MULTI SENSOR FLEXIBLE ASSEMBLY CELL

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Abstract. The use of multi-sensor based flexible assembly cells can increase substantially the scope of applications of manipulators in industry. This paper is concerned with the development of a general purpose assembly cell which can be used to evaluate the feasibility of automatic assembly of different products. The cell is built around a manipulator with six degrees of freedom, a conveyor belt and an assembly table. The sensorial system of the cell comprises real-time vision, gripper force and various detectors on the conveyor belt and assembly table. A simple and high performance distributed control structure enables the integration of redundant sensorial information and real-time path control.

Keywords. Flexible assembly cells, sensors, sensor integration, distributed parameter systems, vision systems, parallel processing.

INTRODUCTION

The use of multi-sensor robots allows the execution of automatic assembly tasks with a certain degree of complexity. The increased flexibility achieved with multi-sensor robots requires however the processing and the integration of substantial amount of sensorial data, which must be performed in real-time.

First implementations of robotic multi-sensor based systems were designed with “ad hoc” sensorial integration techniques. However, the increasing research work devoted to overcome this status produced a set of tools (Henderson, 1984; Nill, 1986) which helps the developing of structured multi-sensor systems.

This paper describes a general purpose flexible assembly cell, see Figure 1, which uses a simple and high performance distributed system for sensor data acquisition and actuation. The cell is built around a Unimation PUMA 560 robot, a conveyor belt, and an assembly table.

A number of sensors placed on the cell gather information about the environment and allow the main processor to carry out real-time path control. The sensorial system of the cell comprises real-time vision, gripper force and various detectors on the conveyor belt and assembly table. The information provided by the sensors is preprocessed by local control units, which transmit to the supervisor workstation high-level information through a high speed serial network. Based on this information and on the task to be performed, the central workstation sends the necessary commands to the robot control unit.

The vision system is based on a VMEbus host computer, a frame grabber and several image processing units. The frame grabber can receive images from up to four cameras with a resolution of 512x512 pixels and has a programmable pseudo-colour output. The image processing units, based on a very fast digital signal processor, carry out the feature extraction operations on the images obtained by the frame grabber. Several image processing units can be connected in a parallel-processor architecture if the time requirements dictate that need.

Fig. 1. Assembly cell block diagram.
The gripper has a force sensor using a thin-film strain gauge bridge. The control of the force of the gripper is implemented using a pneumatic servovalve, allowing continuous variation of the force applied to the objects. The conveyor belt has variable speed, a high resolution encoder, optical detectors and an electromagnetic brake. A table with pneumatic indexing is used for assembly of components. Pneumatic vices and fixing jigs with position sensors can be used for different assembly tasks.

COMMUNICATION NETWORK STRUCTURE

The communication network structure which is used to interconnect the supervisor unit and all the local control units, as it is shown in Figure 1, is based on a high speed serial data bus developed by INTEL and named Bitbus (Intel, 1984). This network was specified with the purpose of simplifying the design of distributed systems for local control (Williams, 1984; Welchow, 1984) and was optimized for fast transfers of small packets of information. Due to the characteristics already mentioned and due to its low implementation cost, it was chosen for the integration of all the cell subsystems.

In this application a bus topology with a hierarchical communication structure was used. The transfer of information between master/slave tasks is supported by three levels or protocol layers:

1. Physical link;
2. Data link;
3. Transaction protocol.

The physical medium consists of two pairs of twisted wires. The information is coded synchronously, circulating at a 2.4 M/s in half-duplex mode. The data link layer is used to implement a subset of the synchronous data-link-control (SDLC) protocol. In order to ensure the transparency in the exchange of information between tasks performed by different control units and the supervising unit, the overall architecture specifies a format message in the transaction level. This format message is the same which is used in the multi-tasking executive running in all the slave units and in the master module of network coupled to the supervisor. To achieve higher reliability, the communications are processed on an order/reply basis.

