Modular Sensory System for Robotics and Human–Machine Interaction Based on Optoelectronic Components

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INTRODUCTION

Presented here is a new unified modular sensory system. The subject of the article is the sampling and information processing used in the conversion of a 2-D CCD array image into three axial and three angular displacement values. The CCD array image consists of four light spots produced by four light beams (planes) from laser diodes. These light beams (planes) form the edges (faces) of a pyramidal shape, with the 2-D CCD array forming its base and the origin of the laser sources forming its apex. The algorithm for the computation of the location and orientation is based on the inverse transformation of the final trapezoidal light spots position, related to the original square light spots position on the 2-D CCD array. This algorithm determines the relative location and orientation of a floating 2-D coordinate system (corresponding to the 2-D CCD array) against a fixed 3-D coordinate system (corresponding to the apex of the pyramidal shape). The modular design presented here enables easy customizing of this sensory system for a wide variety of applications. Various combinations of the modular components enable tailoring of the sensory system properties for applications such as:

- portable modular system for the six-component dynamic measurement in general anisotropic construction in 3-D space,
- detection of microelastic or macroelastic deformation,
- six-DOF force-torque sensors of various properties,
- active compliant links,
- haptic interface,
- multi-DOF hand controllers,
- signature scanners for banking,
- keyboards for blind people,
- tactile sensors,
- range-incline finders-positioners,
- chaser systems,
- accelerometers,
- dynamic weighing, and
- artificial limbs.

In general, this modular design concept allows:

- maximization of service life because of ease of repair and the use of universal modular components for various types of sensors;
- environmentally friendly design, because the modular components are recyclable; and
- customization for a wide variety of design requirements.

Examples include various levels of resolution and operating frequency, enhanced demands for safety and reliability in space robotics, operation in dangerous areas and medical use with supporting self-checking and self-correcting algorithms, and low-cost design for manufacturing. In conclusion, regarding industrial relevance, many fields could benefit from the use of such a sensory system: robotics, telerobotics, rehabilitation robotics, intelligent automation, manufacturing and materials handling, automotive, marine and aerospace industry, medicine, ergonomics, safety accident prevention, defense, and banking.

The function of these sensors is based on the six-DOF system for the scanning of axial shifting and angular displacement. This simple construction enables low-cost customization, according to the demanded properties by means of the modular sensory system consisting of the following basic modules:

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 square CCD elements;
D: The module of the insertion flange with basic light sources configuration and focusing optics;
E: The module of the insertion flange with auxiliary light sources configuration and focusing optics;
F: The module of the plane focusing screen;
G: The module of forming focusing screen;
H: The module of the optical member for the magnifying or reduction of the light spots configuration;

I: The module of switchable muff coupling for changing the scanning mode for the micromovement and the macromovement-active compliance; and

J: The module for the preprocessing of scanned 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 modules:

K: The module of insertion flange with the configuration of light sources with strip diaphragms, creating the light planes with strip light spots;

M: The module of the single or segmented linear or annular CCD or PSD elements with higher operating frequency; and

N: The module of two, parallel working, concentric CCD annulars with higher reliability.

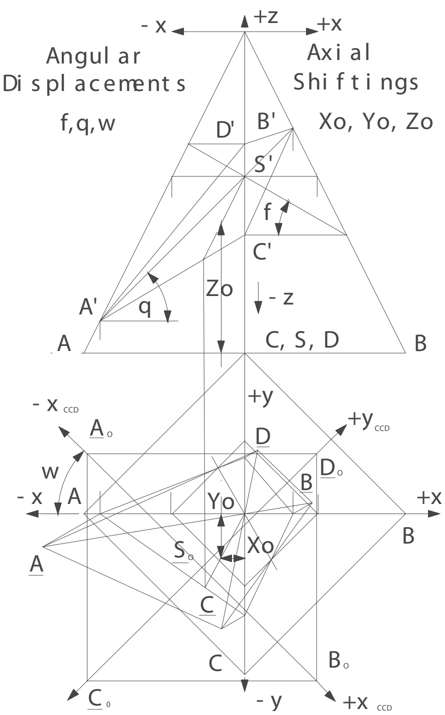
BACKGROUND

The results of our research program concerns the task of how to use a robot to imitate the human activity, as for example inserting a peg in a hole by means of the six-component force-torque sensor. The first robotic systems able to manage this task used a six-component strain gage wrist sensor developed at Stanford University, MIT, and C. S. Draper Laboratory (1960-1970). Using a robot to imitate a human activity in this way marked a historic step in human creative thinking. Recently, several implementations of sensory systems using optical imaging of six-DOF information on a CCD or PSD array have been proposed. An example is the project NASA in the cooperation with the DLR project ROTEX (1993).

SIX-COMPONENT FORCE-TORQUE SENSOR

The explanation of the activity of the majority of sensors described here is introduced with the six-component force-torque sensor (see Figures 1 and 2) composed from modules A,C,D,F,H, of the intelligent modular sensory system. Laser diodes 1 emit the light beams 2 creating the edges of a pyramid intersecting the plane of the square CCD element, 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 micromovement or the reduction of macromovement) projects the light spots configuration from the focusing screen onto the square CCD element 4. Four light beams simplify and enhance the accuracy of the algorithms for the evaluation of six-DOF information. The algorithms for the evaluation of three axial shiftings and three radial displacements are based on the inverse transformation of the final position of points A,B,C,D, related to the original basic position of points A_0,B_0,C_0,D_0,S_0 of the plane coordinate system x_{CCD}, y_{CCD} of the square CCD element (see Figures 1 and 2).

Figure 1. The approach of six-DOF scanning



The information about axial shiftings caused by forces Fx, Fy, Fz and angular displacements caused by torques Mx, My, Mz are sampled and processed according to a calibration matrix. The intelligent modular sensory system enables us to compose in a customized way the various modifications of the multi-DOF force-torque sensors and compliant links for artificial arms or legs, range incline finders, hand controllers for wheelchairs, tactile sensors, keyboards for blind people, and handwriting scanners.

HUMAN ARTIFICIAL LIMBS

The effort to imitate by means of robot the human behavior of inserting a peg in a hole for the purposes of automatic assembly led to the development of the six-component force-torque sensor. For the scientist it is more satisfying to