Development of an Operating Robot System for Die and Mold Polishing

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This paper proposes an operating robot system that assists polishing tasks in die and mold manufacturing. The proposed system consists of an industrial robot and a joystick. The operator manipulates the joystick and remotely moves a tool attached at the hand of the robot. A three-DOF motor-driven joystick was developed, and a force-reflecting bilateral controller was constructed in order to realize interactive manual operation. In addition to manual operation, the system can control the contact force of the tool automatically by the force feedback. The operator can use two control modes according to the task. The combination of the manual control and the automatic control enables effective and flexible polishing tasks of objects having complex shape.

The developed system was applied to simple polishing tasks. Experimental results show that the tool can be manipulated remotely as if we were handling it directly. Moreover, the results suggest that the system increases the efficiency of polishing tasks remarkably.

Keywords: Operating robot, Die and mold polishing, Master-slave robot system, Force control, Force-reflecting bilateral control

1. Introduction

In the die and mold industry, design processes and machining processes are automated by CAD/CAM technology. However, polishing processes, the final stage of manufacturing, have not yet been automated, and almost all such tasks depend on the dexterity of skilled workers. The resulting low efficiency of the polishing tasks decreases the productivity of the overall manufacturing process. Thus, in order to increase the overall productivity, improvement of the polishing process using robot technology (RT) is necessary.

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Several robotized systems have been developed in order to automate the polishing tasks [1-5]. However, the practical use of these techniques has not progressed readily because the shapes of most dies and molds are too complex to robotize. The small number of lots in the manufacturing process has also prevented the use of robots.

One of the practical solutions to these problems is a human-machine cooperative system. If human flexibility is combined with robot systems, several complex tasks which currently can be performed only by human hands might be robotized.

Operating robot systems based on this concept have been developed in various technologically advanced fields, such as medical, space and micro handling[6]-[9]. However, these techniques are not easily applied in industrial fields due to cost considerations. Although the advanced robot systems have been developed without consideration of cost, most of the die and mold industry consists of small businesses, and so the introduction of such expensive machines is difficult.

This paper proposes an operating robot system which can be applied in small industries. We intend to develop a low-cost, high-performance operating robot system by utilizing existing robot technologies. The proposed system consists of an industrial robot and a joystick-like interface by which to operate the robot remotely.

Force feedback to the human operator is important in order to execute tasks remotely [7],[8]. Thus, we have developed a motor-driven joystick (active joystick) and constructed a force-reflecting bilateral controller by which to provide interactive operation through the joystick.

In the following, we introduce the proposed operating robot system and its control system. In addition, several experimental results using the proposed system are presented.

2. Operating robot system

2.1 Construction of an operating robot system

Figure 1 shows an image of a polishing task using the operating robot system. An operator manipulates the joystick and remotely moves the tool attached at the hand of the robot. Both the joystick and the robot are equipped with force sensors in order to realize the interactive force operation.

Based on this concept, we constructed a prototype operating robot system, as shown in Fig.2. The developed system consists of a commercial industrial robot (RV-E2 Mitsubishi Denki Co.) and a 3-DOF motor-driven joystick. The human operator handles a handgrip of the joystick while viewing the motion of the tool attached at the hand of the robot.

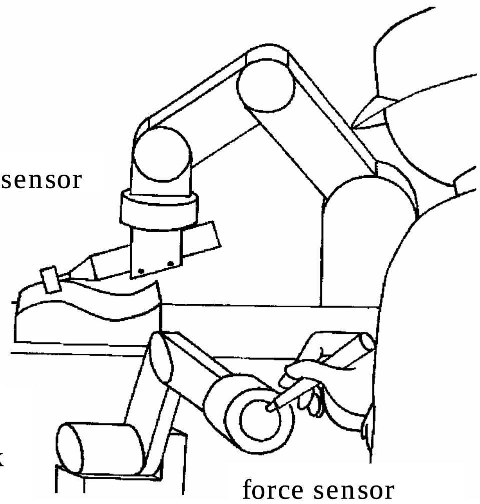


Fig.1 Concept of an operating robot system.

