'89 KACC 1989. 10. 27~28

Current Trends in Force/Torque Sensing

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ABSTRACT

Force/torque sensors are now providing widespread practical solutions to manufacturing problems, particularly in the area of automated assembly. The current state of the industry is discussed, including the evolution of transducer and controller design, and the trend of robot manufacturers to integrate force/torque sensors into their robot systems thereby greatly improving cycle time and simplifying the application development task for the end-user. Current and future application areas are discussed as well as the benefits of force/torque sensing.

Introduction

Force and torque measurement continues to develop into an ever-widening field of transducers, techniques, and applications. The discussions in this paper will be limited, however, to force/torque sensing as primarily applied to robotic applications.

Once found only in research labs, force/torque sensing systems are now being widely used in various forms in actual factory applications. An evolution is occurring from the original sensing system designs, which were aimed primarily at research, to more factory-qualified, economical designs. The real benefits of force/torque sensing, characterized by improved quality, higher productivity -- and as a result cost savings -- are being realized by manufacturers. These benefits are causing sensing systems to be welcomed into factory applications, yet at the same time sensing systems themselves are being subjected to the driving forces of the factory environment -- quality, ruggedness, reliability and cost/performance.

Transducers

Due to the demanding constraints imposed by factory application, force/torque transducers are becoming cheaper, simpler, more reliable, more rugged, and more adapted to efficient on-line maintenance.

The first force/torque transducers were six-axis designs, giving users the ability to measure the entire force and torque state of the end-effector. It was quickly discovered, however, that for many factory applications the full six components of measurement -- three forces and three torques -- are not required. As a result, transducers having fewer than six components of measurement are now available. Typically three- and four-component transducers are available, measuring the three force components and z-axis torque. In the future, even single-component transducers will be developed for the simplest of force sensor applications -- those requiring only a single axis of force measurement.

Controllers

Force/torque sensor controller design is being driven by the same factors driving transducer design. The balance between features, benefits and cost is becoming extremely critical, especially in the highly-competitive Pacific Rim countries. As with transducer design, controller functionality is being defined by factory application. Price constraints, ease-of-use, and reliability are driving controller designs to simpler, low-cost units that provide relatively simple functionality yet are quite adequate for many factory applications.

Several forms of controllers are now available encompassing varying degrees of functionality. Simple controllers operate by resolving sensor data internally and then comparing the resolved data to a preset level, which has been selected by setting a potentiometer. If the force or torque level exceeds this preset level, a binary signal is sent to the robot or other piece of equipment communicating with the controller. More sophisticated controllers allow the user to perform more advanced functions on the force/torque data, and present the data in several formats using various hardware communication methods.

Like transducers, controllers are also adapting to factory requirements. They are becoming smaller, more rugged, more resistant to harsh environments and more noise immune.

Integration with Robot Controllers

Until recently it has been necessary for force/torque sensor applications to be configured in a manner such that the sensor controller communicated with the robot controller through some "external" or "user" interface -- that is, some kind of standard interface such as RS-232C, RS-422, or parallel binary I/O -- supported by the robot controller hardware and software. Although allowing different types of external sensors and other devices to communicate with the robot controller, the primary disadvantage of general interfaces has always been poor communication speed. A general interface must be able to handle inputs from all types of equipment. The robot software servicing I/O communications, and the robot language itself, must also be general in order to handle this wide variety of inputs. The drawback of this approach is that communication speed is sacrificed in favor of flexibility. The time between the occurrence of some outside event and its recognition, interpretation and the execution of the required action by the user's robot program can be quite long. This can especially be a problem in the case of contact sensing, where reactions to sensor inputs are required immediately. Certainly in those applications requiring continuous sensor feedback this delay has been a decided disadvantage. The optimum use of contact sensing data can only be achieved when the sensor output is tightly integrated into the robot controller.

A further disadvantage of such general interfaces is the time required, even with the simplest of interfaces, for the user to develop the necessary hardware and software to implement the interface.

These problems can be effectively solved, however, if the sensor and controller are "designed into" the robot controller, and the robot language contains primitives to make use of the sensory data. Lag times can be greatly reduced with the resulting effect of vastly improving robot response to sensor stimuli. The integration has the added benefit of reducing the application development time required by the user. As an integrated robot option, the force/torque sensor comes "ready to use" -- no special interfacing and low-level communication software development is required on the part of the user. All that is required is to understand the basic operation of the sensor through its robot language interface.

