Cobots for the automobile assembly line
Prasad Akella, Michael Peshkin, Ed Colgate, Wit Wannasuphoprasit, Nidamaluri Nagesh, Jim We
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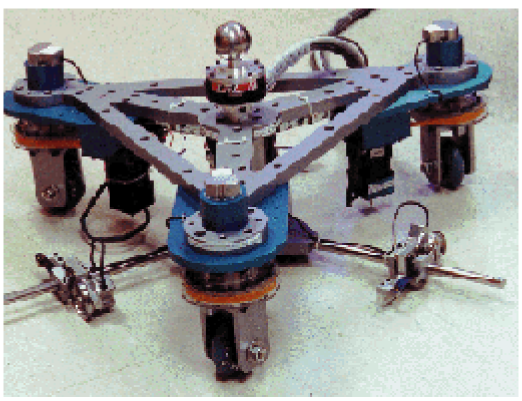
feature article

Cobots for the assembly line

Unlike robots that perform specialized tasks only in restricted areas, cobots—a new class of intelligent devices—have been designed to work with human operators in a shared workspace.

By Greg Paula, Associate Editor

As computer chips have made quantum leaps in capability, equipment used on the factory floor has undergone a similar revolution in performance. But in some ways, the tools workers use in their jobs have yet to take full advantage of the technological leaps achieved over the past 20 years. That is changing, as a new class of intelligent assist devices—called cobots, a conflation of the words *collaborative* and *robot*—are tested on experimental assembly lines.



A computer can independently steer all three wheels of this tricycle cobot, which can limit translation and rotation simultaneously

Although the first cobot designs are only now being tested, one of the devices' primary advantages has already been demonstrated: helping human workers use their muscle power more safely and effectively. According to one of the engineers who designed them, the most novel feature of this new breed of intelligent devices is that they provide guidance rather than raw power.

"Having humans in the same workspace with robotic devices is a hot-button issue because of safety concerns," said Michael Peshkin, a professor of mechanical engineering at Northwestern University in Evanston, Ill. "The cobot approach is based around the recognition that in the industrial environment, intelligent tools are needed more to supply guidance than to supply power. It's the power aspect that is potentially dangerous."

While the worker still must supply some force when working with a cobot, the benefit to his or her safety and long-term health can be significant. For example, it's relatively easy for workers to push objects directly in front of them. By contrast, moving heavy objects in a sideways direction typically is more difficult because the worker must stretch and turn, which can place severe stress on arm and back muscles. Performing such an action even once can throw a person's back out, but more common are problems associated with performing such actions repeatedly over a prolonged period.

Cobots are designed to prevent such problems. The operator only needs to supply the pushing forces, and the cobot steers the object so the worker does not have to stretch and strain arm and back muscles.

"If a worker needs to move an object from one point to another, the cobot creates a virtual wall that keeps the item on track," said Edward Colgate, a professor of mechanical engineering at Northwestern. "The worker still provides the force to actually move the object." Depending on the cobot design, this motion can be in more than one plane, and it can be both translational and rotational simultaneously. Since cobots typically are programmable, they're relatively easy to adapt to a new task.

Industrial Applications

The industrial environment has a wide array of potential applications for cobots. "In an automobile-manufacturing plant, there are applications where it makes sense for workers to do a task manually, while for other applications, the best option is complete automation," said Prasad Akella, a senior project engineer at the Robotics Engineering Department in the North American Operations Manufacturing Center of General Motors Corp. (GM) in Warren, Mich. "Cobots are useful for many of the tasks that fall somewhere in between—tasks in which a worker's abilities to see, feel, and react are needed, but [where] it is also desirable to spare the operator from having to perform certain physically taxing motions."

The cobot concept and early designs were developed at Northwestern's Laboratory for Intelligent Mechanical Systems, with funding from GM. A team comprising engineers from Northwestern and GM has honed the final designs, and is overseeing testing and implementation. Now, the technology has been licensed to Collaborative Motion Control Inc. in Evanston, a new company that will focus on bringing cobots to a variety of industrial applications. "Although technology has advanced significantly in recent years, the assists that are available to workers today are based on technologies that are decades old," Akella said. "We recognized that there were opportunities to use computer-based technologies to build better tools for line operators."