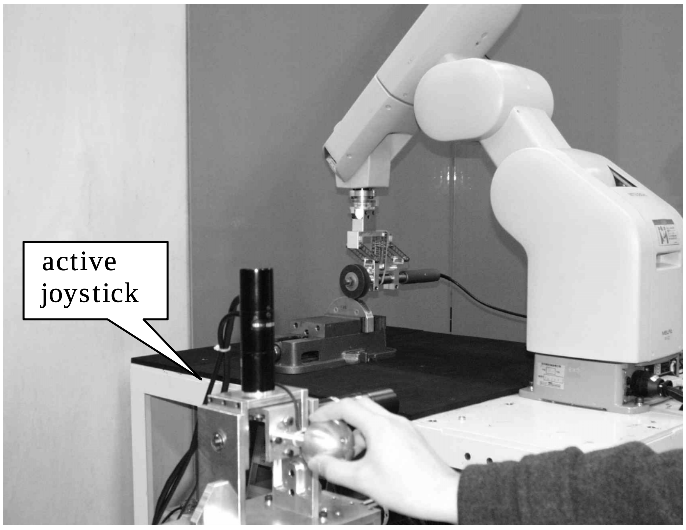


Fig.2 Developed operation robot system.

In order to utilize a commercially available robot, we have to interrupt the robot controller to modify its programmed motion. The robot controller has a real-time interface, which can interrupt the servo controller and modify the position/orientation of the hand during each servo cycle (30 ms).

Since the sampling period is insufficient for the force control, a compliant tool holder was developed. The holder has a parallel link mechanism with a spring and holds a polishing tool (electric micro grinder ASTRO-E 250 NAKANISHI Co.), as shown in Fig.3. The compliance of the tool holder absorbs the position error of the tool that is due to the long sampling period, and enables stable force control of the position-based industrial robot.

In order to measure the contact force of the tool, the holder mechanism is attached to the hand of the robot via a 6-axis force/torque sensor (MINI 8/40 BL-AUTOTEC Co.).

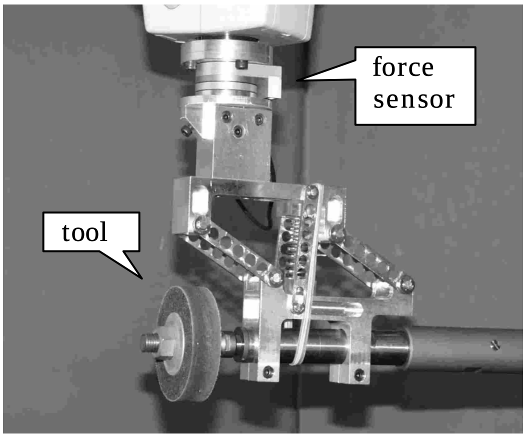


Fig.3 Compliant tool holder.

2.2 Active joystick

In the field of teleoperation and virtual reality, several haptic type mechanical interfaces have been developed as a means by which to provide force sensation to the human operator [10]-[12].

In polishing tasks, the motion of the tool may be comparatively simple. The tool must be moved along the object surface while adjusting the contact force. Thus, the 3D translational motion of the tool should be operated interactively.

In order to achieve this operation, we developed an active joystick as shown in Fig.4. The joystick has a 2-DOF gimbal mechanism and a 1-DOF slide mechanism, which provide 3D translational motion of the handgrip. The motion corresponds to the 3D motion of the hand of the robot in the tool coordinate frame.

A small 6-axis force/torque sensor (MICRO 5/50 BL-AUTOTEC Co.) is built into the handgrip as shown in Fig.5. Here, 3-axis forces provide the translational motion commands of the robot, and 3-axis torques provide the velocity commands of the hand orientation of the robot.

