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DESIGN AND CONTROL TRIPOD ROBOT STRUCTURE

NÁVRH A ŘÍZENÍ TŘÍOSÉ PARALELNÍ STRUKTURY ROBOTU

Abstract

The article describes the design and the control system of a tripod structure for stabilized purposes with the parallel kinematics structure. The stabilized platform is designed to use as an add-on module for different types of the mobile robots. The goal of this platform is to keep a platform moving in vertical direction parallel to the acceleration of gravity. The described control system controls all actuators on the basis of evaluated value given by sensors. The part of this article is a short description of the stabilized platform design.

Abstrakt

Příspěvek popisuje řídící systém stabilizační plošiny s paralelní kinematickou strukturou. Stabilizační plošina je určena jako přídavný modul k různým typům stávajících mobilních robotů. Funkce této plošiny je udržovat její pohyblivou část – horní plošinu - kolmo na směr působení gravitačního zrychlení. Popisovaný řídicí systém ovládá všechny akční členy na základě vyhodnocení hodnot zjištěných pomocí senzorů. Součástí článku je také stručný popis konstrukce stabilizační plošiny.

Introduction

The described system controls three actuators of the stabilized platform. The actuator is composed of the motor MAXON A-MAX 19 2.5W 249993 type, which is equipped by gear GP 19B 149043 with the conversion ratio 1:29 and IRC sensor. This control system controls all actuators according to the value of roll and pitch angle witch are given by a pair of the one-axis accelerometers (ICSensors 3110) working as an inclinometer. The additional equipment of each actuator is a control unit EPOS 24-1. Each of them is equipped by two A/D converters with the measurement range 0-5V. These converters are used to digitalization of an analogue signal measured by accelerometers. The EPOS 24-1unit has two different types of connection, namely with the RS-232 interface working up to speed 115kbit/s or with the CAN bus transferring data up to speed 1Mbit/s. Each of the units can work as a gate between RS-232 and CAN bus. The application described below employs the mentioned.

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Stabilized platform design

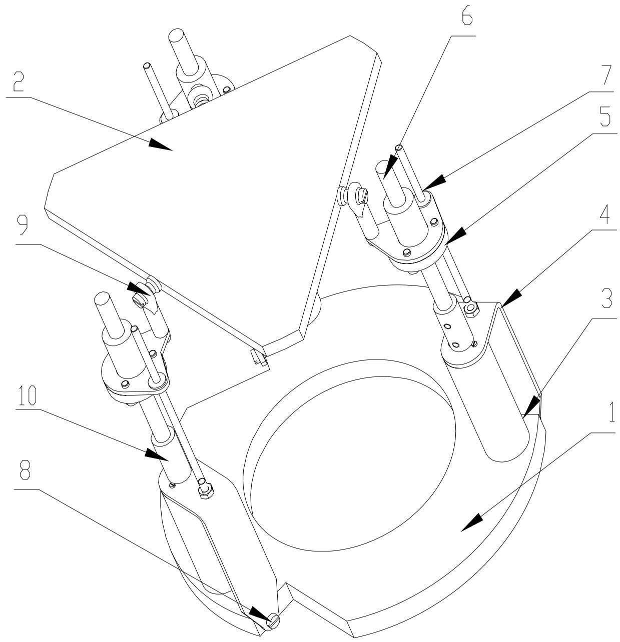

Fig. 1 3D model of stabilized platform

Legend to fig. 1:

1 base of stabilized platform (not moving)
2 moving platform
3 motor MAXON A-MAX 19 2.5W 249993 including gear and IRC sensor
4 motor holder
5 sliding nut
6 lead screw
7 leading rod
8 connection with free rotation about screw axis
9 ball joint
10 clutch connecting leading screw with gear

The stabilized platform consists of three main parts, namely base (1), which is not controlled in any way by actuators, moving platform (2), which is connected to the base in points (8) and (9) by three legs. The legs are rotating by 120° against each other. The connection at point (8) allows rotation about the screw axis, all of this axes together creates an isosceles triangle. The connection of this point (9) is realized by a ball joint, which getting 3° of freedom namely movement in all three axes.

