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# OPTOELECTRONIC SHORT AND LONG TERM SAMPLING OF MICRO AND MACRO DISPLACEMENTS OF THE SIX-COMPONENT INFORMATION

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## ABSTRACT

The paper deals about analyzes 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 subject of this measurement device is the sampling and information processing used in the conversion of the 2-D CCD array images into three axial and three angular displacement values. Every 2-CCD array image consists of one, alternatively four light spot produced by light rays from four laser sources. These light beams form the edges of a pyramidal shape with one, alternatively four 2-D arrays forming its base and the intersection of laser light rays is forming its apex. The analyze 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 analyze of the short and long term measurements of 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. Every 2D-CCD array image consists of one light spot produced by light beam from four laser sources. These light beams form the edges of a pyramidal shape with four 2-D arrays forming its base and the origin of the laser sources is forming its apex. The modular design presented here enables easy customization of six DoF measurements by means of three universal portable modules.

An algorithm for direct determination of normal vector components simplifies the computation of angular displacements. The dilatation and constriction matrix is used for 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 [4], [6]. 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: A -stiff module of two flanges connected by means of microelastic deformable medium; B -compliant module of two flanges connected by means of macroelastic deformable medium; C -the module of the 2-D CCD array; D -the module of insertion flange with basic light sources configuration and focusing optics; F -the module of the plane-focusing screen; H -the module of the optical member for the magnifying or reduction of the light spots configuration. 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, see [3].

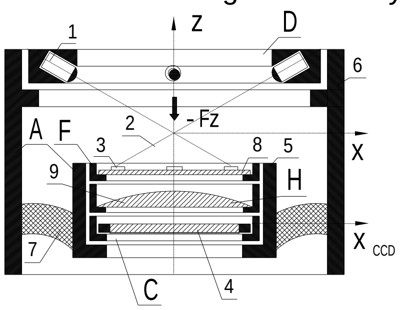


Fig. 1. Six-component force-torque transducer.

The explanation of the sampling is introduced on the force-torque transducer, see Figure 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 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 a calibration matrix to acting forces Fx, Fy, Fz and torques Mx, My, Mz.

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

This modular sensory enables the six DoF sampling of micro-displacements for vibration measurement as well as the macro-displacements at dynamic or force-torque loading of engineering constructions, direct or by means of optical transformations. The modularity of the embedded components of six DoF sensory system enables tailoring of properties for applications such as: portable modular system for the six component dynamic measurement in general anisotropic construction in 3-D space detection of micro-elastic deformation, detection of macro-elastic deformation and in addition six-DoF force-torque sensors of various properties, tactile sensors, accelerometers, dynamic weighing, active compliant links, on-line checking of the dynamic activity of vehicles by means of the sampling of motion parameters, range-incline finders-positioners, and on the man-machine interface the haptic interaction, multi-DoF hand controllers, signature scanners for banking, keyboards for blind people, chaser systems for antiterrorist robots, artificial limbs.
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, see in [6], [7]:
The portable module Ap of four lasers 3 with the presetting control 1 of the angle 2s, which contains mutual opposite light rays 2, see Figure 2.

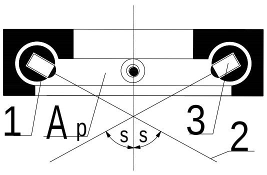


Fig. 2. The portable module Ap of four lasers.

The portable module Cp 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 Figure 3. The module Cp 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.

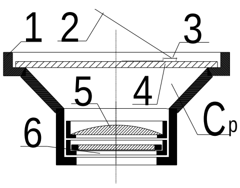


Fig.3. The portable module Cp for the direct sampling.

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 |102|m and angular displacements fi, theta, omega corresponding to the arc longitude (or displacement) from |10-7|m up to |102|m using mostly common modular components.
Current working accuracy of CCD devices is limited by the lowest size of the pixel 3,5x5μm and for the PSDs 1μm. There is possibility to improve the accuracy at least 10x by means of the design and development of structured photonic components using 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 redundant light spots configuration enables the enhancement of the measurement accuracy 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 100Hz and 30kHz, sufficient for the sampling of mechanical vibration. Maximal sampling frequency is limited for the 2-D PSD arrays by the frequency of 1MHz, at linear-1-D PSD by the frequency of 10MHz. Six DoF sensory systems for high frequency sampling based on the PSDs have like all analog devices sufficient stability during the short term measurements, due to drift effect.
For the long term measurements (low frequency sampling based on the CCDs). Supposed sampling frequency is between 2,77x10-5Hz (10hours interval, or more) and 200Hz, 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

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 (fi, theta, omega) 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 Figures 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 Figure 4, N - module of eight segmented linear PSD elements for every light spot separately with higher operating frequency, see Figure 5, O - module of segmented annular CCD arrays intersected by structured light planes for enhanced scanning frequency, see Figure 6 and P-module of two, parallel working, concentric CCD annulars with enhanced reliability using redundant annular with parallel effect of enhanced accuracy, see Figure 7. By the use of PSD elements is for every light spot needed separate PSD.