In some of the control units associated with sensor and actuators, the same executive also manages the local primitives used to perform the local intelligence (data acquisition and actuation). The flow of information in the serial network used to control the manipulator is translated by a control unit, which converts the commands issued by the supervisor to the Digital Data Communications Message Protocol (DDCMP). This protocol is required by the manipulator controller.

VISION SYSTEM

A vision system was developed for image processing in the fields of robotics and product inspection. Taking advantage of the flexibility of a programmable DSP processor and being built around an industrial standard bus, the system can be configured in a number of ways allowing a wide spectrum of applications. Working under the control of a host computer, the vision system, in its minimum configuration, is composed of two boards - a video acquisition display and transmission unit and an intelligent image processing unit - which are capable of handling images with 512x512 pixels with 256 grey levels per pixel.

The described architecture, including a general purpose digital signal processor in the image processing units, allows the construction of a SIMD structure suitable for this type of processing without compromising flexibility. On the other hand, the modular approach taken in the design of the system permits its adaptation to particular applications.

The Acquisition Display and Transmission Board

The video acquisition display and transmission board is a self-contained unit interfacing this system to standard black and white TV cameras using the CCIR norm and to conventional black and white or colour monitors. Up to four video inputs can be connected to the acquisition board which uses a flash 8-bit analog to digital converter to digitize the selected channel. This provides information associated with multiple views of the working cell. Before being stored in the memory, the digitized sample passes through a look-up table of 256 entries allowing simple processing, such as binarization of an image, in real time. Then display section of the board uses a conventional CRT controller and a colour look-up table which incorporates three 6-bit digital to analog converters to generate a RGB video signal with 256 colours from a palette of 256,144.

![Fig. 2. Block diagram of a VMBus based vision system. The analog video signal of one out of four TV cameras is converted into digital form by an acquisition board and is made available, through a video bus, to several processing boards. A VM host computer controls the operation of the whole system.](image-url)
structure since it carries the incoming camera picture in a usable form for the processing units.

**The Intelligent Image Processing Boards**

Each of the intelligent image processing boards used in the vision system consists of four parts: a video input module, a TMS32020 microprocessor (Texas Instruments), a local memory and a VMEbus interface. The video input module uses both the data and the addresses appearing on the video bus to place an image, or a part of it, in memory. Under the command of the host computer the video input module may be configured to acquire images of different sizes (windows) and different resolutions. In choosing a digital signal processor for this system, a special consideration was given to the capability of addressing a large range of external memory, as it is required in image processing. The 16-bit TMS32020 processor with its 200ns instruction cycle and its data address space of 64K words was chosen for this application. The intelligence of the board is only local and the DSP processor is totally controlled by the VME host computer. In fact all the memory of the DSP processor, both program memory and data or video memory, is RAM and appears in the address map of the host which, for example, may halt the DSP processor, download a program or a command, activate the reception of a picture through the video bus and return control to the DSP processor for execution of the command. The program memory of the TMS32020 can be as large as 64K words but only 32K words are used in this application. On the contrary all the data memory, 64K words as well, is used by the processor: the first 32K words are for general use and the second 32K words, or the top half of the data memory, are used for access to the video data.

This intelligent board can store and process a complete 8-bit 512x512 image, i.e. 256K pixels. This information is physically stored on eight 32K bytes RAM chips which may be accessed by three elements: the video bus, the VME host and the TMS32020. For the first two elements this video memory is organized as 128K words originating two pixels transfers per access. For the DSP processor it is organized as 256K bytes in eight pages of 32K bytes with only one of these pages being present at a time on the top half of the DSP memory referred to above. Note that when the TMS32020 addresses the video data on the top of the memory, it only finds 8-bit bytes in each location instead of the usual 16-bit word. This is adequate for pixel data. Another important aspect of the video memory organization refers to the arbitration between the three sources of access. The video bus has the highest priority, having the whole memory available during the total transfer of an image. The host computer has the responsibility of halting the DSP processor before making an access to the video memory, avoiding in this way any conflicts in the access to the shared memory. The VME interface module of the processing board permits the access to the video memory, the access to the TMS32020 program memory, the control of the video interface module and the control of a number of registers to operate the board.

