A MODULAR FORCE-TORQUE TRANSDUCER FOR REHABILITATION ROBOTICS

Milan Kvasnica
Technical University of Zvolen, T. G. Masaryka 24, SK-96053 Zvolen, Slovakia
G.R.A.S.P. Laboratory, School of Engineering and Applied Sciences
University of Pennsylvania, Philadelphia, PA 19104, USA
E-mail: mkvasnic@uvt.tuzvo.sk mkva@grip.cis.upenn.edu

ABSTRACT
Intelligent sensory systems are an essential part of any system aimed at augmenting the functional capabilities of visually or mobility impaired persons. This paper describes a six-DOF force-torque sensor, originally designed for robotic and man-machine interface applications that can be used to improve the communication, control and safety of assitive systems. This modular force-torque sensor transduces three linear displacements and three rotations by measuring the incidence of four light or laser beams onto a photosensitive CCD array. This low-cost, force-torque sensors is easy to build and can be used in artificial arms or legs, range-incline finders, hand controllers for wheelchairs, keyboards for blind people and handwriting scanners.

INTRODUCTION
The function of the intelligent sensors is based on the six DOF system for the scanning of linear displacement and rotation. This is done by means of a square (or annular) CCD element (CCD - Charge Coupled Device) and with appropriate changes by means of the PSD element (PSD - Position Sensitive Device), and four light beams (or planes) creating the shape of pyramid. 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, J -the module for the preprocessing of scanned light spots configuration, see [4], [5], [7], [8]. 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 -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, N -the module of two, parallel working, concentric CCD annulars with higher reliability, see [5].

The explanation of the activity is introduced on the force-torque sensor, see Figure 1 and Figure 2, composed from modules A,C,D,F,H, of the intelligent modular sensory system [7]. 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 linear displacement and rotations 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, see [6]. The algorithms for the evaluation of three linear displacements 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 $\underline{A}_0,\underline{B}_0,\underline{C}_0,\underline{D}_0,\underline{S}_0$ of the plane coordinate system x_{CCD}, y_{CCD} of the square CCD element, see Figure 1 and Figure 2. The information about linear displacements caused by forces Fx, Fy, Fz and rotations caused by torques Mx, My, Mz are sampled and processed according to a calibration matrix, see [10].

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 utilize such sensors to substitute for the missing limbs of the human body by an artificial limb of higher quality. Universal, low cost, intelligent modular sensory systems enable us to evaluate a man’s hand or leg dynamics while in motion. A part of the artificial leg consisted of the joint 10 connecting a shin with a foot 11 is depicted in Figure 3. The motion of the joint 11 is controlled by means of the six DOF information gained from two six-component sensors. The joint’s 10 drive transmission is switched by means of the coupling muff 9 in order to control the dynamics of the motion. The six-component information about the leg's dynamics processed from two force-torque sensors enables us to use the drive Power intelligently, even to convert the damping of the joint 10 motion for energy recuperation into the battery. The joint 13 connects the foot 11 with the toes part 14. The rotation, (here for example a, b), of the joint 13 is used for accommodation to the ground's incline 12a, 12b, according to the information from the range-incline finder.

RANGE-INCLINE FINDER

The ground's incline under the artificial leg is scanned by means of the range-incline finder mounted in a heel, see Figure 3, consisting of the modules A, C, D, H. The light spots 3 from the light beams 2 on the ground 12a, 12b create the configuration scanned by the square CCD element. The processing of this information enables us to evaluate the incline of the ground in two perpendicular planes. Real-time algorithms suitable for the single cheap microprocessor are described in [2], [3]. An acoustic signal as indicator of the ground's incline helps the user to keep stability. The range-incline finder mounted on a wheelchair helps to keep the desired distance from a wall.

CUSTOMIZED DESIGN OF A DEXTEROUS HAND

In rehabilitation robotics and in the health care any tasks occur frequently, see [8], [9], [11], for example at the feeding of disabled people:

- The approaching of the artificial hand with the feeding utensil into the required position in front of a target object
- The sequence of the operations until the time instant of the first contact with the target part of the body
- The inserting into a target part of a body
- Following this is the force-torque manipulation with a target object, with the aim, here for example to load the food into the mouth and to protect the hurt.

Intelligent sensory systems for the solution of these tasks may be implemented instead of a missing part of a human hand, or as the part of a robot's hand. In addition there is a possibility to evaluate the weight of gripped food on dynamic way while a motion of robot's hand in order to check the caloric limit.

