A Force/Moment Direction Sensor and Its Application in Intuitive Robot Teaching Task

Myoung Hwan Choi and Sung Joo Kim

Abstract: Teach pendant is the most widely used means of robot teaching at present. Despite the difficulties of using the motion command buttons on the teach pendant, it is an economical, robust, and effective device for robot teaching task. This paper presents the development of a force/moment direction sensor named COSMO that can improve the teach pendant based robot teaching. Robot teaching experiment of a six axis commercial robot using the sensor is described where operator holds the sensor with a hand, and move the robot by pushing, pulling, and twisting the sensor in the direction of the desired motion. No prior knowledge of the coordinate system is required. The function of the COSMO sensor is to detect the presence of force and moment along the principal axes of the sensor coordinate system. The transducer used in the sensor is micro-switch, and this intuitive robot teaching can be implemented at a very low cost.

Keywords: robot teaching, force moment sensor, force moment direction sensor, micro switch, intuitive teaching

I. Introduction

Robot teaching is a process of moving the robot to desired work points and recording the position data, so that the recorded position data can be used in the subsequent programmed motion. The most widely used teaching method today is teach pendant method, in which the robot motion is generated by pressing the button on the teach pendant corresponding to the desired motion [1]. For example, if joint 1 is to be moved in the positive direction, +J1 button can be pressed, and if the tool is to be moved in the negative X direction, -X button can be pressed. Since there are six axes of motion, and for each axis, there can be positive and negative direction of motion, there are twelve motion buttons to manipulate. Several teach modes are usually provided, such as joint mode, world mode, and tool mode, so that operator can choose a convenient mode among them. The joint mode teach motion is usually used in macro motion to bring the end effector near the desired location quickly and is not suitable for fine motion, while world and tool mode teach motion are used to generate the fine motions near the goal location in Cartesian space.

One of the drawbacks of using teach pendant for robot teach motion is that it is not always easy to predict the robot motion that will be generated by pressing a particular motion button. Consider the world mode teaching. In this mode, teach pendant can be used to generate translations and rotations about X, Y, and Z directions of the base coordinate system. In order to utilize this mode, the operator has to know the direction of each axis. When the operator has become familiar with the base coordinate system, translational motion can be generated without difficulty using the teach pendant. However, the rotational motion by the teach pendant requires more experience because even when the rotational axis and the rotational angle are known, the resulting rotational motion of the end effector is not obvious, and one needs some experience before he/she can predict and visualize the rotational motion.

For tool mode teaching, the teach motions are generated with respect to the tool coordinate system. This mode is very convenient when the operator is experienced. The motion command buttons for X, Y, Z translations and Roll, Pitch, and Yaw rotations are provided. However, the tool coordinate system is not fixed but moves with the robot, so it is still more difficult to predict the robot motion before pressing a button on the teach pendant. These difficulties lead to trial and error in the teaching task, and result in increased teaching time and reduced productivity.

One of the recent areas in robotics research is the field of human friendly service robots and it is expected that in the near future more robots will work close to humans, and more people shall have to operate and teach the robots. So, it is important that people who are not familiar with the reference coordinate systems can teach the robot without difficulties.

Research effort toward the more convenient teaching has resulted in advanced teaching methods. For example, an easy teach system called MOTOMAN-ET [2] for Motoman robots enables an intuitive robot teaching without manipulating the motion direction buttons of the teach pendant. In this method, a force/moment sensor is attached near the end effector of the robot and the operator holds the handle of the sensor, and moves the handle to the desired direction of motion. Force/moment data of the sensor thus generated is used by the robot controller so that the robot moves in the desired direction (Fig. 1). This is an example of force compliant control where the robot moves in such a way that will reduce the force/moment to zero ([3][4][5]). Another type of convenient teaching method is used for KUKA robots [6][7]. In this method, a 6D mouse is attached to the teach pendant, and operator moves the robot using the 6D mouse like a game joystick (Fig. 2). In these type of teaching methods, operator need not know the coordinate systems, and lead the robot through desired locations.