The design of the leg allows moving whose result is its extension and shortening. The motor holder (4) is connected to the base by connection said above (8). In this holder is mounted the actuator (motor) (3), on the output shaft is mounted by clutch (10) a leading screw. On this screw is a moving nut (5). The ball joint (9) is mounted on the nut (5). Leading rod (7) is made to fix rotation about the leading screw axis. Torque which makes this rotation is raised by friction behind thread leading screw and its nut.

Angle sensors are created by a pair of one-axis accelerometers and they are mounted on bottom side of moving platform (2).

This ědesign of the stabilized platform allows rotation of the moving platform (2) about two axes and movement in the vertical direction.

CONTROL SYSTEM

The control system diagram is showed on fig. 2. First control units EPOS 24-1 is connected to a PC through RS-232 interface which is communicating on speed 115kb/s. The first EPOS 24-1 unit works as gate to CAN bus too. Other control units EPOS 24-1 are connected on CAN bus. From programmer's view is the gate to CAN bus absolutely transparent. It means that EPOS's are addressed directly.

Each of EPOS units is supply by 12V and control actuators (motors). Except it the EPOS unit number 3 uses inner two integrated 10 bit A/D converters with range 0-5V for digitalization signals from accelerometers. The accelerometers are supplied by 12V and give information about an acceleration, so acceleration of gravity too, which takes effect on its detection mass (in its center of gravity). Output from the accelerometers is value in range 0-5V. The accelerometer deviation from the center position 2.5V is in direction toward down for positive acceleration and to another direction for negative acceleration. The ranges of both piesoresistive accelerometers are ±2g.

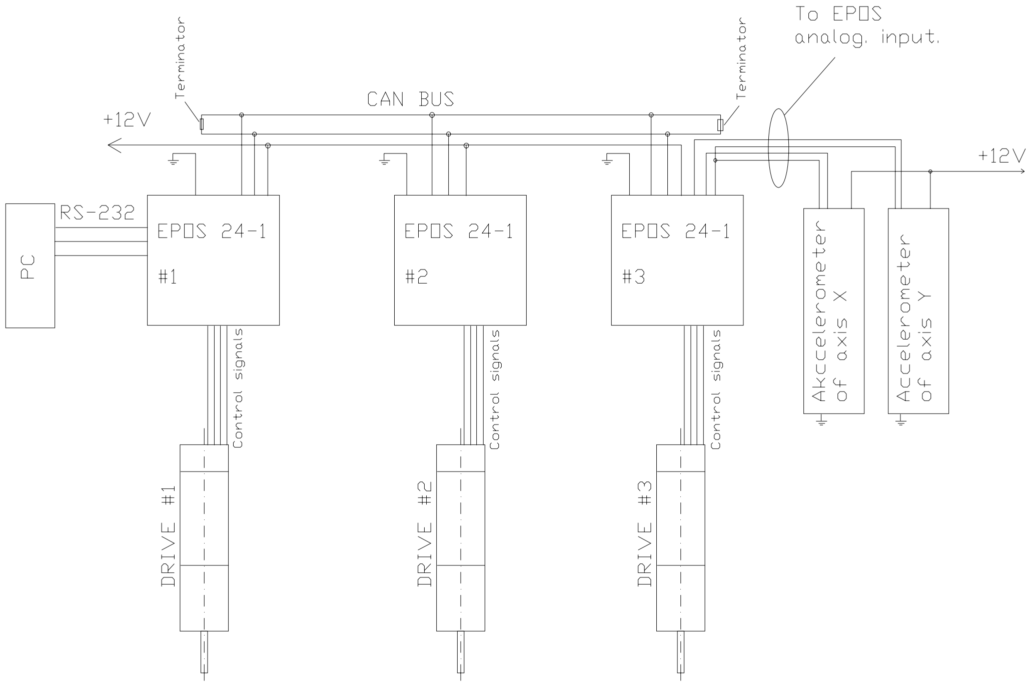

Fig. 2 Control system diagram

Every motor is equipped with the integrated IRC position sensor. The control units EPOS 24-1 provide the kinematics control of the system on the base desired and actual values of the speed and position. The sample time there is 1ms, which is much smaller then the mechanical time constant of a typical drive system.