A simple solution of an universal dexterous hand consists of three sensory system with two independently working CCD, see Figure 4.

The first sensory system is the range-incline finder-positioner, composed of three modules C, D, H, alternatively working into the CCD element 4b. The range-incline finder-positioner consists of two pairs mutual perpendicularly situated cross light beams (planes) 2a radiated from the laser diodes 1a situated on the gripper. The configuration of the light spots (strips) 3a on the surface of the target object is projected by means of the zoom optical member 9a into the

CCD element 4b. This multi-laser scanning equipment is used in the approach of the robot's gripper to the target and for simplifying some tasks in recognizing three-dimensional backgrounds, see [2].

The second sensory system is a six-component stiff force-torque sensor, composed of three modules A, C, D, alternatively working into the CCD element 4b. The laser diodes 1b fastened on the outer flange 6b radiate the light beams (planes) 2b against the CCD element 4b, fastened on the inner flange 5b. The unique light spots (strips) configuration 3b is changed under the force-torque acting between flanges 5b and 6b, both mutual connected by means of microelastic deformable medium 7b.

The third sensory system is the six-component active compliant link composed of six modules B, C, D, F, H, I, working into the CCD element 4c. The laser diodes 1c emits the light beams (planes) 2c against the focusing screen 8c. An optical member 9c mediates the reduction of the macro-movement of the light spots (strips) 3c. The unique light spots (strips) configuration 3c is changed under the force-torque acting between flanges 5c and 6c, connected by means of the active compliant medium 7c. An active compliance is solved by means of pneumatic, programmable switched, segmented hollow rubber annulars 7c. Alternative use of the six-component stiff force-torque sensor or the active compliant link is switched by means of coupling muff 10.

Unified modular intelligent sensory system enables customized design for wide variety of tasks in rehabilitation robotics.

HAND CONTROLLER

Efficiency in using a wheelchair depends on the user's effectiveness in communicating with the driving gear. A low cost six degrees-of freedom hand controller means for many users not luxury but the possibility for personal autonomy in their daily activities. A multi DOF hand controller is possible to use for the control of the feeding utensil combined with a simple mechanism, described in [11]. The multi degrees-of-freedom hand controller (low cost), or of enhanced reliability is depicted in Figure 5, under the influence of the acting force +Fz. This device consists of the (module C of the square CCD element), or of the module N, for example in medical use of enhanced reliability for surgeons with two independently parallel working CCD annulars 4, fastened in mutually opposite directions in front of the (module D) modules K of the (light beams) light planes 2. The configuration of the (light beams) light planes 2 of the pyramid shape is radiated from the laser diodes 1 fastened on the outer flange 6. The configuration of light (beams) planes 2 creates in the plane of (square CCD elements) the CCD annulars the configuration of light (spots) strips 3. The inner flange 5 is fastened on the stand 8 and connected by means of the elastic deformable coupling balks 7 with the outer flange 6. The design of the outer flange 6 is shaped for a human-hand friendly form.

KEYBOARD FOR BLIND PEOPLE

Six-component force-torque sensors that make it possible to pass judgment about the heterogeneity of a man's hand dynamics, for example the handwriting of two different persons, may be used like a keyboard for blind people. Because of the lack of place for the six-component force-torque sensor between a nib and a penholder, the configuration, see Figure 6, was used, where the inner flange 5 is put on the end of a penholder 8. The outer flange creates a steady mass. This handwriting scanner is possible to use as a keyboard for blind people in order to improve their communication with a computer. Another configuration, of the hand writing scanner, where the six-component force-torque sensor is inserted between the writing plate 6 and the support 8 of the writing hand is depicted in Figure 7. This device may be used as a signature scanner in banking.

CONCLUSION

The level of the design concerning the imitation of human sensing is not only the indicator for the progress of a human creative capability. Using sensory systems in producing prostheses as well as other supports for disabled people is a sensitive and reliable indicator of the level of democracy in every country. The aim of this paper is to introduce the use of intelligent sensory systems for robotics and the man-machine interface in order to help disabled people. The main advantage of the described intelligent modular sensory system design is low cost solution of many control problems. Introduced solution has regard for the current trends in the design of the products oriented on easy reparability, uniform spare parts for more types of sensors, service life, accommodation for different purposes and recycling, in order to protect the environment.