The purpose of this paper is to present the development of a low cost force/moment direction sensor named COSMO ([8]) that can be used to improve the teach pendant based teaching task, specifically in the tool mode teaching. In the proposed teach method, the operator moves the robot by pushing, pull-

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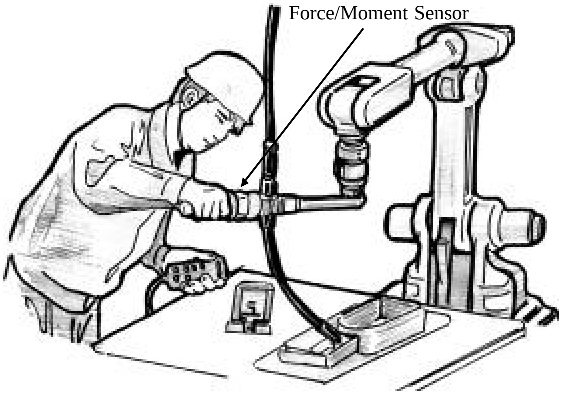


Fig. 1. An intuitive robot teaching method of Motoman Robots, called MOTOMAN-ET. The operator holds the force/moment sensor handle, and lead the robot to desired locations.

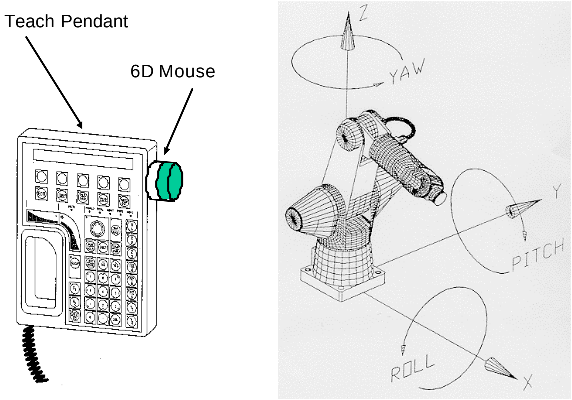


Fig. 2. Intuitive robot teaching method of KUKA robots. The 6D mouse on the teach pendant is used like a game joystick to move the robot.

ing or twisting the sensor to the desired direction. The function of the sensor is to detect the force and moment direction. The sensor does not measure the magnitude of the force/moment. The sensor data are used to move a six joint commercial robot in the desired direction of motion. No prior knowledge of coordinate systems is required. The transducer used in the ensor is micro-switch, and the sensor has a simple architecture, so this teaching method using the COSMO sensor can be implemented at a very low cost. The proposed teaching method is similar to the MOTOMAN-ET teaching method, but the proposed method uses the force/moment direction sensor rather than the force/moment sensor, and the detected force/moment direction data are used in conjunction with the teach pendant. No force control scheme is used in this work. This paper is organized as follows. In section II, the structure and operation principles of the COSMO sensor are described. In section III, the experimental setup for the intuitive robot teaching using the COSMO sensor is described, and experimental result and discussions are presented in section IV, followed by conclusions in section V.

II. Detection principles of force/moment direction

The COSMO sensor, named after COntact Sensor MOdule, is described in this section. The function of the sensor is to detect the external force/moment relative to the sensor coordinate system. In robot teaching by teach pendant, the direction of motion is provided from the operator by pressing a motion button corresponding to the desired motion. The difficult part is to choose the correct button that will generate the desired motion. There are twelve motion buttons involved since six types of motions are possible (three translations and rotations), each in positive and negative direction. The COSMO sensor can provide this direction. The COSMO sensor generates the same type of direction commands as the motion buttons of the teach pendant in tool mode teaching, namely, X, Y, and Z translations and Roll, Pitch, Yaw rotations.

