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# Design and development of a work robot to place ATLAS SCT modules onto barrel cylinders

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## Abstract

More than 2000 silicon modules need to be placed and fastened on the ATLAS SCT barrel tracker. A semi-automatic pick-and-place work robot was designed and developed to cope with the module placement for the SCT barrel assembly. We found that this robot could place modules to a mechanical precision of better than 25  $\mu\text{m}$ .

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## 1. Introduction

The ATLAS [1] detector has a large-scale silicon strip detector system in order to realize high-precision charged particle tracking. As illustrated in Fig. 1, the barrel part of the SCT [2] silicon strip

tracker consists of four concentric cylinders. Modularized silicon strip detectors [3] of about 12 cm  $\times$  6 cm are placed on the cylinders. In total, 2112 modules cover the four cylinder surfaces. Neighboring modules are overlapped to provide hermetic coverage. The clearance between the modules at the overlapping region is about 1 mm.

Placement of the thousands of high-precision silicon modules on the cylinders is a demanding task. Silicon detectors are so delicate that any part

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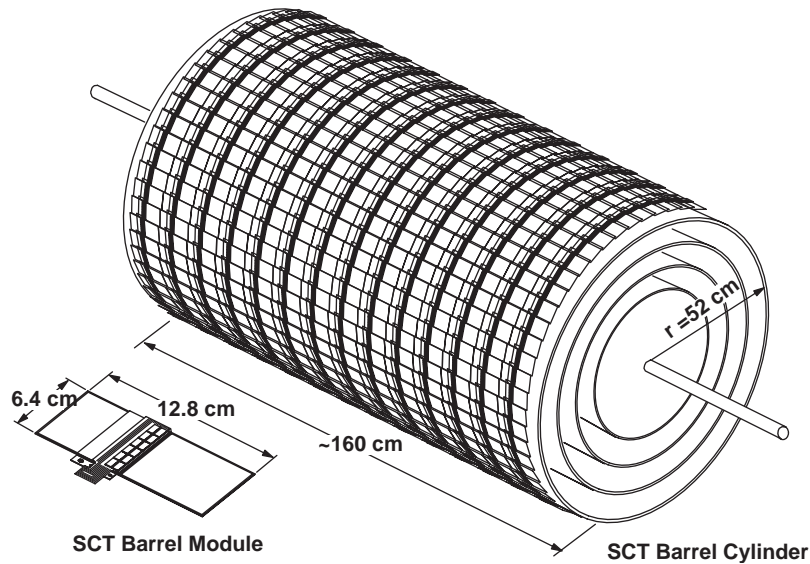


Fig. 1. Conceptual layout of the SCT barrel tracker.

of the silicon sensor surface and bonded wires should be kept intact under any circumstances. Therefore, it is practically impossible to conduct the module placement without using a dedicated apparatus.

In order to cope with the situation, we designed and developed a high-precision semi-automatic work robot. This robot picked up and held the silicon module by itself then brought it to a specified position along a secure trajectory. The robot must place the modules to a precision better than  $30\ \mu\text{m}$  and then fasten them on the cylinders [4].

## 2. Module mounting procedure

The SCT barrel is made of a light-weight honeycomb cylinder on which surface the barrel modules are laid out regularly to cover the interaction region hermetically. The barrel module has a pair of positioning holes on the bottom ceramic extension, which also serves as a cooling facing. Using these holes, the module is precisely positioned and fixed with a pair of small screws to the support bracket, which is bonded on the cylinder surface. The top end of the top ceramic

extension of the module is inserted to the support clip, which is also bonded on the cylinder surface. The clip provides an auxiliary support point, which, together with the bracket, allows the module to be held firmly from three points.

The module mounting procedure can be broken down into the following major steps:

1. measure and register the place where the module is to be placed,
2. pick up and hold the module stored in a module box,
3. bring the module to the registered position on the bracket on the cylinder,
4. fasten the module with a pair of screws to the bracket.

