An ‘Intelligent’ Robot

In conventional automated assembly, a robot is used to pick up parts and assemble them under some pre-taught paths. Yet for tight-tolerance assemblies, slight position errors and disturbances will often hamper the reliability and quality of the operation. A possible advancement to such problem is to enhance the intelligence of the robot by introducing the sense of the environment in which the robot is operating, and to incorporate the power of evaluating the situation such that the best manoeuvre can be planned.

The project is aimed at enhancing the dexterity and the ability to recover from fault conditions of robots used in automatic assembly operations. Resulting force and torque information obtained while assembly parts make contacts with their environment. In particular, the research is focused onto the development of a framework for task-level intelligent assembly using an industrial robot to perform successful assembly tasks such as mating of work-pieces, with the ability to self-correct faults including misalignments and control errors.

Intelligent Assembly Frameworks

The available force/torque measurements obtained during an assembly operation are used to accurately detect and identify these contacts such that appropriate control actions can be issued. As the occurrence of part-contacts and the resulting force/torque measurements are considered to be stochastic processes, while successive part-contacts exhibit some degree of dependency, a task-level assembly process model is to be developed based on hidden Markov models (HMMs). In the context of detecting the change in contact scenarios, a simple rule-based scheme is applied to capture the discrete changes of force/torque information. This framework aims to allow real-time detection and analysis of part-contacts that facilitates an on-line scheme to achieve reliable tight-tolerance assembly even in the presence of disturbances and positional uncertainties.

An HMM-based assembly state recogniser. Multi-HMMs are used to represent different contact scenarios in an assembly operation. By matching the HMMs with the actual situation, a most probable contact scenario can be deduced.
Hidden Markov Models

A hidden Markov model (HMM) consists of a doubly stochastic process in which the Markov chain \( q_i \) is hidden and has to be observed via another stochastic process \( O_t \). Note that a Markov chain models a sequence of states, and that the outcome of a state is affected by the outcomes of the previous state.

Mathematically, an HMM can be defined as: 
\[
\lambda = (A, B, \pi)
\]
where 
- \( A \) is the transition matrix that specifies the probabilities of state transitions (e.g. from \( q_{t-1} \) to \( q_t \)),
- \( B \) is a matrix for storing all the probabilities of obtaining some output (e.g. \( O_t \)) at some state (e.g. \( q_t \)) at time \( t \), and
- \( \pi \) is the initial value of the HMM.

There are fundamentally three problems to tackle in modelling a real situation using HMM, and these are:
- Evaluation – to determine the probability of the observation sequence \( O_1 O_2 O_3 ... O_T \) given a HMM model.
- State Sequence Optimisation – to determine the corresponding state sequence \( q_1 q_2 q_3 ... q_T \) given an observation sequence and an HMM.
- Parameters Optimisation – to adjust the model parameters to maximise the performance of an HMM state recogniser.

The Research Programme

1. Theoretical study of using HMMs and defining strategies to obtain suitable model parameters.
2. Development of HMMs based on contact scenarios of representative assembly tasks and task-level demands.
4. Experimental study of the proposed intelligent assembly framework using the developed experimental system.
5. Evaluate and compare the performance of the framework using a set of representative assembly tasks.

The Experimental System Configuration

An experimental system that consists of:
- a Staubli RX130 six-axis articulated robot
- a force/torque measurement system, and
- a XYCOM Pentium processor and interface hardware
is configured to facilitate the implementation and experimental investigation of the proposed intelligent assembly framework. The sensor that is installed in the robot enables the accurate measurement of force/torque information while the robot is in contact with its environment. Together with Pentium processor that is integrated into the robot controller, this system is capable of performing high throughput computation that is required by the HMM-based system as well as satisfactory control of robot motions.

Achievement To Date

The project was initiated in December 1998. Major hardware for the project had been made available, procured where necessary, and set-up to the specification defined by the investigators in the Flexible Automation Laboratory in the Department. Currently, the robot, the force/torque measuring devices, and the special purpose processing hardware are being integrated to provide a suitable experimental platform.

Theoretical development of the framework for modelling tight-tolerance assembly operations is being undertaken. Initially, the theoretical background and current development of hidden Markov models is being studied by the investigators and the research students. A preliminary scheme for simulating the performance of HMM in relation to assembly is to be drawn up. Through this preliminary study, the fundamental parameters for the model can be determined.