The transducer used in the sensor is micro-switch. Twelve micro-switches are arranged on the six faces of a switch cube, which sits inside a cavity of the sensor block (Fig. 3). The sensor block is cylindrical in shape, and a sensor handle, which is a cylindrical ring in shape, surrounds the sensor block. The switch cube is mechanically coupled to the sensor handle so that the external force/moment applied by the operator's hand to the sensor handle results in the motion of the switch cube inside the sensor block. (Fig.4). The twelve micro-switches are placed in such a way that by analyzing the state of the switches, the presence of external force/moment along the principal axes of the sensor coordinate system can be determined (Fig.5). Two switches are located on each face of the switch cube along the centerline of the face and near the edges of the face. The two opposing faces of the cube have the same switch arrangement, and the four switches on the two opposing faces form a switch plane. There are three pairs of opposing faces of the cube, and the three switch planes thus formed constitute X-Y, X-Z, Y-Z planes of the sensor coordinate system. The sensor coordinate system is located at the intersection of these three planes.

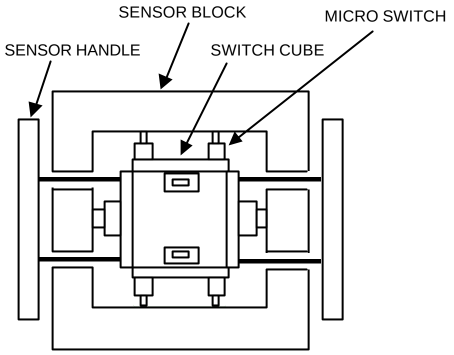


Fig. 3. Cross sectional diagram of COSMO sensor. Transducer used in the sensor is micro-switch.

Consider the cross sectional diagram in Fig. 4. When there is no external force/moment applied, the switch cube is in an equilibrium position inside the sensor block by the internal spring force of the switch. When force F_Z is applied as in Fig. 4 (b) and (c), then the switch cube is pushed towards the Z direction, and one or both of the switches on the upper side of the switch cube in the figure are pressed (shaded switches in the figure). When moment M_y is applied, two switches on the opposing sides of the switch cube on a diagonal line are pressed as shown in Fig. 4 (d). Similar detection principle can be applied to the two other cross sections of the sensor block, and thus the presence of $F_x, F_y, F_z, M_x, M_y, M_z$ can be detected. The magnitude of the force/moment is not measured since the micro-switches detect only the presence of the pressure, not its magnitude. The picture of the switch cube is shown in Fig. 5, and the sensor block with one end and handle removed, with the switch cube inside is shown in Fig. 6 ([10]). The role of the sensor signal processor is to execute the force/moment detection algorithm and send out the detected data.

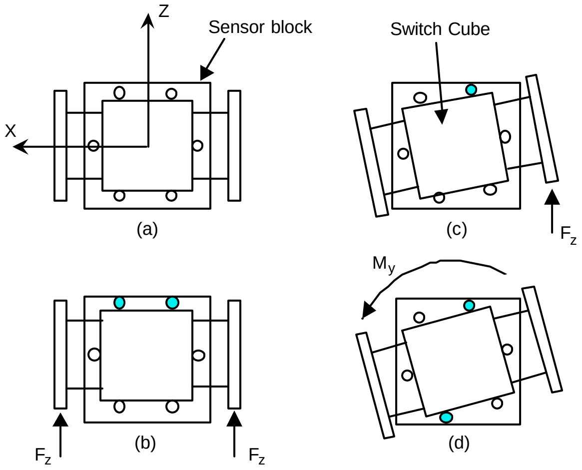


Fig. 4. Detection principle. (a) Equilibrium position. (b) Fz applied (case 1). (c) Fz applied (case 2). (d) My applied. Small circle represents micro-switches. Shaded circle represents the pressed switches.

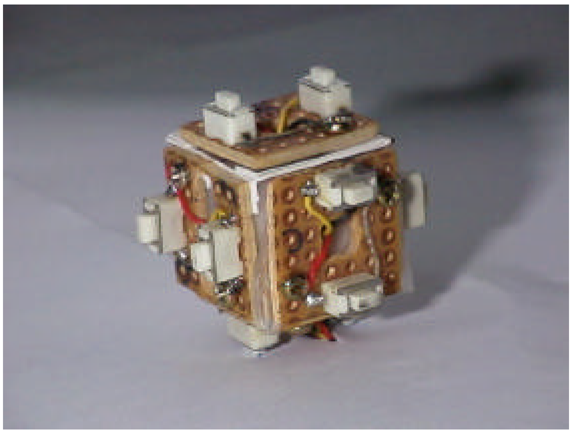


Fig. 5. Switch cube has twelve micro-switches arranged on the six faces of the cube, and it is placed inside the sensor block.