In Step 1, the robot with empty hands moves to the location where the module is to be placed. The robot senses the screw holes of the bracket and the surface of the cooling pipe using cameras and sensors. It then registers the sensed positions as the destination to bring the module. By having this step we could absorb almost all relevant setting errors.

Each module is being stored in a metal module box. The module inside the metal box is positioned

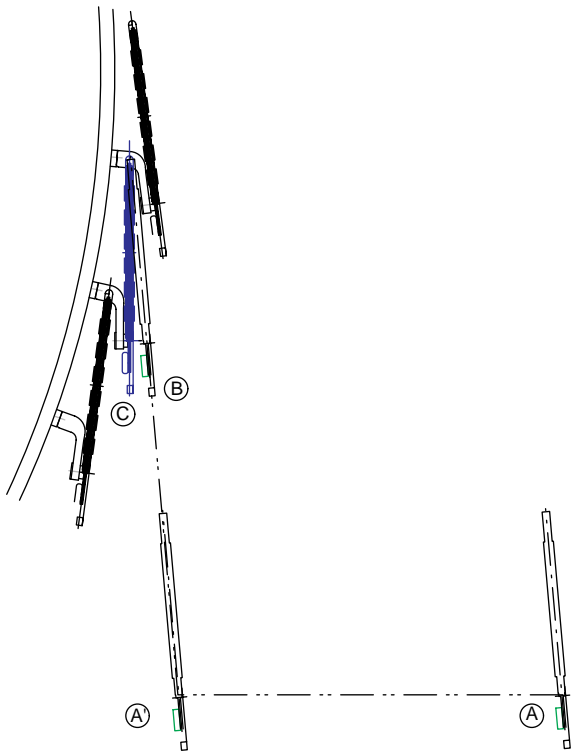


Fig. 2. Typical trajectory of the module placement (A → A' → B → C).

precisely with positioning pins. Therefore in Step 2, as long as the metal box is precisely set at a well-defined pick up position near the cylinder, the robot is able to pick up and hold the module always in the same manner.

During Step 3 the module is brought on the bracket. The cylinder is carefully set at a proper rotational angle so the module can be vertically landed on the bracket. By holding the module vertically we can avoid a stress on the module caused by a gravitational moment. Before landing on the bracket, the top end of the ceramic extension of the module should be inserted to the opening of the clip. This action requires a delicate movement as illustrated in Fig 2. The module is moved upward and forward with some rotation synchronously.

Finally in Step 4, the robot fastens the module with a pair of screws using automatic torque-controlled screw drivers.

We repeat these steps cyclically for every module placement.

### 3. Requirements

In order to meet the high-spatial resolution requirement of the silicon detector modules, the module positioning accuracy is required to be typically  $30\ \mu\text{m}$ . Therefore, naturally the modules need to be handled with an accuracy of better than this. Since variations of module dimensions, the precision of the mounting holes, errors of the bracket position on the cylinder are also comparable to this, the robot should be capable of dealing with these errors to achieve an overall module positioning accuracy of  $30\ \mu\text{m}$ . Accordingly, the work robot should be operational not only with a high precision but also be equipped with appropriate position sensors, monitoring tools and flexible adjusters to be able to compensate these variations and errors. Furthermore, the robot should be fool-proof as much as possible to avoid errors and accidents.

The robot should also be capable of a module removal, which is approximated by the reverse process of module placement.

### 4. Robot hardware

As illustrated conceptually in Fig. 3, the robot consists functionally of three major components each with an associated movement system. These are: a module manipulator with a module chucking head, a pair of screw drivers and a pair of monitor CCD cameras. The robot also has some sensors. For example, a pair of induction sensors embedded in the chucking head measure  $Z$  position (radial distance) of the cooling pipe surface which is nearly the same as the  $Z$  position of the bracket surface. Thus, the robot directly recognizes how far it should reach toward the bracket for each module mounting cycle. Also the manipulator is equipped with stress sensors so that it can come to an immediate halt when it encounters an accidental contact against obstacles.

