Quantitative Evaluation of an Intuitive Teaching Method for Industrial Robot Using a Force / Moment Direction Sensor

Myoung Hwan Choi and Woo Won Lee

Abstract: A quantitative performance evaluation of a robot teaching method using a force/moment direction sensor is presented. The performance of the teaching method using the force/moment direction sensor is compared with the conventional teaching pendant method. Two types of teaching tasks were designed and the teaching times required to complete the teaching tasks were measured and compared. Task A requires a teaching motion that involves four degrees of freedom motion. Task B requires a teaching motion that involves six degrees of freedom motion. It was found that, by using the force/moment direction sensor method, the teaching times were reduced by 25% for Task A and 45% for Task B compared to the teaching pendant method.

Keywords: Robot teaching, force/moment direction sensor, intuitive robot teaching, teaching time.

1. INTRODUCTION

Robot programming is the process of generating a sequence of robot instructions and work locations that will accomplish the desired robotic tasks. Conventional robot programming requires the operator to learn the syntax and semantics of the robot programming language and the usage of the motion generating hardware such as the teaching pendant. It is a process that requires knowledge in robotics and experience in the usage of robots. The difficulty of this robot programming process limits the productivity of the robot and more widespread use of robot technology. In the near future, it is expected that robots will work closely with humans, and be used as assistants to human workers. Hence, there is a need for robot programming schemes that are friendly to inexperienced robot operators.

As a means of human friendly intuitive robot programming, programming by human demonstration has been proposed in many research works. The basic idea is that a human operator executes a robot task, and a set of robot instructions and work locations are generated automatically from the various sensor signals acquired during the execution of the task. Kuniyoshi et al. [1] and Miura and Ikeuchi [2] used computer vision to observe the human operator and to program an assembly task, while Onda et al. [3] and Lloyd et al. [4] used simulation-based demonstration environment. The contact force and torque gathered during the assembly task were analyzed to generate the assembly program by Hannaford and Lee [5], Skubic and Volz [6], Asada and Izumi [7], Kosuge et al. [8], Delson and West [9], Myers et al. [10] and many others. An iterative programming method was proposed in the work by Ikeura and Inooka [11] for trajectory learning application. These schemes can help resolve the difficulties associated with conventional robot programming, such as learning the syntax and semantics of a robot language, and debugging the program by repeated editing and step-by-step execution of the program, and hence contribute to the development of human friendly robots.

One of the remaining difficulties is the generation of robot teaching motion. An operator must move the robot in order to demonstrate the desired task and gather sensor data. In the initial phase of robot programming, robot can be programmed without actually moving the robot, for example, by human hand motion and vision sensor [1,2], by human hand motion and a six dimensional position sensor [9], or by using simulation software [3,4]. However, once the robot program is generated, it must be verified on-line by actually running the program in an actual robot system, and if any of the trajectory or work locations do not satisfy the necessary conditions such as precision requirements or collision avoidance, the robot must then be moved to a new location satisfying the re-

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quired condition, and the robot trajectory or the work location must be modified.

For the purpose of the teaching motion generation, master-slave tele-manipulation schemes were used in [6] and [11], while force/impedance control schemes using a force/torque sensor mounted near the end effector were used in [10] and for Motoman robots [13]. For continuous path programming, a lead-through method can be used in applications such as painting task [14], and a six degrees-of-freedom mouse has been used as a joystick for KUKA robots [12]. However, the majority of the commercial robots still use the traditional teaching pendant based motion generation scheme, because it is economical, robust and effective. However, the scheme is unfriendly to inexperienced robot operators because it requires the knowledge of robot coordinate systems, and manipulation of as many as twelve motion buttons on the teaching pendant corresponding to three translations and three rotations in the three dimensional space. A teaching motion scheme is needed that is more convenient than the teaching pendant based scheme and yet economical enough to be accepted for widespread use.

The purpose of this paper is to present a quantitative performance evaluation of the intuitive robot teaching method using a low cost force/moment direction sensor that was proposed in [15]. Two teaching tasks were designed with different degrees of complexity, and these tasks were performed using two different teaching methods: (1) the proposed teaching method using the force/moment direction sensor; and (2) the conventional teaching pendant method. The times required to complete the teaching tasks using the two teaching methods are compared, and the teaching times are analyzed with the focus on the quantification of teaching time reduction using the force/moment direction sensor.

