Moving beyond robot teaching

BEING SIMPLE-MINDED, ROBOTS REQUIRE A LOT OF TEACHING. PETER M ZAKIT DESCRIBES BERKELEY PROCESS CONTROL'S PATENTED AUTOCALIBRATION TECHNOLOGY THAT SEEKS TO AUTOMATE CRITICAL TOOL CALIBRATION SUCH AS SEMICONDUCTOR WAFER-HANDLING AND FOUP BUFFERING AND HOW AUTOMATION OF PRECISION MECHANICAL ALIGNMENT ENHANCES MACHINE RELIABILITY AND PRODUCTIVITY

Machines have personalities - or at least that's what it seems like to a lot of engineers working on machine startups. Two machines with exactly the same bill of materials have their own unique quirks that only the master engineer can tame. This is often the case with tool subsystems such as semiconductor wafer-handlers, and in particular wafer-handling robots. What if you could depend on a technician who is skilled in maintaining material flow in a fab and performing general maintenance, but is not an expert robot teacher to install, setup, and restart a robot-at the touch of a single button?

Wafer-handling robots are carefully taught each of the locations from which they retrieve delicate semiconductor wafers, and each of the locations to which they deliver them. Robots have to be taught after a tool is manufactured, so that the whole tool can be tested. Robots have to be taught after the tool is installed in the semiconductor fab. Robots have to be taught again as part of maintenance, and again with many repairs of the tool. Sometimes, out of frustration that a tool is not behaving properly, a technician will say, "let's re-teach the robot".

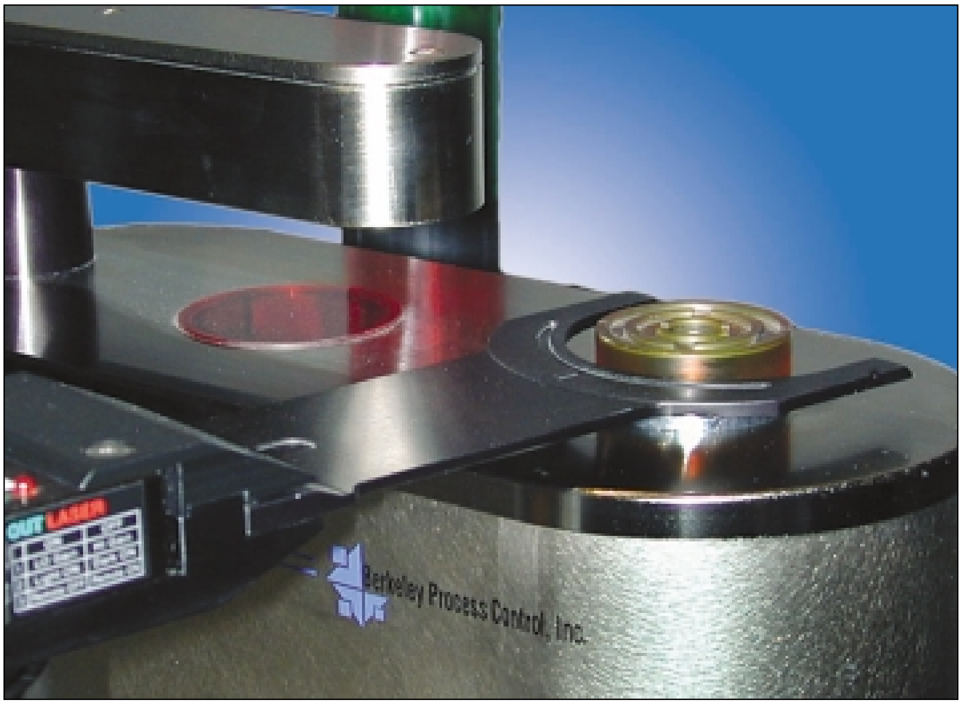


Fig.1: Robot end-effector automatically touch calibrating to the vacuum chuck of a wafer pre-aligner

Limitations of legacy teaching

Legacy manual robot teaching is time consuming and takes a lot of skill and judgement. The stakes are large. An incorrectly taught point can later result in a damaged or broken wafer. In order to calibrate wafer handoff positions, a semiconductor tool's teaching expert must be able to direct the appropriate robot motion and critically determine teach points.

Manual teaching requires the teaching expert to manually jog the robot on the proper path to the teach points — typically with several hardware or software interlocks defeated. This situation is ripe for human error and tool damaging collisions.

To determine appropriate teach positions, the teaching expert must subjectively eyeball the location of the wafer handoff point to within plus or minus a quarter millimeter. Complicating the task, this must be achieved in a semiconductor fab cleanroom, in a bunny suit, in the bowels of the semiconductor tool being calibrated. Taught points commonly vary due to the teaching expert's point of view, idiosyncrasies of the wafer transfer devices, and subtle differences in optimal handoff points for a given tool. The result is substantial taught point variation from teaching-to-teaching, and even more deviation with a change of teaching expert. Tool performance and reliability are compromised, and wafers frequently worth tens of thousands of dollars each are placed in jeopardy.

Many customers are used to wafer-handler manual teaching times of six hours, minimum. When their tools are upgraded with Berkeley Process Control's patented Autocalibration technology, the newly automated teaching process is typically reduced to less than 20 minutes - and the need for teaching experts eliminated.