The sensor signal processor consists of two components: AT89C2051 one chip micro-controller, and MAX232C for serial communication interface (Fig. 7). The input to the micro-controller from the sensor block is the 12 bit digital state of the micro-switches, and the switches are directly connected to the micro-controller input pins. The state of the micro-switches are read and analyzed by the micro-controller, and the force/moment direction data are sent out via RS232C asynchronous serial communication line at 25Hz. The output data is in an 8-character data packet, where the first three

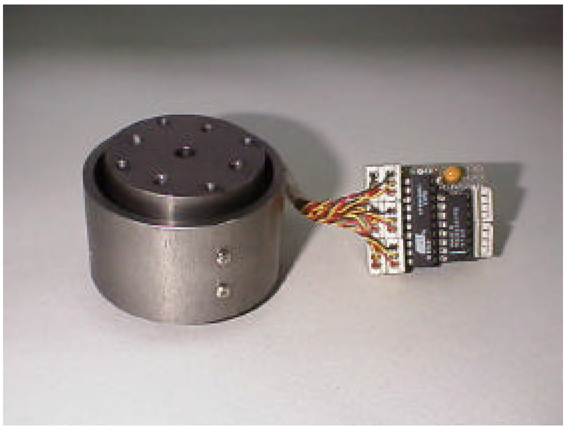


Fig 6. COSMO sensor consists of a sensor block and signal processor. The sensor block contains the switch cube. The signal processor consists of two ICs.

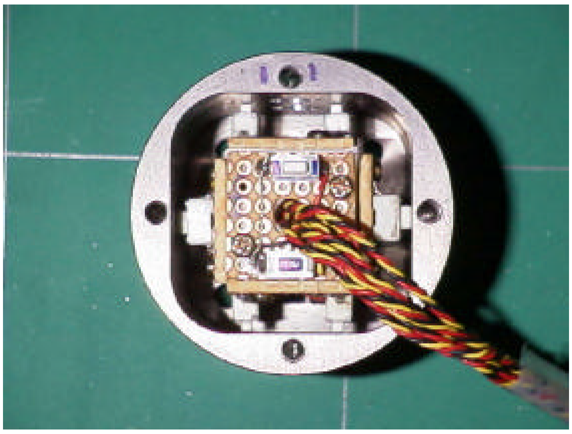
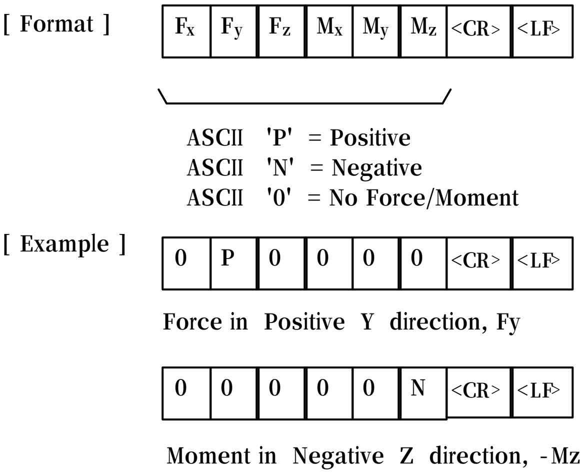


Fig. 7. Sensor block is shown with one end of the block and the sensor handle removed. The switch cube is inside the cavity of the block.



[Format]

F_x	F_y	F_z	M_x	M_y	M_z	<CR>	<LF>

ASCII 'P' = Positive
ASCII 'N' = Negative
ASCII '0' = No Force/Moment

[Example]

0	P	0	0	0	0	<CR>	<LF>

Force in Positive Y direction, Fy

0	0	0	0	0	N	<CR>	<LF>

Moment in Negative Z direction, -Mz

Fig. 8. Output format of the force/moment direction sensor, COSMO. Eight character data packet is sent out.

characters represent three force components and the next three characters represent the three moment components (Fig. 8). Each component can have one of the three values, 'P' for positive direction, 'N' for negative direction, and '0' for no force/moment. Examples of output data are shown in Fig. 8. The end of data packet is indicated by the carriage-return and line-feed character sequence.