2. DESCRIPTION OF THE TEACHING TASKS

The force/moment direction sensor used in the experiment is named COSMO sensor, is described in detail in [15] and shown in Fig. 1. The experimental setup used in this work is shown in Fig. 2. The six-axis robot A460 from CRS Plus Inc. is shown at the initial location. The COSMO sensor is mounted between the robot tool flange and the end effector. Two goal locations are also shown in the figure. Goal location A is on the horizontal worktable A, and goal location B is on the inclined worktable B. An end effector with two sharp end points made of hard plastic was used as shown in Fig. 2. Two micro switches are located at each goal location, and a teaching task is completed when the two tips of the end effector press the two micro switches at the goal locations simultaneously. An electronic timer measures the time from

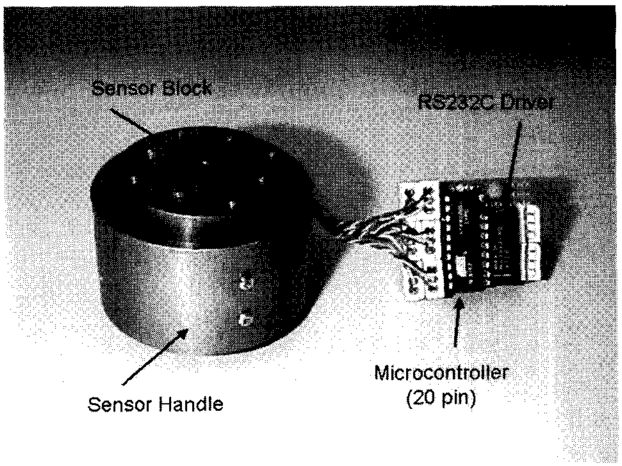

Fig. 1. COSMO force/moment direction sensor consists of a sensor block, a sensor handle, and a signal processor consisting of two ICs: a microcontroller, and a RS232C driver.

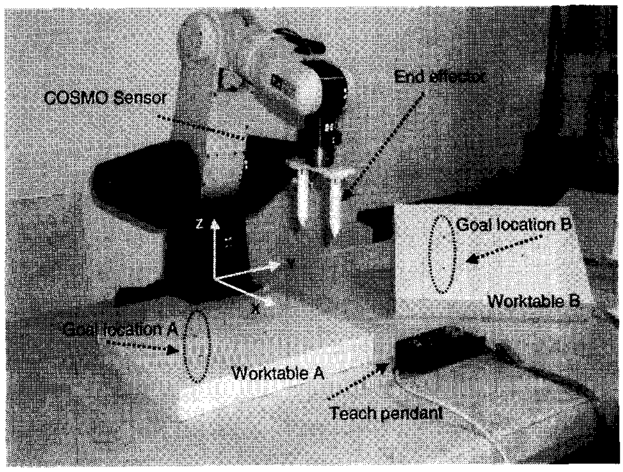

Fig. 2. Experimental setup for the robot teaching tasks. The six-axis robot A460 from CRS Plus Inc. is shown at the initial location. The COSMO sensor is mounted between the robot tool flange and the end effector. Goal location A is on the horizontal worktable A, and goal location B is on the inclined worktable B.

the beginning of the teaching task to its completion. The allowed tolerance in the plane of the worktable that will result in a successful action of the individual switch is ± 0.5 mm, and the displacement in the direction of the push that is needed for the action of the switch is 0.5 mm. The two end points of the end effector are 100 mm apart.

The operator holds the sensor handle and push/pulls or twists the sensor handle in the desired direction of motion. The speed of the teaching motion is determined by the state of the speed knob of the teaching pendant, just as in the normal teaching pendant motion. The velocity profile of the teaching motion also remains to be determined by the robot controller. The robot joint position can be recorded by pressing the record button provided in the teaching pendant. Fig. 3 shows the operator's hand guiding the tool to the goal location B.

