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Short and Long Term Sampling of Micro and Macro Displacements in Robotics

MILAN KVASNICA (CZ) kvasnica@fai.utb.cz

ABSTRACT
The paper deals with the analysis of the accuracy of the short and long term measurements in the six degrees-of-freedom (DoF) measurement system used for the sampling of axial shiftings and angular displacements, structural dynamic properties of robotic systems, engineering constructions and for the control operation in space. The analysis of the accuracy is based on algorithms for direct and inverse transformation for the computation of three axial shiftings and three angular displacements values in order to determine the relative location and orientation of a floating 2-D coordinate system against fixed 3-D coordinate system of laser rays.

KEYWORDS
positioning accuracy, direct and inverse transformation, sampling of six DoF (degrees of freedom) information, measurement of three axial shiftings and angular displacements, short and long term sampling of micro and macro displacements.

INTRODUCTION
The paper is focused on the analysis of short and long term measurements and the accuracy in the six degrees-of-freedom (DoF) measurement system used for the sampling of axial shiftings and angular displacements, structural dynamic properties of robotic systems, engineering constructions and for the control operation in space. Described sampling system is derived from a pyramid modular sensory system for the scanning of six-component information about three axial shiftings and three angular displacements. The subject of this device is the sampling and information processing used in the conversion of four 2-D CCD arrays images into three axial and three angular displacement values. An algorithm for direct determination of normal vector components simplifies the computation of angular displacements. The dilatation and constriction matrix is used in the direct and inverse transformation of mutual position between two bodies.

The function of modular portable device is derived from the pyramid modular sensory system for robotics and human-machine interface, which enables to compose for example force-torque transducers of various properties and multi DoF hand controllers, see in [2]. This is done by means of a 2-D CCD array (CCD - Charge Coupled Device) and with appropriate changes by means of the PSD element (PSD - Position Sensitive Device), and four light rays creating the shape of pyramid. Simple modular construction enables low cost customization, according to the demanded properties. The problem of the customization of six-DoF sensory systems according to the enhanced accuracy and operating frequency of scanning of the six-DoF information is possible to improve by means of the module of insertion flange with the configuration of light sources with strip diaphragms, creating the light planes with strip light spots and by means of the module of the single or segmented linear or annular CCD or PSD elements with higher operating frequency, respectively using the module of two, parallel working, concentric CCD annulars with higher reliability.

The explanation of the sampling is introduced on the force-torque transducer, see Fig. 1 composed from the modules A, C, D, F, H, of a modular sensory system. Laser diodes 1 emit the light rays 2 creating the edges of a pyramid intersecting the plane of the 2-D

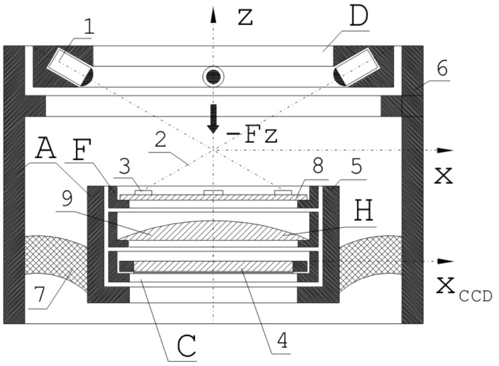

Fig. 1: *Six-component force-torque transducer.*

CCD array, here alternatively the focusing screen 8 with light spots 3. The unique light spots configuration changes under axial shifting and angular displacements between the inner flange 5 and the outer flange 6 connected by means of elastic deformable medium 7. An alternatively inserted optical member 9 (for the magnification of micro-movement, or the reduction of macro-movement) projects the light spots configuration from the focusing screen onto the 2-D CCD array 4. Four light rays simplify and enhance the accuracy of the algorithms for the evaluation of the six-DoF information. The algorithms for the computation of three axial shiftings and three radial displacements values is based on the inverse transformation of the final trapezoidal position of four light spots related to the original square light spots position in the plane coordinate system x_{CCD}, y_{CCD} on the 2-D CCD array. This algorithm determines the relative location and orientation of a floating 2-D coordinate system against a fixed 3-D coordinate system corresponding to the apex of the pyramid shape, or contrary.

The information about three axial shiftings and three angular displacements is sampled and converted according to the calibration matrix to acting forces F_x, F_y, F_z and torques M_x, M_y, M_z.