**MANIPULATOR GRIPPER**

The manipulator is a general purpose machine (PAMA 560) with six degrees of freedom and pneumatic gripper. The gripper has a force sensor using a thin-film strain gauge bridge, which is deposited in vacuum over the element which is going to be deformed, as shown in Figure 3.

An object handled by the gripper causes the deformation of the strain gauge. The design of the finger in which is enclosed the strain gauge bridge prevents too much stress to be applied to the sensor. The signal from the strain gauge bridge is processed in a single integrated circuit which includes an instrumentation amplifier and a 10 bit analog to digital converter with a serial output (see Figure 4).

![Twe-Finger Gripper](image)

**Fig. 3. Gripper**

![Strain Gauge Bridge](image)

**Fig. 4 Strain gauge bridge acquisition**

The gripper is also equipped with an optical sensor to detect the presence of objects between the fingers. The sensor consists of a pair of an infrared LED and a photodiode installed near the bottom of the fingers (see Figure 3). The control of the forces of the gripper is implemented using a pneumatic pressure servovalve, allowing continuous variation of the force applied to the objects. The servovalve regulates the pressure is regulated with a pulse-width modulated waveform generated by the control unit. This unit receives the commands from the master unit through the BitBus and, with the information from the force and optical sensors, controls the servovalve.

**CONVEYOR BELT AND ASSEMBLY TABLE**

The conveyor belt has variable speed, a high resolution incremental encoder, miniature optical detectors and an electromagnetic brake. The conveyor has a light box to produce backlighting with objects placed on a translucent belt (see Figure 5). This facility is useful when dealing with objects presenting difficult recognition due to their low level of contrast with the belt.

The assembly table, placed by the side of the conveyor belt, is driven by a pneumatic indexing actuator. Fixed jigs and pneumatic vices can be placed on the top of the table to enable the assembly of miscellaneous objects. A local control unit is dedicated to supervise the operation of the conveyor belt and assembly table. This control unit interacts with the others parts of the cell receiving commands from the master unit through the BitBus.
SENSOR DATA INTEGRATION

The execution of an assembly task generally comprises three different phases including target search, movement between work positions and close-range manipulation. These phases are characterized by using different types of sensor information.

In the phase of target search the role of vision sensors is dominant. Vision information may be complemented by range sensors (such as ultrasonic or laser). With the information obtained with the vision system it is possible to identify roughly the positions of the parts to be assembled, and thus to carry out the planning of the next phase. The phase of movement between work positions consists in manipulator gross motions and the positioning of the conveyor and indexed table. In the close-range manipulation phase, it is performed the final approach to the parts to be handled including the accurate positioning and the actuation of the gripper. The sensors which play an important role in this phase are the proximity, tactile and force sensors.

The sensor information is preprocessed by dedicated local control units connected in a distributed structure. This structure enables the inclusion of additional sensors of the same type to achieve the degree of redundancy required.

The overall assembly cell control, which is under developing, is logically organized in three hierarchical structured levels: task level, action level and supervision level.

The task level makes the interface with the user, receiving high-level task descriptions and visualizing information related with the state of the cell, generates action plans and processes failure analysis. The action level manages the cell operations activating supervisor level procedures, sending commands and receiving sensing information and asynchronous events. The low level is composed by a set of environment dependent procedures which handle, through the local control units, the cell actuators and sensors.

CONCLUSION

A flexible assembly cell equipped with a significant amount of sensing and an efficient control and communications structure is under developing. This structure can be used to evaluate the feasibility of automatic assembly of different products. Future planned enhancements include the use of ultrasonic sensors for collision avoidance, the use of a wrist sensor and the use of a miniature camera in the gripper to allow operation with lower performance manipulators as well as the assembly of parts with tighter visual feedback.

REFERENCES