Two teaching tasks were designed with different degrees of complexity that represent a wide range of teaching motions in practice. Task A corresponds to a basic motion required in robot tasks that take place on a horizontal worktable, and it is designed to represent the tasks of SCARA type industrial robots. Task A is to move the end effector from the initial location shown in Fig. 2 to goal locations A. The goal location A is on the worktable A that is parallel with the X-Y plane of the robot world coordinate system. The transform from the initial location to the goal location A is given by (X, Y, Z, Yaw, Pitch, Roll) = (13.9 mm, -283.1 mm, -159.8 mm, -26.6 deg, 0 deg, 0 deg) in the world coordinate system. Hence, the teaching motion to the goal location A involves three translational motions and a single rotation. Task B corresponds to a basic motion required in robot tasks that uses the full six degrees of freedom of the robot. It is designed to represent the tasks of a six axes industrial robot, such the arch welding of a car frame. Task B is to move the end effector from the initial location shown in Fig. 2 to goal location B. Goal location B is located on the inclined plane of worktable B. The teaching motion from the initial location to goal location B involves three translational motions as well as three rotational motions as indicated by the required transform (X, Y, Z, Yaw, Pitch, Roll) = (58.2 mm, 296.8 mm, -125.9 mm, 133.1 deg, -25.5 deg, 178.6 deg). Task B is designed to represent a spot welding task of six joint vertical robots.

Each of the two teaching tasks was performed with two different teaching methods: (1) the conventional teaching pendant method and (2) the proposed force/moment direction sensor method. Hence, the test consisted of four types of teaching experiments as shown in Table 1. A total of eighty students participated in the teaching experiments as robot operators, twenty students per experiment. The participants were volunteers from junior to graduate students, and only students with no prior experience of robot operation participated. Each operator was given instructions for 5 minutes on how to operate the teaching pendant or the COSMO sensor, and one practice run before beginning the experiment. The robot was brought to the initial location shown in Fig. 2, and then the operator was allowed to proceed with the experiment. Each operator repeated the same experiment ten times and the time required to complete each experiment was recorded to observe the change in teaching time as the operator accumulated experience in the teaching task. No help was given to the operators while the experiment was in progress.

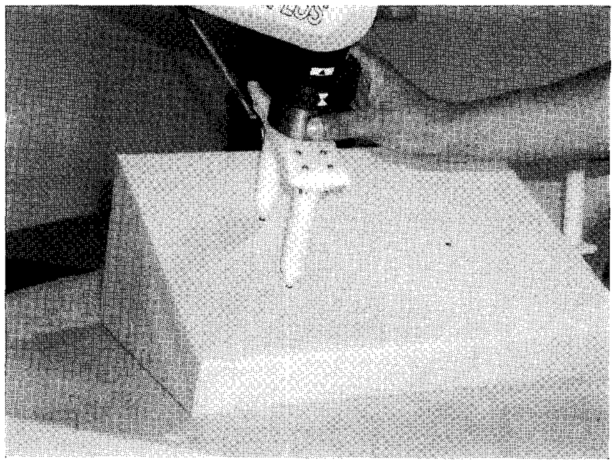

Fig. 3. An operator holds the COSMO sensor and guides the tool to goal location B.

Table 1. Four types of teaching experiments.

Teaching Method / Teaching Task	Teaching Pendant Method	Force/moment Direction Sensor Method
Task A (4 DOF motion)	Experiment A-TP	Experiment A-FD
Task B (6 DOF motion)	Experiment B-TP	Experiment B-FD

3. EXPERIMENTAL RESULT AND PERFORMANCE EVALUATION

The teaching times required to complete the four experiments are shown in Fig. 4. For each of the four experiments, the teaching times of the twenty participants were averaged for each trial count. For example, for Experiment B-TP, the average teaching time of the twenty participants in the first trial was 300 seconds, and it decreased to 273 seconds in the second trial. The teaching times for the four experiments decreased as the trial count increased and the operators gained experience in teaching gradually, as shown in Fig. 4. For Task A, the average teaching times of Experiment A-TP decreased from 160 seconds to 84 seconds after repeating the same experiment ten times, while those of Experiment A-FD decreased from 110 seconds to 60 seconds. For Task B, the teaching times are about twice as long compared to those of Task A, since the teaching motion involved a full six degrees of freedom motion. For Task B, the average teaching times of Experiment B-TP decreased from 300 seconds to 160 seconds, while those of Experiment A-FD decreased from 164 seconds to 87 seconds.

