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RECENT APPLICATIONS OF FORCE/TORQUE SENSORS

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1. Introduction

Multi-axis force/torque sensors are being used in increasing numbers of robotic applications. Initially experimental devices found only in laboratories, they are now available as rugged, reliable factory-floor devices. Their availability and utility has spurned an ever-increasing number of installations, through which the benefits of force/torque sensing are becoming more evident.

It is logical that any process that involves contact between objects can only benefit from the additional sense of touch provided by force/torque sensing. Relying only on open-loop positioning systems to assemble close-tolerance parts can and does lead to problems. Tolerance variations of parts, slight inaccuracies in robot position and part-presentation devices and other common sources of positional error are often the cause of jams, broken parts or low-quality assemblies. The information provided by a force/torque sensor adds another level of sensing to the process and thereby adds another level of quality control. The occasional bad assembly does not go undetected. Indeed, applications that would normally be impossible are made possible through the use of force/torque sensing.

Another important benefit provided by force/torque sensing is flexibility. Without sensing, robots are forced to operate in a highly-structured environment. The addition of another sensing capability allows the robot to operate in a less structured environment and gives it the ability to detect changes and variations and thus adapt. In many cases tooling and hardware costs are reduced and the ability to handle a wider variety of parts and assemblies is increased due to this added level of adaptability.

2. Integratability

The use of a force/torque sensor in robotic applications requires some type of interface between the sensor and the robot. Common interfaces are RS-232C and binary I/O. Many applications only require a signal that a specified force/torque envelope has been violated. The Lord F/T series sensing systems provide a convenient method of achieving this with the Force/Torque Language (FTL). This language allows the user to pre-define allowable force/torque windows. These windows are selectable through a simple binary I/O interface, found on most industrial robots. If a window is exceeded, a simple binary signal is returned to the robot. Using this method, the simplist robot can utilize the benefits of force/torque sensing.

For more advanced functions, an RS-232C interface may be used to send commands to the sensor and receive data. Common functions performed at this level include selecting sensor reference frames, starting and stopping force/torque condition evaluation and reading sensor data. Presently, however, most commercially available industrial robots lack the ability, either due to basic functionality limitations or to lack of sufficient robot controller processing speed, to make use of actual force/torque data in a truly real-time fashion. For this reason applications involving real-time robot path adjustment are largely still in research labs and the majority of actual applications are of the force/torque window type.

Regardless of the interface, the force/torque sensor can provide useful information which can be used in a number of different ways. The following examples illustrate this utility.

3. Applications

3.1 Automotive Piston Assembly

In a recent application a force/torque sensor was used to verify the quality of a piston insertion process. An automotive manufacturer wanted to verify that when pistons were being robotically inserted into engine blocks error conditions such as missing piston rings, jammed rings or piston, and crankshaft collisions could be detected. The force/torque sensor, mounted between the robot's tool flange and the end-effector made it possible to detect all of these error conditions.

The pistons have been fitted with piston rings and connecting rods prior to the insertion process. The pistons are inserted into the engine block with the assistance of an insertion guide. The guide is positioned over the cylinders and located with dowel pins. Each cylinder has a corresponding hole in the guide whose walls are tapered. The opening at the top of the guide gradually reduces to the diameter of the cylinder. The pistons are inserted from above and pushed through the guide into the cylinders. The tapered walls of the guide compress the piston rings as the piston is pushed into the cylinder. As the rings snap into the cylinder just past the guide, a slightly greater insertion force is encountered. This change in force is detected by the force/torque sensor and analyzed to determine the presence or absence of each ring.

The force/torque sensor is also used with the Force/Torque Language during the insertion process to detect a piston ring jam, a jammed piston body, and collisions between the connecting rod and the crankshaft. Also detectable are piston mis-acquisions, dropped pistons, collisions and errors when exchanging end-effectors.

To perform this task, a Lord Corporation F/T 30/100 force/torque sensor is mounted on a Seiko RT-5000 robot. An IBM-AT personal computer is used to perform the signal analysis. The force/torque transducer controller provides data to the IBM-AT through an RS-232C port. The AT also communicates serially with the Seiko RT-5000 robot. Additionally, a 16-bit parallel port between the F/T controller and the robot provides communication for the F/T system's Force/Torque Language (FTL). An exceeded force threshold is detected and communicated within 10 ms of the occurence.