KEYWORDS

Intelligent Modular Sensory System; Six Degrees-of-Freedom Force-Torque Sensor, Artificial Arm or Leg; Hand Controller for a Wheelchair; Keyboard for Blind People; Handwriting Scanner; Range-Incline Finder.

ACKNOWLEDGMENTS

This paper was inspired by the research program of the General Robotics and Active Sensory Perception (GRASP) Laboratory, directed by Prof. R. Bajcsy, University of Pennsylvania, 3401 Walnut Street 300C, Philadelphia, PA 19104 USA. The support of NATO Scientific Affairs Division - grant award EXPERT VISIT HIGH TECHNOLOGY, EV 950991 is gratefully acknowledged.

REFERENCES

[1] Hirzinger G., Dietrich J., Gombert J., Heindl J.,Landzettel K.,Schott J. (1992). „The Sensory and Telerobotic Aspects of Space Robot Technology Experiment ROTEX“. Proceedings of the International Symposium on Artificial Intelligence, Robotics and Automation in Space, Toulouse, Labege, France.

[2] Kvasnica, M.. (1986). „Scanning and Evaluation System of Object Surface Using Cross Light Beams with the CCD

Camera". Proceedings of the International Symposium on Robot Manipulators: Modeling, Control, and Education, Albuquerque, USA.

[3] Kvasnica M.. (1992). „New Concept of Sensory Outfit for Space Robotics". Proceedings of IFAC Symposium on Automatic Control in Aerospace, Ottobrunn, Germany.

[4] Kvasnica M.. (1992). „Six-Component Force-Torque Sensing by Means of One Quadrate CCD or PSD Element". Proceedings of the 2nd International Symposium on Measurement and Control in Robotics, AIST Tsukuba Science City, Japan.

[5] Kvasnica, M.. (1993). „Fast Sensory System for the Scanning of the Six-Component Linear displacements and Radial Displacements". Proceedings of the International Symposium on Measurement and Control in Robotics, Torino, Italy.

[6] Kvasnica, M.. (1993). „Algorithms for the Scanning of the Six-Component Linear displacements and Radial Displacements by Means of Only One CCD Element". Proceedings of the International Symposium on Industrial Robots, Tokyo, Japan.

[7] Kvasnica M.. (1997). „Flexible Sensory Brick-Box Concept for Automated Production and Man-Machine Interface". Proceedings of the NOE Conference in Intelligent Control and Integrated Manufacturing Systems, Budapest, Hungary.

[8] Kvasnica M.. (1998). „Intelligent Sensors for the Control of Autonomous Vehicles". Proceedings of the 6th International Conference and Exposition on Engineering, Construction and Operation in Space and on Robotics for the Challenging Environments - Space and Robotics'98, Albuquerque, New Mexico, USA.

[9] Merklinger A., Sly I.. (1997). „Rendez-Vous and Docking". Proceedings of the 3rd International Symposium on Measurement and Control in Robotics, Torino, Italy.

[10] Sásik J.. (1987). „Multi-component Force-Torque Sensors Calibration Methods for Robotics Application". Strojnícky časopis, 38, No.6, Bratislava, Slovakia.

[11] Vezien J-M, Kumar V., Bajcsy R., Mahoney R., Harwin W. (1996). Design of Customized Rehabilitation Aids. Proceedings of the IARP Workshop on Medical Robots, Vienna, Austria.

[12] Kvasnica M.. (1992). The Equipment for the Robot Control in Defined Distance from the Object. Patent CSFR AO 272457.

[13] Kvasnica M.. (1993). The Equipment for the Force-Torque Scanning. Patent CZ AO 278212, SK AO 277944.