First, the tool posture is aligned to the objective surface by twisting the handgrip. Then, the 3D translational motion of the hand in the tool coordinate frame is adjusted by the joystick motion. (Fig.6)

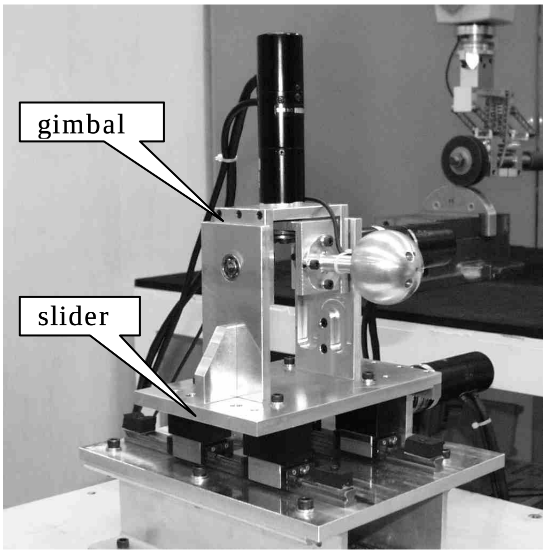
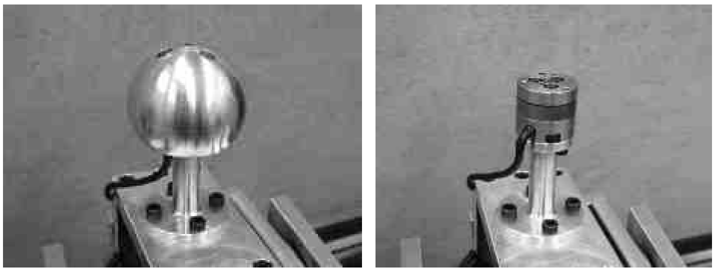


Fig.4 Prototype active joystick.



(a) outside view (b) inside,6-axis force sensor

Fig.5 Handgrip of the active joystick.

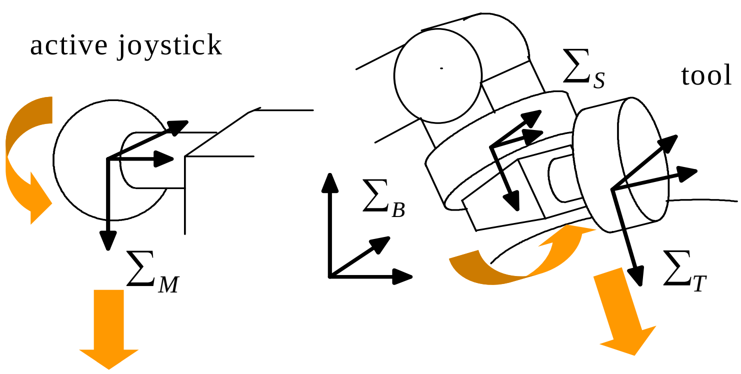


Fig.6 Operation of the active joystick.

3. Control system for force operation

Figure 7 shows the control system for the force operation. Variables in the block diagram are vectors corresponding to 3D motion of the joystick and the tool. Here, ${}^{S}R_{T}$ is the rotation matrix from Σ_S to Σ_T, and ${}^{B}R_{T}$ is that from Σ_B to Σ_T respectively.

The system is basically a symmetrical force-reflecting bilateral servo mechanism. In free space motion, the operation force of the handgrip is fed back to position command of the joystick, which provides arbitrary compliance to the joystick.

When the tool comes into contact with the object, the contact force is controlled by the wrist force feedback and can be adjusted via the grip force. The wrist force is also fed back to the joystick. Thus, forces identical to those on the tool can be felt through the handgrip, and the contact forces of the tool can be adjusted as if we were handling the tool directly. The operation force can be scaled up or scaled down by changing the feedback gains, K_J and K_R.