THE POSITIONING ACCURACY IN SHORT AND LONG TERM SAMPLING OF MICRO AND MACRO DISPLACEMENTS

The accuracy of the six-DoF pyramid sensor is investigated like the influence of the deflection of the independent variable, here the coordinates of four light spots positions Δx_i, Δy_i, where $i = A, B, C, D$ on the dependent variable consisting of three axial shiftings x, y, z and three angular displacements φ, θ, ω in the working range of the CCD or the PSDs. There is the $m = 8$ the number of the independent variable $q_m = (x_A, y_A, x_B, y_B, x_C, y_C, x_D, y_D)$ and the $n = 6$ is the number of the dependent variable $z_n = (x, y, z, \phi, \theta, \omega)$, where the inverse transformation is $z_n = F^{-1}(q_m)$, and the direct transformation is $q_m = F(z_n)$, see in [4].

The generalization of described method from micro to macro environment led to the customization of measurement of six-component information according to the size and position of measured object by means of universal portable modules and their combination:

The portable module A_p of four lasers 3 with the presetting control 1 of the angle 2s, which contains mutual opposite light rays 2, see Fig. 2.

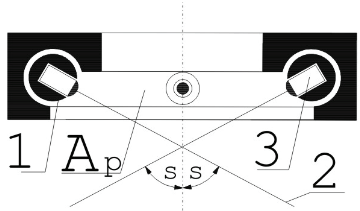

Fig. 2: *The portable module Ap of four lasers.*

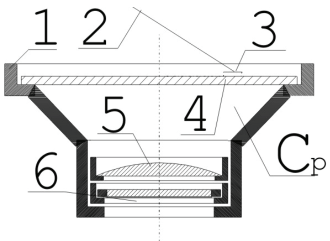

Fig. 3: *The portable module Cp for the direct sampling.*

The portable module C_p for the direct sampling of small or medial fluctuation of measured values of the light spot 3 position from the laser light ray 2 which is imagined on the translucent screen 4. This module consists of the 2-D CCD array 6 with focusing optics 5 and of the flange 1, see Fig. 3. The module C_p is placed and centered in the axis of the module Ap. This configuration enables the sampling of small and medium fluctuation of the light spot position.

The enhancement of the dynamic range of sensory system is possible using the substitution instead of one 2-D CCD array for all four laser light beams using for every light beam one separate 2-D CCD array. Six DoF modular pyramid sensory systems for the sampling of six-component information introduces new state of the art not only in robotics and human machine interface but also in measurements of the macro elastic and micro elastic deformations. Modular design enables to compose measurement devices for the sampling of six DoF information for different tasks in the working range for axial shiftings x, y, z from $|10^{-7}|$ m up to $|10^2|$ m and angular displacements φ, θ, ω corresponding to the arc longitude (or displacement) from $|10^{-7}|$ m up to $|10^2|$ m using mostly common modular components.

Current working accuracy of CCD devices is limited by the lowest size of the pixel $3{,}5\times 5$ μm and for the PSDs by the inaccuracy of 1 μm. There is possibility to improve the accuracy at least 10-times by means of the design and development of structured photonic components using a new photonic nanotechnology. The design and construction of pyramid sensory system guaranties an output working accuracy in the same order of magnitude like the input inaccuracy (for example the inaccuracy caused by the construction or the production of the sensor). Using a redundant light spots configuration enables the enhancement of the measurement accuracy approximately 10-times.

The sampling frequency (the measurement speed) is proposed and based on modular brick box design in two variants:

- For the real-time measurements (high frequency sampling - based on the PSDs): Supposed sampling frequency is between 100 Hz and 30 kHz, sufficient for the sampling of mechanical vibration. Maximal sampling frequency is limited for the 2-D PSD arrays by the frequency of 1 MHz, at linear-1-D PSD by the frequency of 10 MHz. Six DoF sensory systems for high frequency sampling based on the PSDs have like all analog devices sufficient stability only during the short term measurements, due to the drift effect.

- For the long term measurements (low frequency sampling based on the CCDs): Supposed sampling frequency is between $2{,}77\times 10^{-5}$ Hz (10hours interval, or more) and 200 Hz, sufficient for the sampling of long term static and dynamic tests, for example the measurement of temperature and humidity stability for various constructions at dynamic loading, or for the size stability of nuclear reactors. Six DoF modular sensory systems for low frequency sampling based on the CCDs have sufficient stability during the short term and long term measurements. Special high speed camera systems are working up to 50 KHz.