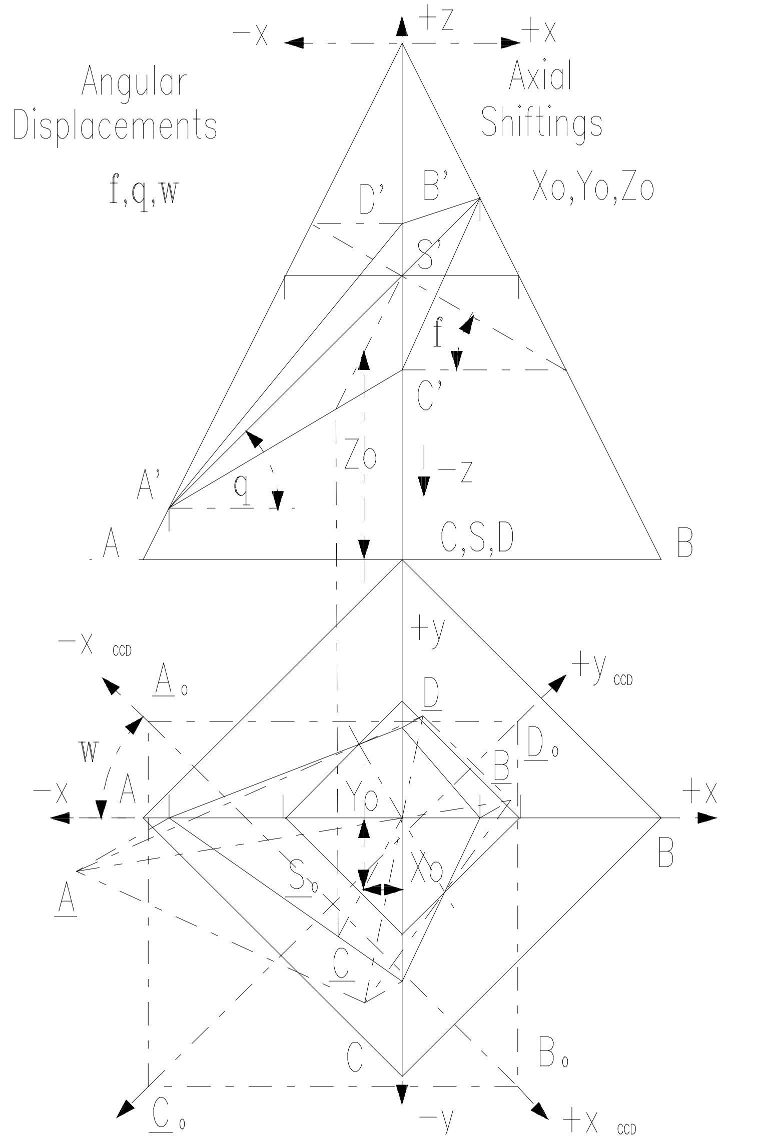


Figure 1. The Approach of Six-DOF Scanning

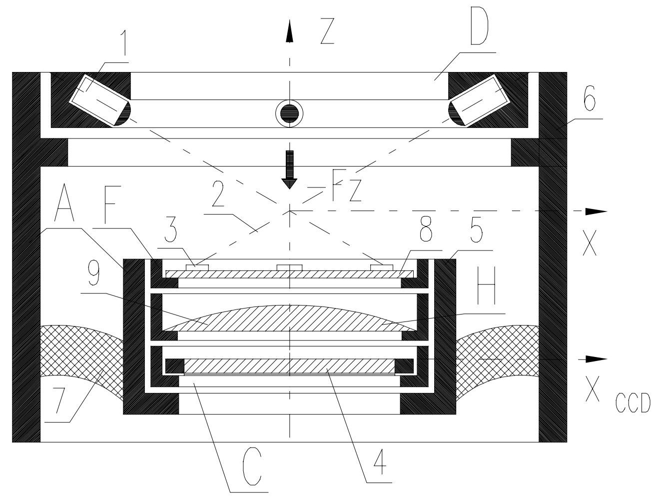


Figure 2. Six-Component Force Torque Sensor