The teaching time reduction obtained by using the proposed teaching method is shown in Fig. 5. The ratios of the teaching time of the force/moment direction sensor method to that of the teaching pendant method are shown for two tasks in the figure. For example, the teaching time for Task A using the force/moment direction sensor method was 110 seconds in the first trial (Fig. 4, Experiment A-FD), and the teaching time for Task A using the teaching pendant method was 160 seconds in the first trial (Fig. 4, Experiment A-TP). The ratio of the two teaching times is 110/160 = 68.8 % in the first trial, and it is the first data point of the Task A graph in Fig. 5. It is found that the teaching time of Experiment A-FD, which uses force/moment direction sensor is, on average, 75% of the teaching times for Experiment A-TP, which uses the teaching pendant. For Task B, the teaching time for Experiment B-FD is, on average, 55% of the teaching time for Experiment B-TP.

As the trial count increased, the teaching times decreased gradually. The reduction ratios of the teaching times, however, remained roughly the same as shown in Fig. 5. The relative increase of the teaching times at the eighth trial was observed in Fig. 4. It occurred with Experiments A-TP, B-TP, and B-FD. It is due to the fact that the operators gained confidence as the experiments progressed, and they used gradually higher teaching motion speeds. The increased speed resulted in erroneous moves, and time was wasted to recover from these errors.

The increase in the teaching time as the teaching task complexity increases from Task A to Task B is shown in Fig. 6. In the case of the teaching pendant method, the teaching time for Task B is on average 202 % greater than that for Task A, while in the case of force/moment direction sensor method, it is 145 % greater. Hence, as the complexity of the teaching task increases, the increase in the teaching time is less when the force/moment direction sensor method is used.

The analysis of the experimental results shows that the teaching method using the force/moment direction sensor effectively reduces the times required to complete the teaching tasks. The effectiveness is more evident in Task B that involves three rotational as well as three translational motions, than in Task A that requires three translational and only one rotational motions. This is because, in the case of the teaching pendant method, as the complexity of the teaching motion increases, more teaching pendant motion buttons need to be used and because of the difficulty of using twelve motion buttons, a longer teaching time is required. On the other hand, in the force/moment direction sensor method, the difficult decision of choosing the correct motion buttons of the teaching pendant is replaced by the intuitive push/pull or twist of the sensor in the desired direction of motion.

The operators who participated in the experiments had no prior experience in operating a robot. Hence, it can be said that the teaching method using the force/moment direction sensor is friendlier to people who are unfamiliar with the robot operation than the teaching pendant method. This suggests that the proposed teaching method is more appropriate in the area of human friendly robots than the teaching pendant method. As the participants repeated the same experiment, and gained experience in teaching, the overall teaching times decreased. However, the reduction ratio of the teaching time of the force/moment direction sensor method to that of the teaching pendant method remained roughly the same as shown in Fig. 5, implying that the proposed method is effective for the experienced as well as the inexperienced operators.

A few characteristics of the end effector used in this work need to be mentioned. From the viewpoint of moving the end effector to a location, the most difficult task would be a task where three positions and three orientations of the end effector are specified. In this case, since six components of the motion are constrained, there can be no uncertainty in the location of the end effector. There is no freedom of motion while satisfying the constraint. In this paper's experiment, the two tipped end effector is used. One orientation component remains free while satisfying the goal constraints, and the end effector can rotate about the axis going through the two tips. An example of the teaching tasks that requires specification of three positions and three orientations is the assembly of mechanical parts. An example of the teaching task that allows one degree-of-freedom motion while satisfying the motion constraints is the spot welding or arc welding task. Hence, the teaching experiment and the end effector used in this work represent a class of teaching tasks, and the experimental result should be interpreted in view of these teaching task characteristics. For teaching tasks that requires the specification

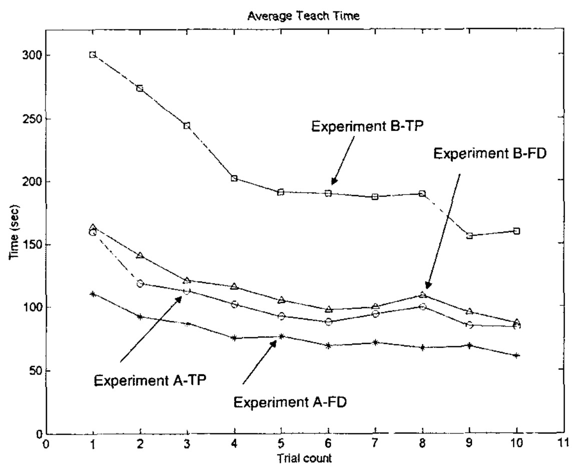

Fig. 4. The teaching times for the four experiments. For each of the four experiments, the teaching times of the twenty participants were averaged for each trial count.