Control algorithm

The accelerometers detect tilts about two axes which are perpendicular to each other and the axes is X and Y. Output is voltage, which is proportional to resultant value of the acceleration which acts to center of gravity of detection mass of accelerometer. In idle or very small acceleration it is possible to convert output value to angle of tilt about axis according to following formula.

$$\alpha = \arcsin \frac{U_{0^\circ} - U_{akt}}{U_{0^\circ} - U_{90^\circ}}$$

$$-\alpha = \arcsin \frac{U_{akt} - U_{0^\circ}}{U_{-90^\circ} - U_{0^\circ}}$$

Where is

U_{0° … output value of accelerometer at zero tilt [V]

U_{akt}… actual output value of accelerometer [V]

U_{90°…output value of accelerometer at 90° tilt [V]

U_{-90°…output value of accelerometer at -90° tilt [V]

The system makes measuring of 4 successive values and calculates their average value. The angle is computed from calculated value of voltage according to above-mentioned formula for tilt about axis X and Y. Rated angle is rounded to integer.

Now it is necessary to set up coordinate systems for moving platform and for platform base. The system of coordinates of moving platform was taken in its center - see fig. 3. The system of co-ordinates of base was taken in the same point according to idea: "if tilt is zero, the booth systems of coordinates are identical".

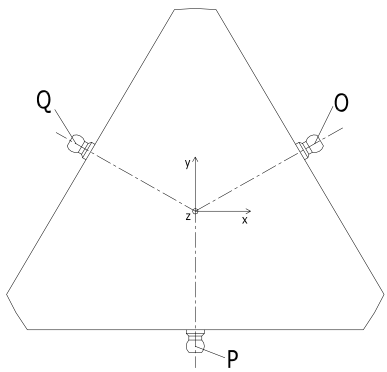

Fig. 3 The choosing of coordinate system and position of O, P, Q, points

Now the coordinates of O, P, Q points in system of coordinates of moving platform (next only SSP) are found out. These points are positioned in center of ball joints.

Next the conversion of points coordinates from SSP to the base system of coordinates (next only SSZ) by transformation matrix (see below) will be done.

When the tilt is equal to zero the points system coordinates defined in SSP and SSZ will be identical. When the moving platform is tilted, the rotation of SSP about SSZ occurs. We define a point (for example O) in SSP a SSZ and substitute this two coordinates in to SSZ. This way we get two points in the same system of coordinates and distance between them is deviation which must be minimizing (best zero) by actuators - see fig. 4. For next point P and Q the procedure is applied ana-logical way.

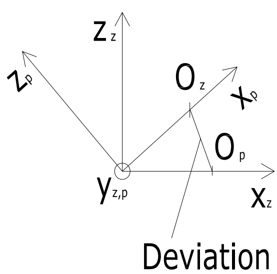

Fig. 4 The showing deviation for point O when there is rotation about axis Y

Transformation matrix is obtained by multiplication the matrixes of rotation about axis X and about axis Y.

$$Rx := \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) \\ 0 & \sin(\alpha) & \cos(\alpha) \end{pmatrix} \qquad Ry := \begin{pmatrix} \cos(\phi) & 0 & \sin(\phi) \\ 0 & 1 & 0 \\ -\sin(\phi) & 0 & \cos(\phi) \end{pmatrix}$$

$$TB := \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) \\ 0 & \sin(\alpha) & \cos(\alpha) \end{pmatrix} \cdot \begin{pmatrix} \cos(\phi) & 0 & \sin(\phi) \\ 0 & 1 & 0 \\ -\sin(\phi) & 0 & \cos(\phi) \end{pmatrix}$$

$$TB := \begin{pmatrix} \cos(\phi) & 0 & \sin(\phi) \\ \sin(\alpha)\cdot\sin(\phi) & \cos(\alpha) & -\sin(\alpha)\cdot\cos(\phi) \\ -\cos(\alpha)\cdot\sin(\phi) & \sin(\alpha) & \cos(\alpha)\cdot\cos(\phi) \end{pmatrix}$$

Where angles α and Φ are angles of rotation about X and Y got by accelerometers see above. The way of obtaining the matrix of rotation about axis X and Y is described in literature [1]. The conversion by this matrix will be done for each point by the way below.

$$Oz = TB \cdot Op \qquad Pz = TB \cdot Pp \qquad Qz = TB \cdot Qp$$

Next the vectors Ov, Pv, Qv, behind points Oz, Op; Pz, Pp; Qz, Qp will be defined.

$$Ov = Op - Oz \qquad Pv = Pp - Pz \qquad Qv = Qp - Qz$$

The vectors magnitudes Ov, Pv, Qv, are sizes of deviations that attach to actuators. Because of sign lost during evaluation of the vectors magnitude is to need to add the identify value of sing. Its value is identified by coordinate Z of the think point at SSZ. For negative coordinate Z is deviation negative respectively.