GM refers to these technologies collectively as "intelligent assist devices." The cobots developed as part of the GM-Northwestern collaboration are the first such devices to appear. To keep their collaborative effort focused from the beginning on assisting workers, project team members included not only robotics specialists but also experts on worker productivity and safety.

The cobot concept was first demonstrated using a tabletop prototype called the unicycle cobot, which was built by Northwestern graduate student Witaya Wannasuphoprasit. The cobot had two modes: free and constrained. In free mode, the operator could push the cobot anywhere and provided all the motive force. In constrained mode, the operator still provided the motive force. However, if the computer sensed that the cobot was coming up against a preprogrammed virtual boundary, a motor turned the wheel about its vertical axis and prevented the cobot from crossing that boundary. When in contact with a virtual wall, the wheel simply steered tangent to the wall. If something went wrong with the motor or controls, the unicycle might begin to steer improperly, but it still wouldn't go anywhere unless the operator pushed it. The device also could not harm the operator because the user supplied the only kinetic energy in the system.

Once the development team proved the effectiveness of the concept, it built several more prototypes, eventually leading to a tricycle cobot in which all three wheels are independently steered. This cobot can control translation like the unicycle could, but it can also simultaneously control angular orientation. The prototype served as the basis for the larger version that will eventually be used in GM's manufacturing facilities.

The first cobot will be used to handle car doors on a GM automobile assembly line. In the factory, car doors are connected to the chassis relatively early in the manufacturing process so that their color and finish match exactly during painting. To make it easier for workers further down the line to install the instrument panel and other components, the doors are removed as soon as the car comes out of the paint shop. The doors are put back on near the end of the assembly process.

This continuously variable transmission, which uses a sphere

constrained by four rollers to restrict angular motion, helps control the cobot

Currently, workers handle the doors with one of two tools: a pneumatic air balancer or an overhead-rail-based arm with a pneumatic actuator. Both tools do the actual lifting of the door, but the human worker still needs to push or pull the door as well as guide it. The pushing or pulling motion is relatively easy; guiding the door can be difficult, however, because of the stretching and turning. With the cobot, all the worker will need to do is push or pull the door, and the cobot will guide it.

Controlling Rotation

Before developing the cobot, team members considered a number of existing technologies to accomplish the same goals. For example, haptic devices—the name of which comes from the Greek term meaning "to touch"—allow an operator to interact with a computer through hand and arm motions. In such an application, a high-performance servo typically would be connected to a computer controller linked to the haptic device.

"At first glance, it would seem natural to adapt existing haptic technology to industrial uses," Northwestern's Peshkin said. "However, the project team considered this approach unsuitable for safety reasons. The forces involved with existing haptic devices are relatively small, but the motors would have to be much more powerful to lift and guide large objects. If control of these motors was lost, or if one or more of the motors malfunctioned, there is the chance that they could harm the operators." For this reason, the development team had to come up with an entirely new approach to providing workers with guidance so that they, in turn, can manipulate objects safely on the factory floor.

Controlling the translational motion of an object is relatively easy through the use of a wheel steered by a motor. The heading of the wheel determines how fast it moves in the x-axis relative to the y-axis. The challenge for Northwestern was that most applications require control of not only translation but rotation as well, and restricting angular motion is not nearly as straightforward as connecting a wheel to a motor. To address this problem, the development team created a new type of continuously variable transmission (CVT) that imposes a fixed ratio on a pair of angular velocities.