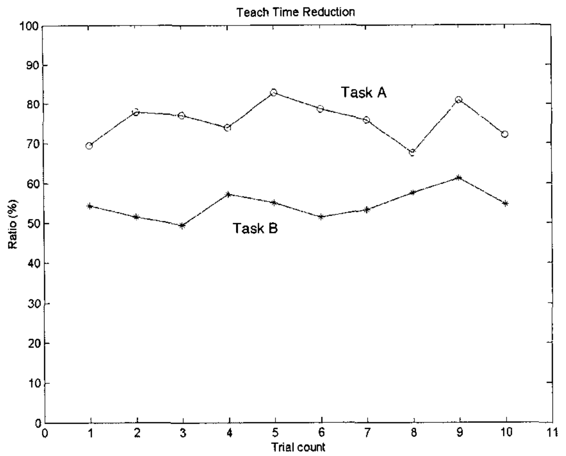

Fig. 5. Reduction in teaching time by using the force/moment direction sensor method. For Task A, the teaching time using the force/moment direction sensor is reduced on average to 75% of that using the teaching pendant, while for Task B, it is reduced on average to 55%.

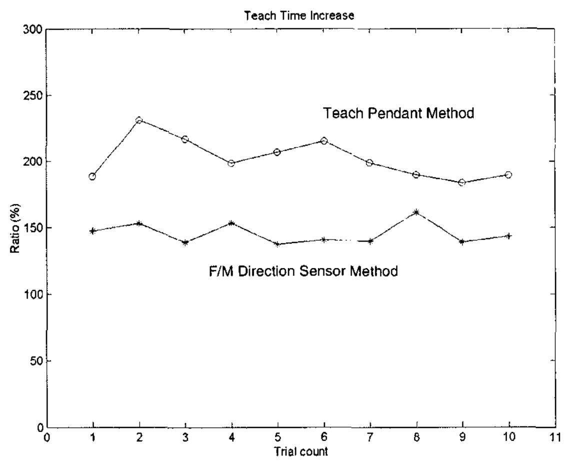

Fig. 6. The increase in the teaching time as the teaching task complexity increases from Task A to Task B. The ratios of the teaching time for Task B to that for Task A are shown. In the case of the teaching pendant method, the teaching time for Task B is on average 202% longer than that for Task A, while it is 145% in the case of the force/moment direction sensor method.

of three position and three orientation, the efficiency of the teaching method tested in this work needs to be reviewed, although it can be expected that the general trend of the reduction in teaching time is the same.

4. CONCLUSIONS

A quantitative performance evaluation of the robot teaching method using a force/moment direction sensor was described. The performance of the teaching method using the force/moment direction sensor was compared with the conventional teaching pendant method. Two types of teaching tasks were designed and used in the performance comparison. The teaching times required to complete the two teaching tasks were measured and compared. Task A required a teaching motion that involved four degrees of freedom motion, and Task B required a teaching motion that involved the full six degrees of freedom motion. It was found that by using the force/moment direction sensor method, the teaching times were reduced to 75% for Task A and 55% for Task B compared to the teaching pendant method. It was shown that the proposed teaching method is useful for the experienced as well as the inexperienced robot operators. The effectiveness of the proposed teaching method was more evident in the execution of the more complex teaching task.

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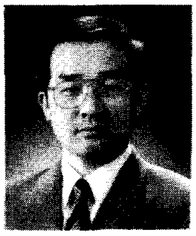

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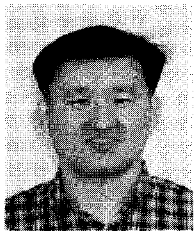

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