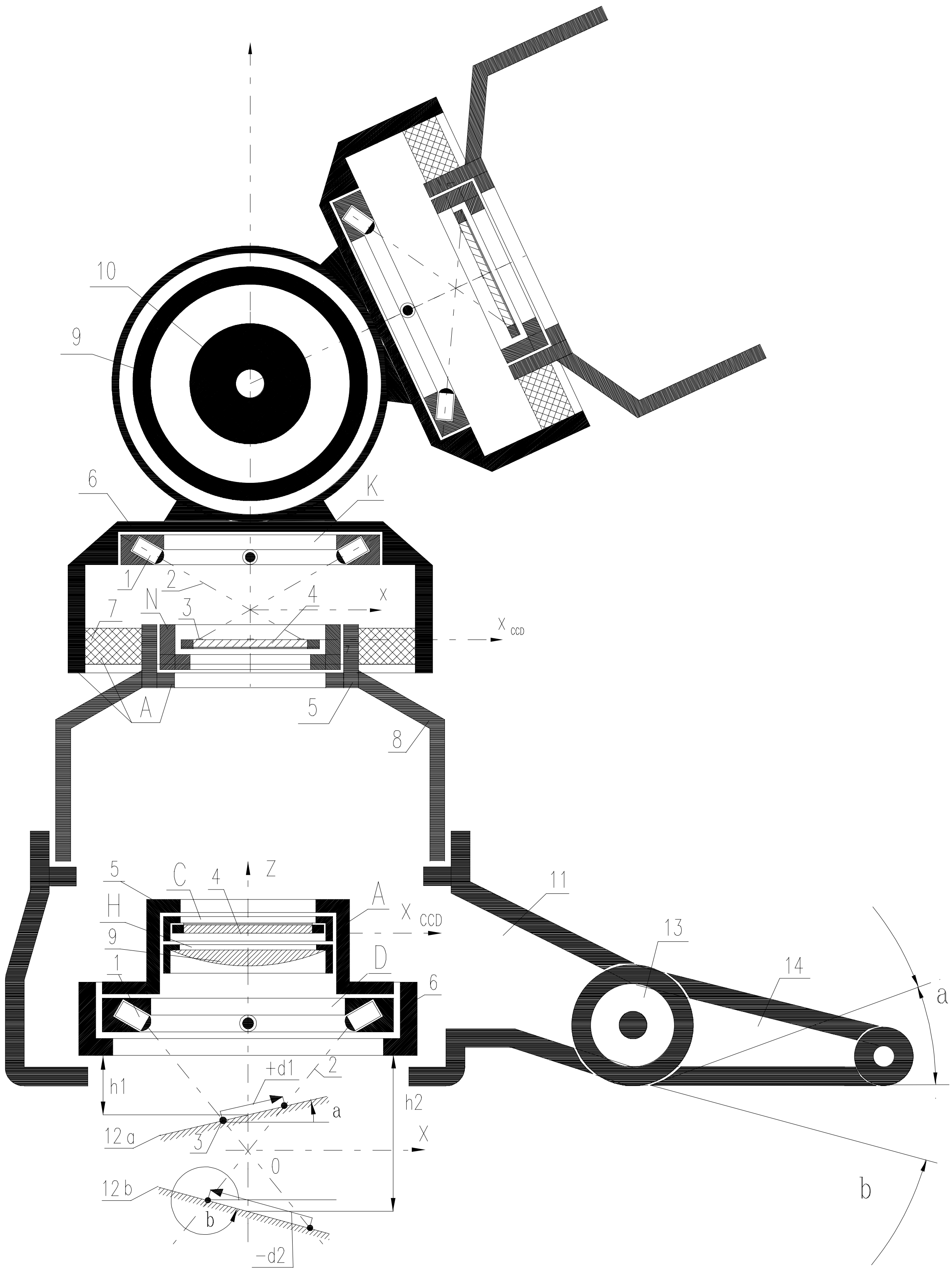


Figure 3. Six-Component Force-Torque Sensors Mounted in Artificial Leg and the Range-Incline FinderBuilt in the Heel.