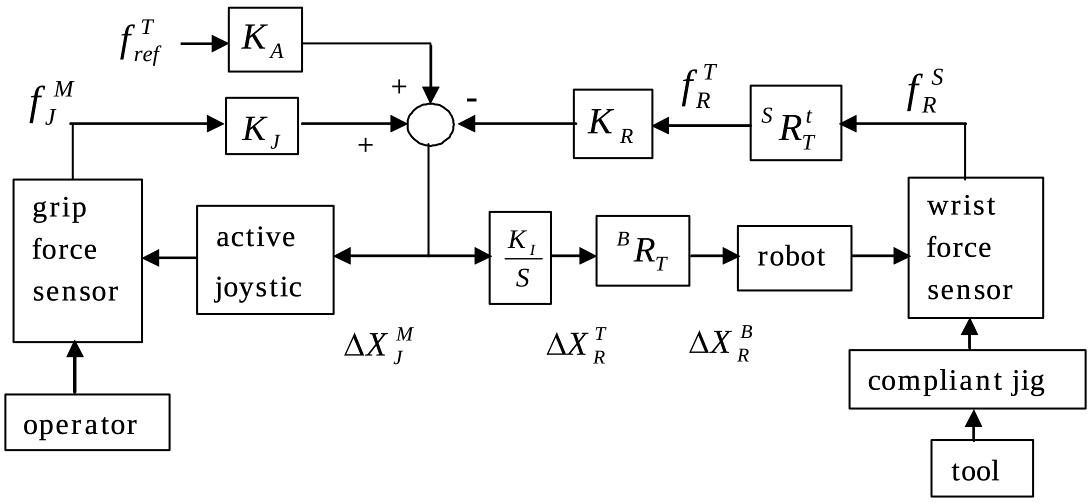


Fig.7 Control system for force operation.

In addition, we can switch the control mode from manual operation to autonomous force control of the robot by setting the gain so that $K_J = 0$ and $K_A = 1$. In the automatic force control mode, we do not need to adjust the contact force and therefore are able to concentrate on the tool motion along the surface. Even in the automatic mode, the contact force can be sensed by the operator and the mode can be returned to manual operation at any time.

4. Experiments

In order to confirm the basic effectiveness of the operating robot system, the system was applied to simple polishing tasks using a buff tool (SST UNI-WHEEL SUMITOMO-3M Co. Dia.75 mm). The rotation speed of the wheel is approximately 3000 RPM.

Figure 8 shows the operation force of the joystick and the contact force of the tool during the manual operation. The tool is moved from free motion to constrained motion smoothly without large collision force. After the tool has come into contact with the object, the operation force is adjusted so as to maintain constant polishing force.

Figure 9 shows an example of the force scale-down. The operation force can be scale-downed by setting the feedback gains as K_J=0.5K_R . Here, the larger operation force enables fine force control. The result suggests that precise polishing tasks can be executed by the scale-down of the operation force.

Figure 10 shows an example of switching control modes. In the manual operation mode, the operator moves a tool along the surface while maintaining constant contact force. In this case, precise adjustment of the force is difficult. However, in automatic mode, the contact force is automatically maintained constant, and the operator can concentrate on the tool motion. The operator can return to the manual operation whenever desired. The combination of the manual control and the automatic control enables effective polishing tasks of objects having complex shape.

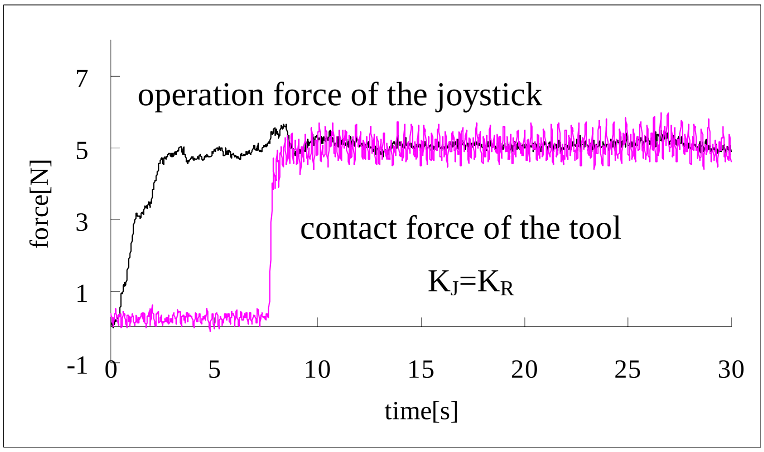


Fig. 8 Example of the force operation.