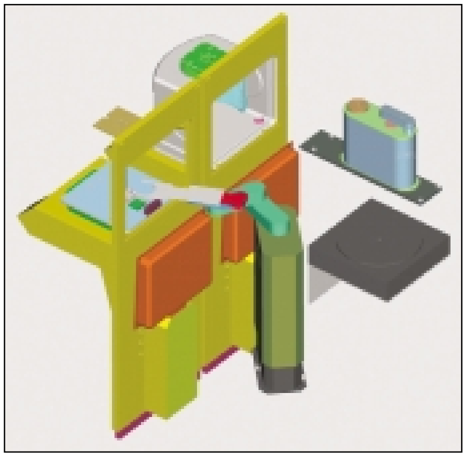


Fig.2: Solid model showing major semiconductor front-end components

How it works

In a semiconductor tool equipped with Autocalibration, a technician presses a single button to execute a pre-programmed calibration route. That routine automatically finds critical wafer-handler physical reference features using various application-specific sensing methods. The control system thereby quickly and precisely learns all of the wafer handoff positions. There's no judgement or skill involved.

Autocalibration is enabled by the tight integration of a robot to the critical elements in its operational environment, under a highly capable machine controller. Typical robot control architectures using multiple disparate controllers present large barriers to successful implementation of automatic calibration functions resulting from serial communications delays or the absence of a user-programmable software layer. Berkeley implements calibration automation with its shared-state, multitasking BX-series motion-and-machine controller.

The controller is programmed to drive the robot's motors that move its arms to a commanded position, and to process I/O data. High-resolution encoders provide feedback to the controller indicating the present position of each motor. The controller software continuously compares the actual motor feedback position and the software commanded motor position to generate appropriate drive signals. The controller's integrated drives provide necessary motor drive current. Through this tight integration, the controller has real-time knowledge of the velocity and torque of each of the robot's motors.

Touch calibration is the most powerful Autocalibration feature. No added hardware or sensor is required. As stated earlier, the controller has real-time knowledge of the present velocity and torque of each robot motor, and the present position of the robot's end effector. The controller also knows the approximate location of the robot's wafer handoff positions, and the geometry of the end effector based upon previous information provided by the tool application developer.

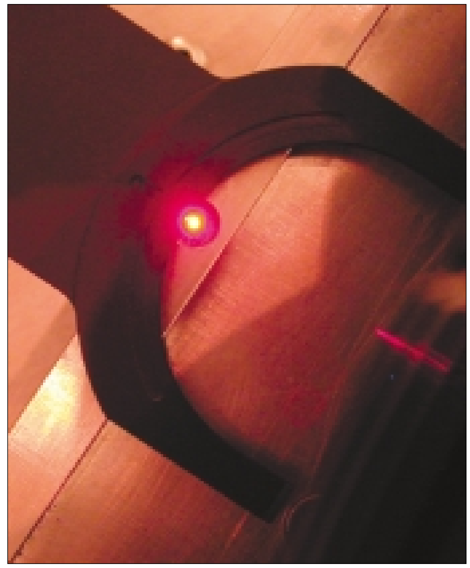
In touch calibration, the controller commands a robot axis to slowly move the robot's end effector into the predefined nominal location of a given wafer handoff position reference. When the end effector makes light contact, that axis slows down and the motor torque changes, indicating physical contact. The controller instantly captures the encoder position as the calibration point. Since the controller is aware, in real-time, of the precise torque requirements of each motor, touch calibration is achieved with very low contact forces. Sophisticated torque data processing algorithms eliminate false triggers and ensure Autocalibration consistency despite robot mechanism aging and changing friction characteristics (Figure 1).

Autocalibration technology implemented via a robot's common laser wafer mapping device also has the appeal of requiring no additional hardware or sensors. Such mappers are normally used to accurately detect the edges of wafers in a wafer carrier or FOUP (Front Opening Unified Pod). In this Autocalibration implementation, the robot moves the laser mapper a small distance up and down while moving it slowly toward the nominal reference location. Upon the mapper's reflective optical detection of the reference edge, the controller instantly captures encoder position data as the calibration point. Autocalibration technology can also be implemented in a similar manner via added through-beam or reflective optical sensors physically associated with wafer handoff positions (Figure 2).

A typical Autocalibration sequence in a simple semiconductor front-end tool proceeds as follows:

- Laser wafer mapper calibration to height reference (Z position) of the Master FOUP (a calibration fixture) on each PDO (Pod Door Opener)
- Touch calibration to reference post on Master FOUP (X, Y position) on each PDO
- Laser wafer mapper calibration to top (Z position) of chuck on pre-aligner
- Touch calibration to pre-aligner chuck (X, Y position)

Fig.3: Autocalibration eliminates the need for precision mechanical alignment of storage shelves in a 12 FOUP buffer



Robot end-effector cutting through-beam optical sensor path

- Calibration to pre-aligner optical sensor using the sensor (X, Y position)
- Application-specific (sensor, mapper, and/or touch) calibration to wafer process handoff location (X, Y, Z position)

Autocalibration has been implemented with a wide variety of robot vendors' mechanical designs. The controller architecture enables an effective implementation of the technology with both legacy belt-drive robot designs and state-of-the-art direct drive robots. In addition to their typically greater positioning accuracy and repeatability, the newer direct drive robots' greater torque sensitivity enables superb touch calibration sensitivity. Although Autocalibration provides an automated teaching process, its value can only be realised if it can demonstrate repeatable recognition of devices. In a laboratory test, Berkeley recorded positions calculated by Autocalibration for a wafer transfer station using a modern direct drive robot. The data shows repeatability of better than plus or minus 0.2mm.

In a different semiconductor application example, Autocalibration eliminates the need for precision mechanical alignment of shelves in a 12 FOUP (wafer cassette) storage buffer. The buffer employs a fast two-axis gantry equipped with a FOUP gripper. An Autocalibration routine employs optical emitter-detectors and torque sensitivity to rapidly reference features on each storage shelf and on a master FOUP, thereby precisely and repeatably calibrating the system in just minutes (Figure 3).

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