The reference input for drivers are its revolutions. The dependence between revolutions (speed) of drive and trajectory of nut on leading screw is described below.

$$u(t) = k \cdot \frac{dy}{dt} \quad \text{where } k = \frac{pr}{s}$$

pr... gear ratio in our case 1:29
s… pitch of leading screw [mm]
y…trajectory which travel nut on leading screw (same as trajectory of points O,P,Q) [mm]
u... motors revolutions [1/s]

Value of reference input will be computed by formula showed below.

$$u(t) = q \cdot e(t)^2$$

q…is gain that is determined by measuring on finished model - in our case 10.

e…is deviation got by enumeration showed above

u…demanded revolutions of drive

The EPOS 24-1 is looking after about desired revolutions. The square in formula is used for lower effect of disturb acceleration about minimal deviation value, nevertheless keep high speed when is deviation high.

The algorithm is repeating with 50ms period, which is set with respect to communication speed between PC and EPOS 24-1 units that provide A/D conversion too. The algorithm is showed below.

1) Detection of tilt angle about X and Y.
2) Deviation evaluation
3) Setting speed to drive.
4) Back to 1.

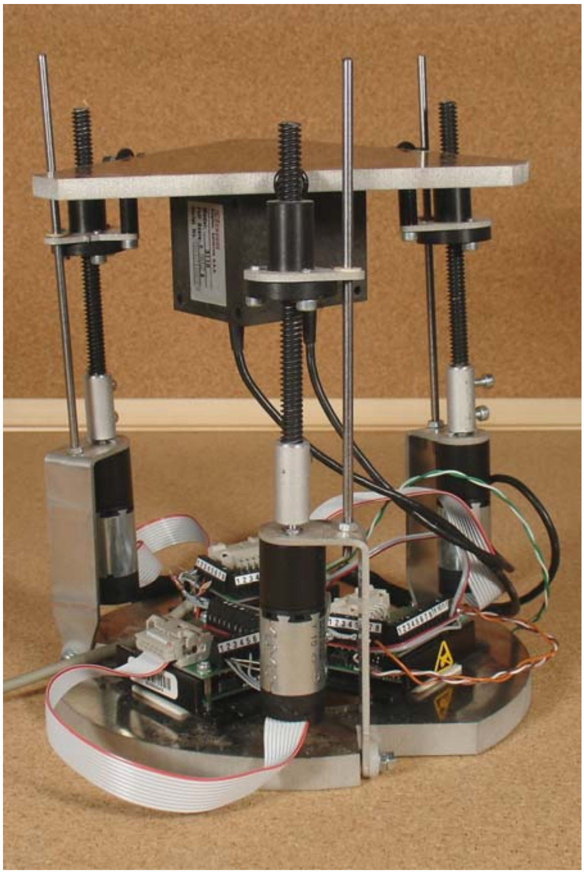

Fig. 5 The realized stabilized platform

Conclusion

The stabilized platform can be used on almost robots, namely mobile or stationary, where it is needed to have one stabilized platform. The platform is stabilized against acceleration of gravity when the base is relative stationary. It can be used for camera stabilizing, liquid transport and bulk material in open container. For more accurate reading value of tilt (reduce of the parasitic dynamic acceleration) it will be useful to add a gyroscopic sensors.

The control system looks after about the control of all actuators (drives) in support by the control unit EPOS 24-1, and reads value of tilt which is measured by accelerometers in two-axes X and Y. In present the unit is controlled by PC. The whole program is written in higher language Visual Basic.net 2005 and uses the DLL library for communication with EPOS 24-1. The DLL library was delivered with EPOS 24-1 as equipment.

Next step can be replacement of PC with an embedded control system. With this smaller control system the energy requirements and its size will be rapidly reduced. But there is one problem, because the library for EPOS units doesn't exist.

This stabilized platform was developed to real and function model so we could deeply test and verify all presumptions and ideas.

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