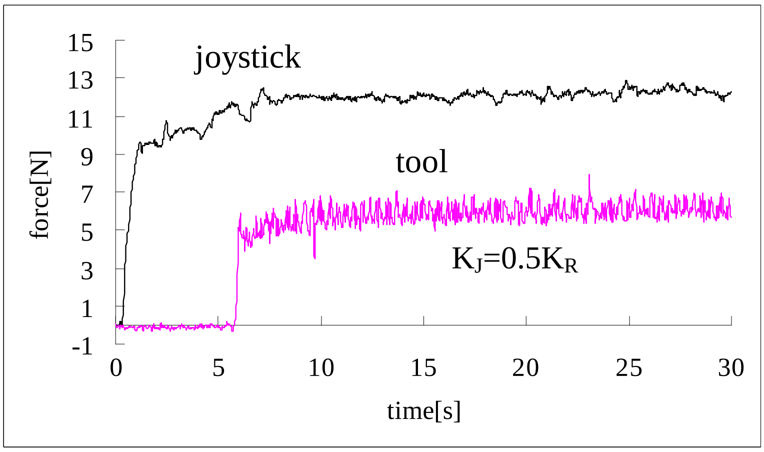


Fig. 9 Example of the force scale-down.

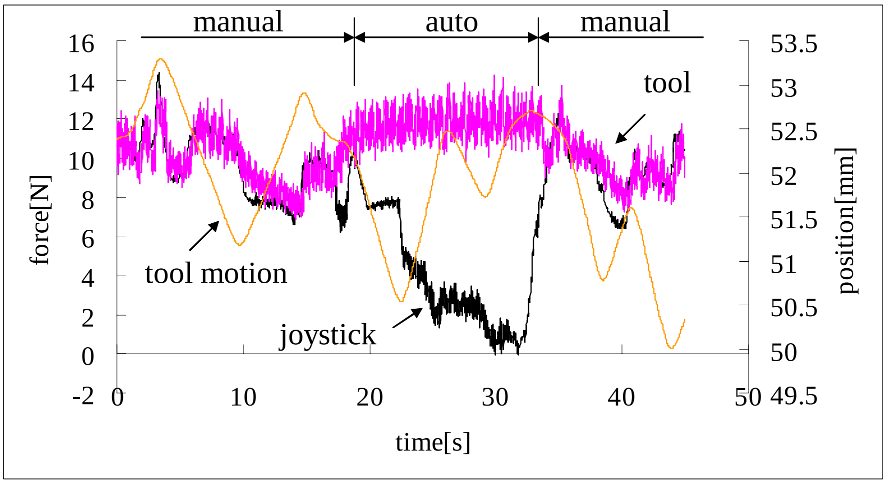


Fig. 10 Switching from the manual operation to the automatic operation.

5. Conclusion

This paper proposed an operating robot system for die and mold polishing. The proposed system consists of an industrial robot and an active joystick by which to manipulate the robot interactively.

The control system, based on a force-reflecting bilateral servo controller, was constructed and implemented. The proposed control system enables interactive force operation, and we were able to remotely manipulate a polishing tool attached at the hand of the robot.

In addition to the manual operation, the system can control the contact force of the tool automatically by direct force feedback to the robot. The operator can select either of two control modes according to the task. The resulting function of the proposed system enables effective polishing tasks of objects having various shapes.

The proposed system was applied to a simple polishing task, and experimental results show that the tool can be manipulated remotely as if we were handling the tool directly. In addition, we can switch the manual operation to autonomous force control smoothly as desired according the progress of the task.

An advantage of the proposed system is that the system makes use of commercial industrial robots. A practical, low-cost robotized polishing machine will be realized by the proposed system.

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