The robot end-effector is a three-fingered gripper having fingers that are designed to close around the piston rings, centering and compressing them slightly while grasping the body of the piston. A Lord Corporation QC-150 automatic tool changer is used to exchange the piston end-effector with another end-effector used to install and remove the piston insertion guide.

Data from the z-axis (co-linear with the insertion direction) force component is collected as the piston is pushed through the guide and into the cylinder. The time derivative of this signal is taken and used for all further processing. The piston rings appear as zero-crossing spikes in the derivative signal. The compression rings generate single spikes while the oil ring generates a double spike. This is due to the fact that the oil ring is actually comprised of a plastic spacer sandwiched between two steel rings. The two steel rings cause the double spike to appear.

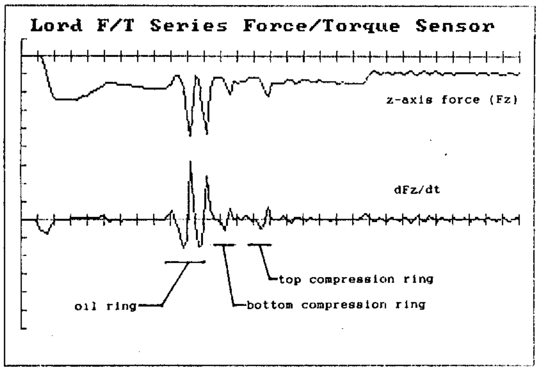

Figure 1 - Piston Ring Present

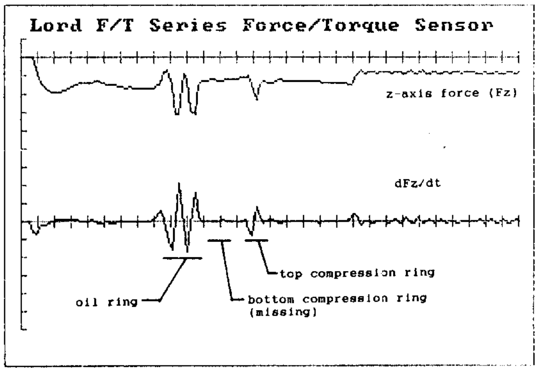

Figure 2 - Piston Ring Missing

To detect the spikes and thus detect the presence or absence of a particular piston ring, the derivative signal is compared to a pre-determined threshold value. The comparisons are done in specified windows of time, each window corresponding to a piston ring. The beginning and end of each window are referenced to the start of the piston insertion as detected by the first spike in the signal. Figure 1 shows data obtained during the insertion of a piston having all rings present. In Figure 2 data from a similar insertion is shown but in this case the bottom compression ring is not present. This is detected by the analyzing software and an error condition is signaled.

By using the time derivative of the force signature rather than the signature itself, the ring detection problem is simplified by eliminating the variations in absolute insertion force which are commonly found. These variations are simply due to slightly different insertion conditions for each piston/cylinder combination. The derivative of the force signal proves to be a simple yet very useful tool in applications such as this where monitoring changes in forces and torques can provide useful information.

Using a force/torque sensor for an application such as this provides information critical to maintaining quality assemblies and ensures the success of the robotic application.

3.2 Motor/Fan Assembly

A manufacturer of vacuum cleaner motor/fan assemblies encountered a problem with fans being bent during the assembly process. As the thin-gauge steel fans were robotically installed onto the motor shaft slight misalignments of the fan and shaft would cause the fan to catch on the threaded end of the motor shaft, slightly damaging the fan. These defects would not be discovered until the completed assembly was tested for dynamic balance, where the damaged fan would cause the assembly to be rejected. It was desired to detect the error during the assembly process and eliminate further wasted down-line assembly of the unit prior to the final test.