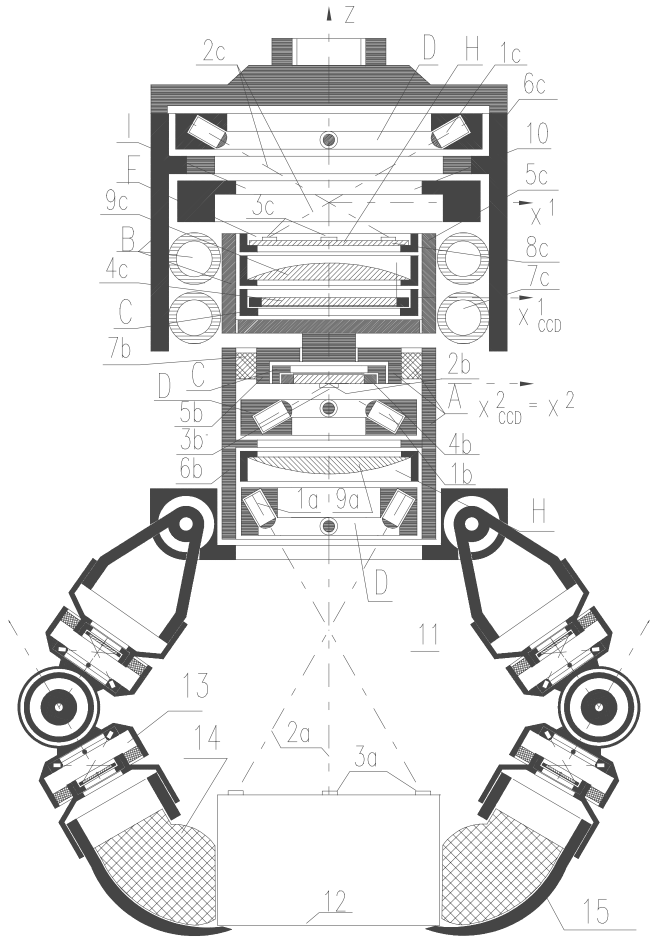


Figure 4: Customized Design of Dexterous Hand

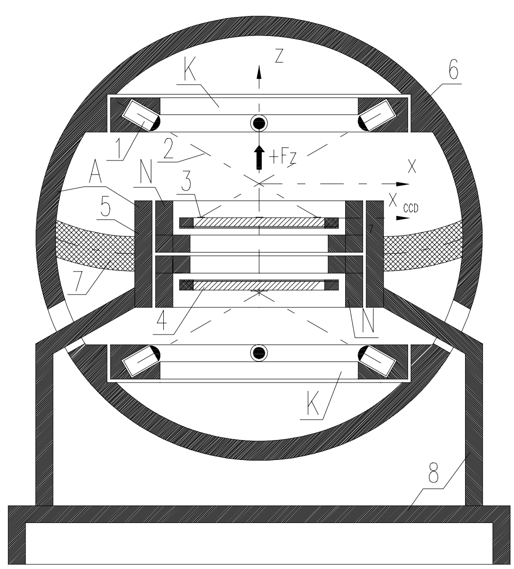
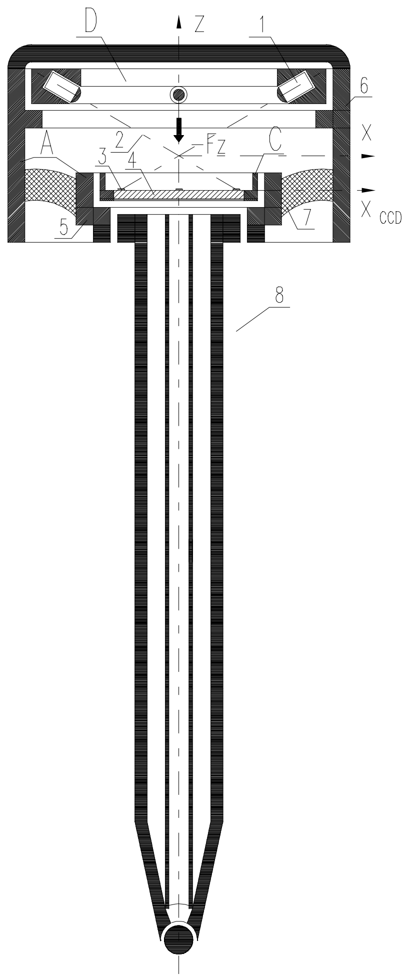


Figure 5: Multi-DOF Hand Controller



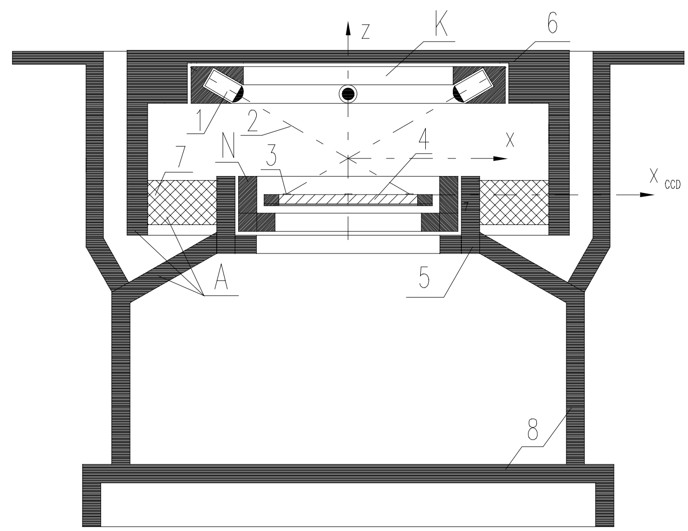


Figure 6. Keyboard for Blind People.

Figure 7. Signature Scanner.