Six DoF modular pyramid sensory system for the sampling of six-component information is according to results of the proof of the linearity for 3 DoF (x, y, z components) linear and for 3DoF (φ, θ, ω) moderately nonlinear with the possibility of appropriate compensation. Six DoF modular pyramid sensory systems for the sampling of six-component information enable the self calibration and the enhancement of the accuracy by the use of redundant laser beams.

THE ENHANCEMENT OF THE SAMPLING FREQUENCY AND RELIABILITY

The problem of the customization of six-DoF sensory systems according to the enhanced accuracy and operating frequency of scanning of the 6-DoF information is possible to improve by means of the modules: K- module of insertion flange with the configuration of light sources with strip diaphragms, creating the light planes with strip light spots, see in Fig. 4, 5, 6 and 7 in three positions over the configurations of CCD or PSD arrays, M - module of four single linear CCD elements, see Fig. 4, N - module of eight segmented linear PSD elements for every light spot separately with higher operating frequency, see Fig. 5, O - module of segmented annular CCD arrays intersected by structured light planes for enhanced scanning frequency, see Fig. 6 and P-module of two, parallel working, concentric CCD annulars with enhanced reliability using redundant annular with parallel effect of enhanced accuracy, see Fig. 7. By the use of PSD elements is for every light spot needed separate PSD, in order to avoid dynamic distortion at switching of light spots, because every light spot is evaluated separately.

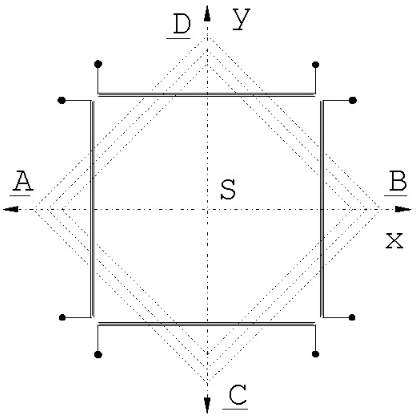

Fig. 4: *The module M of four segmented linear CCD arrays intersected by structured light planes for enhanced scanning frequency.*

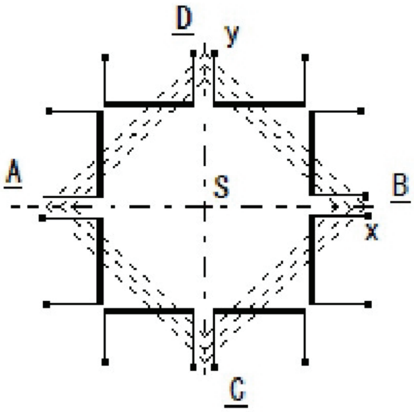

Fig. 5: *The module N of eight segmented linear PSD arrays intersected by structured light planes for enhanced scanning frequency.*

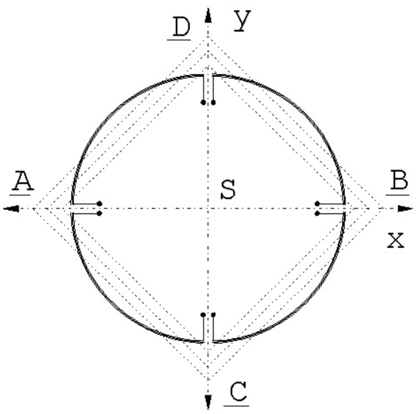

Fig. 6: *The module O of segmented annular CCD arrays intersected by structured light planes for enhanced scanning frequency.*

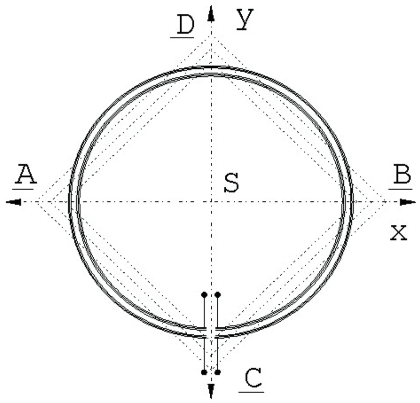

Fig. 7: *The module P of two parallel working concentric annular CCD arrays intersected by structured light planes for enhanced scanning frequency and enhanced reliability.*

CONCLUSION

The modular design for six-component sensory system presented here enables according to vide dynamic range of sampling frequency and the micro and macro scanning easy customizing for wide variety applications.

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