III. Experimental setup overview

The force/moment direction data of the COSMO sensor was used in the intuitive teaching of a six axis commercial robot, CRS A460 from CRS Plus Inc. [9]. The experimental setup is illustrated in Fig 9. The sensor is located between the end of the last link and the end effector. For this experiment, a sharp ended pointing device was used as the end effector to observe the tip motion easily.

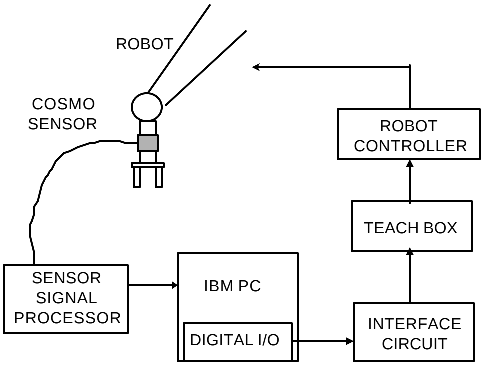


Fig. 9 The experimental system setup for intuitive robot teaching. An IBM PC reads the sensor signal and manipulates the teach pendant motion button signals to move the robot as directed by the sensor data.

An interface circuit was constructed to manipulate the teach pendant motion button signals based on the sensor data. The manipulation of the teach pendant signals is commanded by the control signal from the digital Input/Output board installed in an IBM PC. The IBM PC reads the force/moment direction data from COSMO sensor via asynchronous serial communication line, and uses the direction data to generate appropriate control signal through the digital Input/Output board. The manipulation of the teach pendant motion button signal is achieved by externally short-circuiting the connection between the motion button pins as shown in Fig 10. For example, if the operator pushes the sensor handle in the positive Y direction of the tool coordinate systems, the COSMO sensor sends out the data packet "0 P 0 0 0 0 <CR> <LF>" and the control program running in IBM PC sends out the control input to the teach pendant interface circuit so that the motion button in the teach pendant corresponding to the tool mode +Y motion is short-circuited. This is exactly the same end-result as the pressing of the switch by the operator, the robot will move in the positive Y direction. Thus by manipulating all teach motion buttons in this way, the teach motion of the robot in the tool mode can be controlled from the IBM PC.

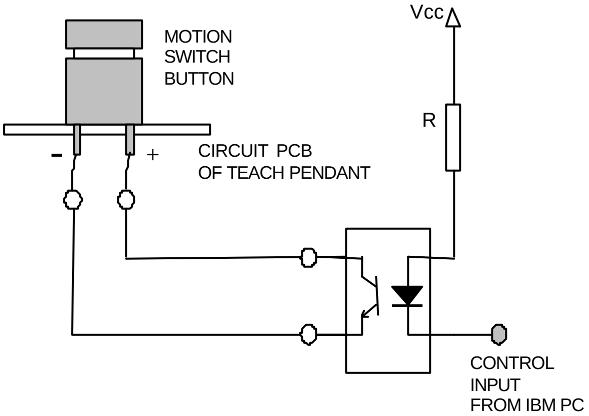


Fig. 10. The manipulation of teach pendant motion button signal by the control input from IBM PC.

The controller has to be setup for the tool mode teaching. The motion direction command is generated with respect to the sensor coordinate system located at the center of the COSMO sensor. Since the motion of robots in the tool mode is generated with respect to the tool coordinate system, and the tool coordinate system in this intuitive teaching is the sensor coordinate system, the TOOL transform variable in the controller has to be set to represent the transformation from the tool flange at the end of link 6 to the sensor coordinate system. Since the robot teach motion is generated via teach motion buttons, the speed of teach motion in this experiment is determined by the teach motion speed setting of the robot controller just like in a normal teach motion. In the case of CRS PLUS A460, the teach speed is provided by the speed knob on the teach pendant. The six axis commercial robot was used without any additional robot motion software [9].