The first rotational CVT model that the team developed consists of a sphere caged by six rollers, with the rollers arranged as if on the faces of a cube surrounding the sphere. Each roller is pressed in toward the center of the sphere by an externally applied force, which serves to keep the rollers in rolling contact with the sphere. Two rollers are considered drive rollers and interface to other parts of a machine that incorporates the CVT. Two other rollers, diametrically opposite the drive rollers, are followers; they serve only to confine the sphere and apply the externally applied force. The drive rollers and followers have axes of rotation that lie in a single plane, which passes through the center of the sphere.

The remaining two rollers are steering rollers, located at the top and bottom of the sphere, that can turn freely on their axes. Unlike the drive rollers and followers, the axis of the steering rollers is adjustable. The angle that the axis of the steering roller forms with the horizontal is the steering angle.

Rolling—as opposed to sliding—occurs between two rotating rigid bodies in contact when the axes of the two bodies are coplanar. Their axes do not need to be parallel: The axes of two bevel gears, which are in rolling contact, are coplanar but not parallel. If, on the other hand, the axes of the two bodies are skewed, sliding occurs. Similarly, if the coefficient of friction is adequate, motion is prevented. The rotational CVT requires a sufficient force and coefficient of friction high enough to prevent sliding.

Considering all possible axes of rotation of the sphere, the sphere must be in rolling contact with all six rollers if it is to move at all. Since the center of the sphere is stationary, the sphere's axis of rotation must pass through its center. Rolling contact with a given roller requires that the axis of the sphere lie in the plane containing the axis of the roller and passing through the center of the sphere. Each roller forms such a plane. The planes for the followers and the bottom steering roller can be ignored because of symmetry.

The axis of rotation of the sphere must be the intersection of the three planes demanded by the two drive rollers and one steering roller. Such an axis is either in the plane passing through the center of the sphere or parallel to the axis of the steering roller.

After evaluating this model, the project team determined that a rotational CVT used to power a cobot would require only four rollers instead of six. (Four is the minimum number of point contacts needed to confine a sphere.) Accordingly, the two follower rollers were eliminated in the version that the developers actually built. The rollers contact the sphere at four points that form the corners of a tetrahedron. (The tetrahedron isn't regular but is stretched such that the angle subtended by the points of contact of either pair of rollers with the center of the sphere is 90 degrees; this makes the device easier to machine.)

The need for a robotic device is more to provide guidance to the worker than to supply power

Moreover, in the CVT used in production cobots, the rollers do not need to be independently preloaded. Instead, a rigid frame holds the two drive rollers, and another rigid frame holds the two steering rollers. The frames can be simply drawn together by a spring, which applies the same force to all four contacts.

Field Testing

Once the cobot for unloading doors had been designed and proven using the new CVT, the team began testing the device at GM's General Assembly Center in Warren. In this facility, which has a large laboratory with a mock-up of an assembly line, GM can develop and test new manufacturing techniques in an authentic environment without impacting production. "Since this is the first tool of its nature," GM's Akella said, "we intend to test it rigorously to ensure that it is safe and effective. We are inviting the end users—the line operators from our plants—to participate in the process and provide feedback. Their participation will also help ensure their acceptance once the cobot is ready to be installed on the actual assembly line."

Meanwhile, GM, along with other partners in industry and academia, is developing other intelligent assist devices. With the University of California, Berkeley, for example, GM engineers are developing a device that will amplify the power a human worker supplies in the course of doing his or her job.

One of the first applications of this device will be to lift batteries from a skillet and install them in vehicles. At GM's assembly plants, several different automobiles—each of which may require a different battery—are manufactured on the same line. Workers use pneumatic tools to lift each battery off the skillet and put it into the car. However, each brand of battery used has a different weight. Typically, operators set the pressure regulator to provide a moderate amount of lift. If the actual battery is lighter, the tool overcompensates, and the operator has to provide some downward force. If the battery is heavier, the operator needs to provide the extra lift. It is not practical to adjust the regulator to accommodate each new battery.

By contrast, the intelligent assist tool that is under development self-compensates for any battery weight it encounters. The operator directs and guides the tool, which provides a uniform lift regardless of battery weight—all the while ensuring that there is no chance that it will harm the worker in the process.

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