For these reasons and due to the fact that robot manufacturers and users recognize that a definite economical justification exists for force/torque sensing, a trend has been developing towards force/torque sensor/robot integration. Several robot manufacturers in the United States and Japan are developing this capability. The force/torque sensor, with appropriate application software, is available to the robot customer as an option, in the same way as vision systems are now available as robotic options.

Proven factory applications with robot controller-integrated force/torque sensors have shown that cycle times, and therefore throughput, can be improved by factors of 3-5 with a corresponding rise in quality. The overall benefits of faster throughput and higher quality can be tremendous.

A further advantage of a tightly integrated sensor and robot is the realization of the fast robot response required to effectively implement real-time path following algorithms. Without fast robot response, these applications are far too slow to be considered for practical applications.

Force/Torque Transducers vs. Load Cells

In the context of this paper "force/torque transducers" is taken to mean those devices specifically designed for robotic and automation applications. "Load cells" are force/torque measurement devices also, but constitute a more general class of device and a much broader range of applications. Load cells typically measure a single component of force or torque, while force/torque transducers typically measure multiple forces and/or torques.

Main differences between the two types of devices are found both in transducer design and controller design. In designing load cell transducers, the dominating factors are measurement range and resolution. The resulting mechanical design is directly related to these parameters. Force/torque transducers are also designed with these parameters in mind, but other important factors are also considered in the design. Chief among these is a large overload capacity, especially in the case of torques, since robotic applications generally involve many opportunities for the sensor to be severely overloaded, usually unintentionally. Also taken into consideration are weight, size, profile, and mounting considerations. These physical properties are much more critical in robotic applications, where end-of-arm payload is at a premium, than most others, and the result is a mechanical design that can be very different from a load cell with an equivalent measurement range.

A load cell typically puts out an analog voltage representing the measured parameter. It is left to the user to somehow transform this voltage into useful information accessible by his robot program. A force/torque transducer, however, typically has a controller which has at least some comparison and decision-making capability and can output at least a simple binary signal. In addition, force/torque sensor controllers having more advanced functions are available. Examples of these more advanced functions are the ability to translate and rotate the measurement reference frame in space, zero existing forces and torques at any instance, and simple yet powerful programming languages.

Research Trends

Force/torque sensing research is still being conducted in many university and company labs. Much of the work is centered on advanced control algorithms for real-time robot path control. This includes algorithms for contour-following applications such as metal deburring and polishing, plastic deflashing, and contour learning. Research is also being conducted in using force/torque sensing in mechanical and electrical assembly, primarily to increase throughput and improve reliability and quality.

Actual factory applications of real-time contour following still prove to be elusive, again due to the problem of relatively slow sensor/robot controller communication speeds causing robot motion to be too slow for practical application.

New Measurement Technologies

Strain gauge technology, old yet proven and reliable, still dominates the force/torque sensing industry. Newer technologies such as optical and magnetic techniques are now appearing. These new measurement methods have the advantage of being non-contact, and therefore not subject to the mechanical limitations faced by strain gauges. Strain gauge technology, however, has made some of its own advances over the years, and remains a strong competitor.

International Developments

The United States is the leader in real factory applications, mostly in the electronics industry. Japan is starting to embrace force/torque sensing, but the applications are more diverse and not centered on electronic component insertion. One possible reason for this is the fact that Japanese vendors provide electronic parts with high quality reliably-positioned leads and electronic circuit boards with very few mechanical defects, eliminating the main causes of insertion failures. Many sensors now being used in Japan are simply being evaluated -- each vendor's sensor being tested and compared with the others, while some are being used in specific application studies. Mechanically-oriented applications are of more interest than electronic component insertion.

In Korea, Taiwan and Singapore force/torque sensing is also being studied in the research labs of universities and large companies. Research is being performed in the areas of contour-following, and mechanical and electronic assembly.

Conclusion

Force/torque sensor systems continue to evolve and find their place on the factory floor. Whatever trend factory automation follows, be it dedicated functionality or increased flexibility, force/torque sensing will always be advantageous in many applications. As long as quality and productivity demands continue to rise, and as long as these parameters depend so heavily on part contact processes, the application of force/torque sensing in automation will also continue to expand.

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