IV. Teaching experiments and discussions

Before beginning the intuitive teaching, the robot was moved, using joint mode teach motion, to the neighborhood of the desired goal locations. The teach mode was then changed to the tool mode, and the sensor handle was pushed, pulled, or twisted to the direction of the desired motion. With a slight pressure on the sensor handle, the robot end effector moved in the direction of the push by the operator, and with a slight twist of the sensor handle, the robot end effector changed its orientation as directed by the twist. The pressure required to move the robot is the pressure to make the contact in the micro-switch, and its magnitude is dependent on the stiffness of the internal spring of the switch. The direction of motion is provided by the COSMO sensor, and the speed of motion is determined by the teach speed setting in the teach pendant. Hence, if a fast motion is desired, the teach speed is set to a high value, and if a slow and fine motion is needed, the teach speed is reduced to a small value. The velocity profile of the teach motion is also determined by the robot controller. The COSMO sensor only provides the direction of motion, and the motion itself is generated as programmed by the robot controller.

Since the sensor handle is coupled mechanically to the switch cube, and the micro-switches on the switch cube are pressed on and off, the operator can feel the click of the switch by his hand. The feeling of the click is similar to the click of the computer mouse buttons. The force required to activate the micro-switch is also roughly equal to the force required to activate the computer mouse button.

In this intuitive teaching experiment, all six directions of motion (three translations and three rotations) possible with the teach pendant in the tool mode is also possible with the COSMO sensor. The difference is that the operator does not need to know the reference coordinate system. Since the transducer is the micro-switch, and the signal processor is simple, this intuitive robot teaching can be implemented at a very low cost. As shown in this experiment, the intuitive robot teaching using the COSMO sensor can be applied to most of the commercial robots with a small modification. The teach pendant signal can be manipulated as was done in this work, or a control software can be added to the robot operating system software, that reads the COSMO sensor data, and generate the required teach motion.

The cost of the COSMO sensor is one of its characteristics. The sensor was constructed using twelve micro-switches, and no complex signal conditioning is necessary as the signals involved are digital signals from the micro-switches. The signal processor consists of two ICs, namely, one AT89C2051, a 20 pin micro-controller, and one 16 pin MAX232C for serial communication interface. In the experiment, the COSMO sensor proved to be simple but effective means of implementing the intuitive teaching.

The sensor detects the presence of force/moment along the principal axes of the sensor coordinate system and not its magnitude, hence it cannot detect the direction of force in arbitrary direction. For example, if $1.0F_x$ is applied, the correct force F_x will be output, but if $(0.3F_x + 0.9F_y)$ is applied, the output will be F_y. This is the consequence of using micro-switches as the transducer, which does not detect the magnitude of the pressure. Thus, in order to achieve efficient teach motion using the COSMO sensor, the possible point of push, pull, and twist was marked on the sensor handle, and the operator need to apply the force and moment at the marked location so that the force and moment are applied along the principal axes of the sensor coordinate system. The intuitive teaching with the COSMO sensor was more convenient than the teach pendant method, since all of the motions possible with the motion buttons of the teach pendant can be achieved, without the difficulty of using 12 motion buttons. The micro switches are activated by a force exceeding a threshold value determined by the internal spring in the switch. Hence, if a force magnitude is varying in the neighborhood of the threshold value, it can result in the switch state toggling on and off. Since the robot teach motions are activated according to the switch states, this toggling in the switch state can result in the jerky motion of the robot. In order to avoid this undesirable robot motion, only one of the six components of the sensor output is allowed to be active at a time.

V. Conclusions

Development of a low cost force/moment direction sensor named COSMO was presented, and an intuitive robot teaching method using the sensor was demonstrated. The sensor provides the force/moment direction information that can be utilized in robot teaching. The operator need not know the reference coordinate system of the motion. Motion can be generated by holding the sensor and pushing, pulling or twisting the sensor in the direction of the desired motion. The transducer used in the sensor is micro-switch and the sensor makes possible a low cost, but effective intuitive teaching.

The future work is the quantitative evaluation of the performance improvement in this proposed teaching method. The quantitative data on the time reduction in the teach task execution by human operator are required, and this issue is the topic of the ongoing research.

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