A Lord Corporation F/T 15/50 Force/Torque sensor was used between the robot tool flange (an AdeptOne) and the end-effector to monitor forces during installation of the fan. The end-effector was a vacuum gripper which would acquire the fans from a pallet. If, during the assembly process, a fan would get caught on the motor shaft, the F/T system would signal the robot and the fan would be removed and rejected. Another fan would then be acquired and the process repeated.

3.3 Printer Logo Installation

A manufacturer of computer printers wished to install the company logo, a thin piece of metal about 1 inch square, into a recess in the plastic printer housing. Problems with variability in the location of the printer housing, a large plastic molding, required a method of locating the exact position of the recess for each assembly to ensure that the logo was properly seated. It was determined that a cost-effective solution could be achieved by using a force/torque sensor during the insertion to "feel" for the edges of the recess.

An AdeptOne robot equipped with a Lord F/T 15/50 Force/Torque sensor was used in this application. The logo is first picked from a pile using a simple vacuum end-effector. A small amount of adhesive is applied to the bottom of the logo using a stationary adhesive dispenser. The logo is brought to the logo recess in the printer enclosure and held with slight pressure against the housing. The logo is then moved into the recess, first in one direction then in the other, 90 degrees apart. During the first motion, the sensor is used to detect when the logo reaches the raised lip of the recess and the robot is stopped. The other motion is performed, detecting the other edge in a similar manner. At this point, both edges of the recess have been located and the logo has been squared up with respect to the recess. Slight pressure is applied to firmly seat the logo and the installation is complete.

The F/T sensor provided a simple cost-effective solution to this problem without the use of expensive hard tooling or vision systems.

3.4 Contour Teaching and Part Location

Many robotic applications involve programming the robot to follow a contour. This usually requires the tedious process of teaching many points along the desired tool path and in many cases the process requires a somewhat constant force between the tool and the workpiece. This is often accomplished by operator "feel" - a very subjective process and not very consistent. In these cases a force/torque sensor can be used advantageously both to guide the robot along a path while it is being taught and to ensure that the force between the tool and the workpiece remains at the desired value.

In a recent application, a Lord 30/100 Force/Torque sensor was used with a GMF S-100 robot to actively "learn" the contour of molded plastic parts. The parts were to be deflashed (removal of mold flash) by the robot and each different part required its own pre-programmed path.

An algorithm was developed that used force/torque sensor data to adjust the force of the tool to a specified value, determine the normal and tangential direction of resultant forces and thus the edge tangent, move a specified amount along the tangent, and repeat the process at the next point. The point spacing, tool force and starting direction are all specified by the operator. The algorithm, written in the KAREL language, allowed the robot to automatically teach itself new countours in minutes. Once learned, the automatically-generated paths were stored in files to be used when the part was subsequently encountered by the robot for deflashing.

Additionally, the force/torque sensor was used to locate each part prior to the deflashing process. The parts were held in a universal fixture and not precisely positioned. The sensor was used to touch a total of three points on two edges of the plastic part and thus determine its location. The stored path for the part was then adjusted (in software) based on the actual location of the part and the deflashing process was performed.

3.5 Steering Column Inspection

A manufacturer of automotive steering columns has used force/torque sensors to perform various inspections on the steering column assemblies. Used in conjunction with a Yaskawa robot and appropriate end-effectors, a Lord F/T 30/100 Force/Torque sensor was used to measure steering shaft pre-load torque, ignition switch torques for the various positions of the switch and turn-signal actuation forces. Using the Force/Torque Language, if any of these parameters were found to be out-of-tolerance, the steering column would be rejected and subsequently repaired.

4. Conclusion

It has become clear that through the use of force/torque sensing many previously uneconomical or unsuccessful applications can now be performed successfully. The earlier-anticipated boom of robots dominating factory production has not yet occured. Many robot installations have not met the initial expectations of users or have failed completely, souring the prospects of future robotic applications. Yet the reason many of these earlier applications have failed is very basic, that is that the robot was expected to blindly perform a task perfectly in an imperfect environment. There must be an additional level of feedback so that the robot may adapt to these imperfections, thus ensuring the ultimate success of the application. This additional level of real-world sensing is provided by force/torque sensors and their continued use will ensure the eventual proliferation of factory robots.