1. Introduction

The demand for machine tools with much higher accuracy causes the development of ultra-precision mechanisms associated by accurate metrology system which can cover the wide working range with the sophisticated control properties. However this traditional approaches need much of cost to construct and energy consumption to maintain indeed. As an alternative approach to this problem, many unique insect size robots with precise tools workable in microscopic range have been developed by our group for these years[1]. These small robots are composed of piezo elements for micro locomotion and electromagnets for clamping as an platform mechanism. This simple arrangement can allow them to move on any inclined planes with submicron positioning resolution and good design modularity of optional micro facilities such as micro hammer, micro grating and dust capturing capillary probe[2],[3],[4]. These small robots with low production and maintenance costs have a great potential ability in the application of precision engineering.

In order to open up to the application fields, many small robots with the single tool on the desktop have to work simultaneously for more complicated tasks. In this report, we show the micro drilling system where many small insect size robots with micro tools are controlled to drive the thin drill shaft and transport the sample materials automatically.

2. Small Robots with Tools for Micro Drilling

As an useful application of the multiple insect size robots with a fine positioning and a high flexibility, the automatic micro drilling system for small parts are proposed as shown in Fig. 1. Since the small size robots can facilitate just a small and simple actuator, it is required that multiple robots have to cooperate to perform the specified precise tasks. Each small robot is composed of piezo elements for micro locomotion and electromagnets for clamping on the steel surface. One small robot with the thin drill shaft is surrounded by the many tiny robots with the pinion gear driven by the micro DC motor. So they can rotate the thin drill together if they are controlled to move on the specified path. Then the other small robot which has the passive sample holder can transport the material to be machined on the vertical wall to fix it onto the drill top. Finally
the sample can be pushed down so that the through-hole is accomplished.

Fig.2 shows the photographs of the insect size robots with micro tools. The robot in Fig.2(a) has a thin drill shaft of 0.4mm diameter with the large reduction gear on the axis. This small drill is supported by the brass bearing and magnetic thrust levitation to provide smooth rotation. The other small robot with the pinion gear and the micro motor is shown in Fig.2(b). The simple micro pager motor with the diameter of 6mm is mounted on the robot and the pinion gear is set on the motor axis. And the plastic oval outer frame is attached on its body to prevent the robots from unexpected dead locking. The remaining one in Fig.2(c) has the mechanical frame with the adhesive tape to fix the sample material although this holder should be improved to be an active device such as magnetic clamping mechanism. The experimental setup is shown in Fig.3.
3. Control System for Distributed Insect Size Robots

In order to realize the high reliability to the distributed robots system, it is required to maneuver them into cooperating each other with the help of the visual monitoring system and the multiple computer controls. A part of our control system on going development is shown in Fig.4. In the beginning stage, a single CCD camera is mounted on the inclined frame of 45 degrees and it can monitor the position of the small robots on the horizontal and the vertical plane simultaneously to avoid the system to be complicated. The target of the optical reflector on each robot can be monitored and the coordinate position is acquired by using the special real-time image processing system which can provide the numerical data \((x, y)\) of the center points of the brightening target with the resolution of 5000 x 5000 over the monitoring area with the sampling rate of 60Hz. These information are transmitted to the central computer to calculate the relative 3D positions and then passed on to the sub computers which are responsible to control remotely the robot motions. So the position and the orientation of each robot can be controlled easily by the visual camera based feedback loop. These computers can exchange such coordinate data, commands as well as robot's status with the shared memory bus interfaces. This parallel control system can make it possible to provide the appropriate sequences for small robots with much of flexibility.

4. Performance

The control sequence for the small robots become so simple because the drilling task by multiple small robots can be performed almost by the path control as mentioned above. In the primary experiment, the positions of two small robots, one of which has a sample on the vertical plane and the other one has the thin drill on the horizontal plane are monitored and controlled. At first, the 2D position data of
the through-hole location to be machined are given by the operator to the central computer and then the robot with the thin drill is controlled to move and fix at the specified position. The command signals to activate the robots with a micro DC motor are given to the machine controllers and then they can approach to the robot with the drill. When all of the pinion gear come in contact with the reduction gear, the mechanical micro switch can turn on the motor drive electronics and the drill can be rotate. This means that a part of the system such as simple repeatable action is designed by the local reactive loop to eliminate the complex properties. The small robot with the sample plate on the wall can be governed to move down and fix the sample on the drill top, and push down to be machined as shown in Fig.5. The next through-hole can be also produced by repeating this simple sequence. In the actual experiment, the unique task that four through-holes of 0.4 mm diameter were given at the corner of square with the separation of 5mm were achieved on the aluminum plate shown in Fig.6. It seems that the absolute accuracy and the repeatability are not enough yet due to some error sources from such as visual camera measuring system and its alignment although they should be improved.

5. Conclusions
As a practical application of multiple insect size robots, the automatic micro drilling system was proposed. In this system, small robots which consist of piezo elements and electromagnets have a micro thin drill, a micro motor with a pinion gear and a passive sample holder. With the help of camera vision coordinate measuring system and parallel computers system, they can be controlled to perform the cooperative action to get the through-hole on the specified point of the sample. We succeeded in conducting the automatic micro drilling system by multiple insect size robots although the accuracy of coordinate metrology system should be improved.

References