mm for 3D position determination	Optical system
3D radio location system/ [9,10]	Trilateration/ TOA	up to 2 m	about 0.1 mm for 1D position determination	RF system
MScMS/ [11]	Trilateration/ TOA	up to 8 m	about 5 mm for 3D position determination	US system
MScMSII/ [12]	Triangulation	up to 2 m	1–4 mm for 3D position determination	IR system
Microwave Position Sensor/ [13]	Trilateration	up to 0.8 m	0.1–0.8 mm for 1D position determination	RF system

Generally, optical systems have target accuracy. But such systems have two main limitations caused by necessity of the direct line of sight and low accuracy in dynamic mode of measurement.

There are some requirements to develop RF position determination system with target accuracy:

– direct line of sight between transmitter and receiver of the signal;

– precise synchronization of system elements for all methods except TDOA;

– complex data processing.

In dynamic mode of the position determination RF systems have lower accuracy.

The iGPS system is the most applicable for the position determination of the planar drive units (as evident from the Table 1). The system consists of satellites (emitters of the laser beams) and sensors which should be fixed on the object of the positioning. Measured data transfer from sensors to the receiver hub for the position calculation. System was produced by Nikon [8]. The system is flexible for increasing of the working area (working distance for one satellite: 2–55 m). The standard deviation of the position determination for 3D is about 0.1 mm.

It is necessary to note that position determination of the planar drive units can be realized by means of RF systems designed in accordance with requirements mentioned above.

Conclusions

Classification of the topologies, approaches and methods for the position determination systems has been presented. The advantages and disadvantages of the main topologies and approaches have been analyzed. The main requirements for the RF and optical based position determination systems have been described. The systems and solutions base on different principles have been compared.

As follows from the analysis, there is no available system that corresponds to all requirements for position determination of the planar drive systems. The accuracy parameters of the iGPS are acceptable. But using of this system is limited to special applications because of necessity of the direct line of sight and a big number of the equipment.

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АНАЛІЗ ПРИНЦИПІВ ТА РІШЕНЬ ДЛЯ ВИЗНАЧЕННЯ БАГАТОКООРДИНАТНОЇ ПОЗИЦІЇ У ВЕЛИКИХ РОБОЧИХ ПРИМІЩЕННЯХ

Б.П. Гальовський, І. Зентнер

Існує ряд рішень, в яких необхідне застосування систем планарного приводу які складаються з декількох планарних одиниць. Позиція планарних одиниць має бути визначена для контрою системи. У цій роботі описано основні принципи та рішення для визначення позиції планарних одиниць з великим діапазоном переміщень (до 10 м) на робочій площі. Проаналізовано переваги та недоліки основних топологій та методів визначення позиції. Розглянуто сучасні системи що забезпечують вимірювання невизначеністю близько 1 мм.

Ключові слова: *планарний привід, велика робоча площа, система визначення багатокоординатної позиції.*

АНАЛИЗ ПРИНЦИПОВ И РЕШЕНИЙ ДЛЯ ОПРЕДЕЛЕНИЯ МНОГОКООРДИНАТНОЙ ПОЗИЦИИ В БОЛЬШИХ РАБОЧИХ ПОМЕЩЕНИЯХ

Б.П. Галёвский, И. Зентнер

Существует ряд решений, в которых необходимо применение систем планарного привода состоящих из нескольких планарных единиц. Позиция планарных единиц должна быть определена для контроля системы. В этой работе описаны основные принципы и решения для определения позиции планарных единиц с большим диапазоном перемещений (до 10 м) на рабочей площади. Проанализированы преимущества и недостатки основных топологий и методов определения позиции. Рассмотрены современные системы обеспечивающие измерение неопределенностью около 1 мм.

Ключевые слова: *планарный привод, большая рабочая площадь, система определения многокоординатной позиции.*