The robot moves on a linear stage ( $X1$ ) set in parallel to the cylinder axis. The manipulator has a module chucking head, two rotation joints ( $\theta1$  and  $\theta2$ ) and a set of linear stages ( $Y2$  and  $Z2$ ). Those stages and joints can be operated simultaneously in an accordant way.

The robot is required to have other movable joints and stages for precise adjustments to

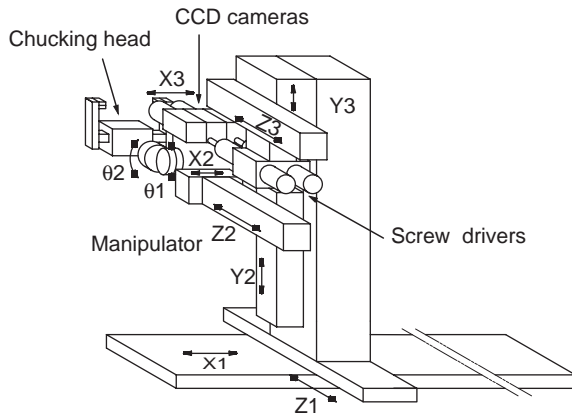


Fig. 3. Concept of the module placement robot.

compensate variations of the module dimensions, errors of the bracket positions, setting errors of the cylinder and so on. All the movable joints and stages are shown in Fig. 3. Their features and functions are summarized in Table 1.

Position reproducibility of the manipulator and other moving mechanisms is better than  $25\mu\text{m}$ , and the accuracy of all position adjustments is also better than  $25\mu\text{m}$ .

Fig. 4 is a picture of the robot together with the simulation barrel stand shown in the left and the control rack in the right. Shown in Fig. 5 is a close-up of the head of the robot manipulator. Here, a dummy barrel module held by the robot is about to be brought to the bracket on the simulation barrel stand.

## 5. Control system and software

The control system consists of a graphic touch panel, a programmable logic controller and a motion controller. A pair of stage controllers with

Table 1  
Movable joints and stages of the robot

Movable directions	Roles and functions	Range (mm)	Powered with	Comments
$X1$	Movement along the cylinder axis	1600	Stepping motor	Manipulator, cameras and screw drivers move all at once
$Z1$	Movement to the fall-back position	100	Ditto	Ditto
$X2$	Manipulator position adjustment	10	Ditto	Adjustment of manipulator wrt cameras
$Y2$	Movement of manipulator	100	Ditto	Movement of module to support bracket
$Z2$	Movement of manipulator	100	Ditto	Ditto
$\theta1$	Head rotation in $Y-Z$ plane	$0\sim5^\circ$ tilt from vertical, click stop at $90^\circ$	Ditto	Movement of module to support bracket, module pick-up
$\theta2$	Head rotation in $X-Y$ plane	$\pm 20\text{mR}$ with $\pm 2\text{mR}$ fine adjustment	Ditto	Rotation for the stereo angle
$X3$	Movement of cameras	100	Air cylinder	Between regular and recessed positions
$Y3$	Overall height adjustment	10	Stepping motor	Adjustment of cameras and screw drivers
$Z3$	Movement of screw drivers	200	Ditto	Movement to recessed positions, and progression for screw fastening



Fig. 4. Picture of the robot together with a simulation barrel stand shown in the left and the control rack in the right.



Fig. 5. Close-up of the robot head; the robot holding a module is approaching toward the bracket on the simulation barrel stand.

manual controller pendants for fine adjustment is also attached to the system. The conceptual layout of the system is shown in Fig. 6.

The graphic touch panel, which is equipped with a CPU, works as the central commander in the system. It collects all the information, such as

stage positions, various sensor outputs, camera views, screw driver status and so on. Based on this information, it examines the status of the robot and makes a judgment whether to proceed to the next step. It provides for a human operator, a guide and an instruction about what to do for the next step. Each step is initiated by an operator through use of the graphic touch panel.

The programmable logic controller has sets of preprogrammed strings of action steps. Each string corresponds to a specific action sequence such as the movement from A to B in Fig. 2. Following an order initiated from the graphic touch panel, the programmable logic controller chooses an appropriate string for the required action step. Then the programmable logic controller issues corresponding commands to the motion controller.