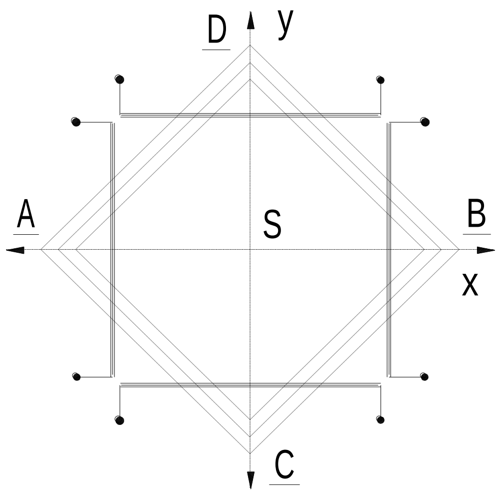


Figure 4. The Module M of Four Segmented Linear CCD Arrays Intersected by Structured Light Planes for Enhanced Scanning Frequency.

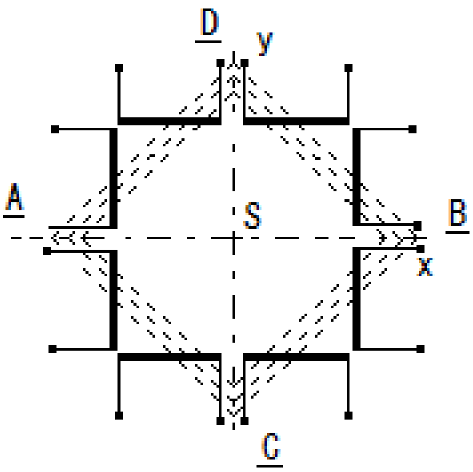


Figure 5. The Module N of Eight Segmented Linear PSD Arrays Intersected by Structured Light Planes for Enhanced Scanning Frequency.

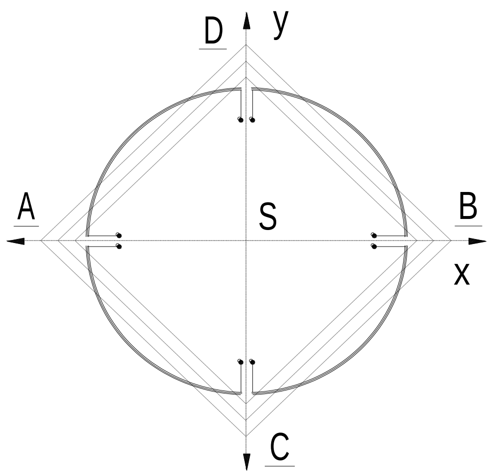


Figure 6. The Module O of Segmented Annular CCD Arrays Intersected by Structured Light Planes for Enhanced Scanning Frequency.

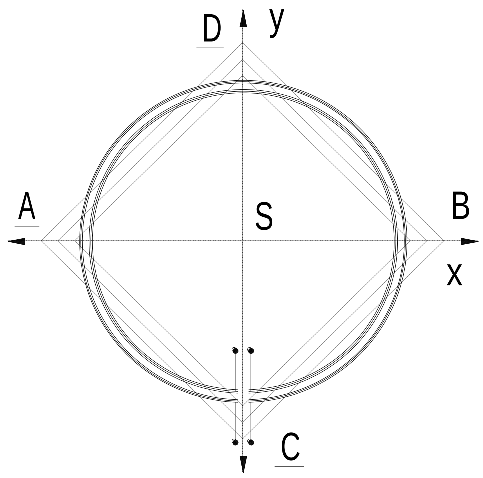


Figure 7. The Module P of Two Parallel Working Concentric Annular CCD Arrays Intersected by Structured Light Planes for Enhanced Scanning Frequency and Enhanced Reliability.

## CONCLUSION

The modular design for six-component sensory system presented here enables according to vide dynamic range of sampling and scanning frequency easy customizing for wide variety applications in walking humanoids. Various combinations of the modular components enable tailoring of the sensory system properties including the use of the haptic interface for applications such as: detection of microelastic or macroelastic deformation, active compliant links, multi-DoF hand controllers, signature scanners, keyboards for blind people, tactile sensors, and range finders-positioners. In general, this modular design concept allows the maximization of service life because of ease of repair and the use of modular components for various types of sensors and the customization for a wide variety of design requirements. For example various levels of resolution and operating frequency, enhanced demands for safety and reliability in space robotics and medical use, and low cost design for manufacturing.

In conclusion, introduced six component sensory system enables to built walking robots appropriate for experiments in the field of assistive technologies, human-machine interface, walking platforms for military, security, antiterrorist and rescue robotics and for the swarm robotic systems.

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