The actual movement of each basic action is defined by preprogramming the motion controller. The motion controller sends a set of corresponding signals to the movable components i.e. the stages, joints and so on to make them move coherently to perform a required action step.

A set of operation software was developed using a conventional PC. Then, the corresponding programs were downloaded to the graphic touch panel, programmable logic controller and motion controller, respectively.

Overall operation and control is done by the graphic touch panel.

The system was programmed to provide various operation modes including: the motion check mode, the module placement mode, the module removal mode and the error recovery mode.

All movable stages and joints can be individually operated and checked in the motion check mode. The module placement and module removal modes are the sequences of the module placement and removal processes, respectively. When a malfunctions or miss-operation occurs, the program automatically goes into the error recovery mode. In this mode, the task is immediately ceased. Then it examines the situation by collecting all the information and instructs the operator how to bring the robot back to a safe position. For each operation mode there are guides and cautions on the graphic panel for the operator.

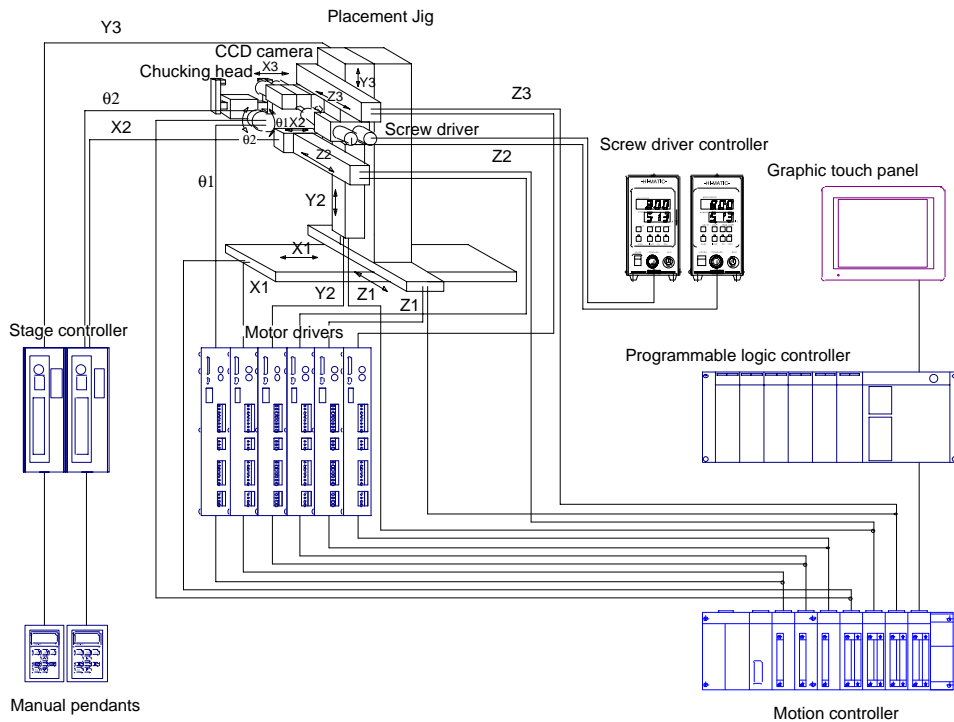


Fig. 6. Conceptual drawing of the operating system.

## 6. Conclusions

We developed the semi-automatic work robot dedicated for the task of the SCT barrel module placement. The robot was carefully developed and tuned using the barrel simulation stand. It was verified that the robot handled the barrel module reliably and securely with an accuracy of about  $25\ \mu\text{m}$ . In practice, it took about 10 min to mount one module cautiously with deliberate precautions.

Several operation modes have been provided to deal with various situations. The error recovery process was particularly emphasized to make the operation as safe as possible.

Further tunings and improvements may be needed, however, to cope with the actual barrel

assembly. Interlocks and safety measures should be carefully examined by means of the real barrel cylinders.

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