Developing of Vibration Sensors As Event Signature Sensors In Assembly

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Abstract

In an assembly task, which involves moving and fitting parts, one of the most important kinds of information for a robot is event signatures – information about something happening or changing. This paper describes two types of inexpensive event signature sensors for assembly robots, using piezo electric PVDF film. One type of sensor developed detects the change of force on the contact surface of the robot finger and the other type detects sound occurring during an assembly. These sensors have been used dynamically in an assembly task performed by an Adept1 robot, demonstrating the suitability for assembly tasks.

Key words : robot assembly, event signature sensor

1 Introduction

In order for a robot to interact reliably and flexibly in an uncertain world, suitable sensors are required. In an assembly task, which involves moving and fitting parts, one of the most important kinds of information is event signatures – information about something happening or changing. Although many sophisticated sensors are available, suitable ones for assembly tasks are scarce, or require intensive computation. In this work, two kinds of event signature sensors were developed using piezo electric PVDF (polyvinylidene fluoride) films. As event signature sensors, these sensors can be substituted for vision systems, conventional force/torque sensors, and tactile sensors.

The event signature sensors developed are **Clunk sensors** and **Force sensors** [3]. The Clunk sensors respond to the audible sound generated by contact in an assembly task, such as when the gripped part touches other objects. The Force sensors respond to the change of force applied to the sensor, rather than measuring the absolute level. The output of the Force sensor is proportional to the rate of change of deformation of the sensor body. This is used to stop the robot (guarded motion) when the gripped part touches another object by detecting the change in force applied to the surface of the fingers. They are also used to explore the location and orientation of objects. These sensors were used in an assembly task performed by an Adept1 robot, to demonstrate their suitability for assembly tasks. We explain how they simplify the information processing.

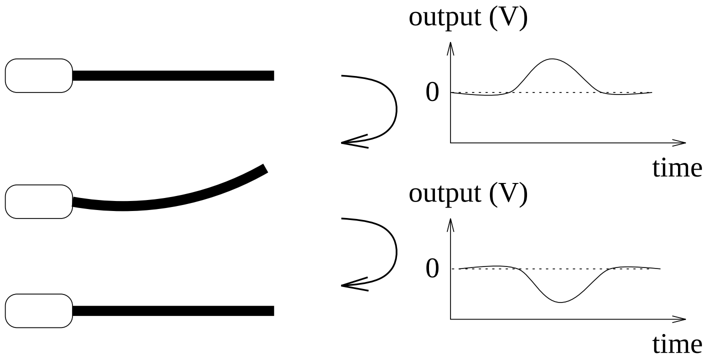


Figure 1: Bending experiment of the film

2 Sensor Development

A PVDF film [1] develops an electric signal according to the mechanical strain applied, thus it can be used to pick up vibrations (from less than 10 Hz to ultrasonic). The Clunk sensor developed uses a PVDF film as a microphone, and the Force sensor exploits the characteristic (see Figure 1) of the film where the output is proportional to the rate of change of bending (global deformation), which is at a comparatively low frequency (usually less than 30 Hz depending on the speed of bending). We used 40 by 15 mm wide 28μm thick films and in order to detect low frequency signals, a high input resistance $\approx 10\text{M}\Omega$ is used. (otherwise normally $1\text{M}\Omega$ is used).

The Development of the Clunk Sensor

Basically, the Clunk sensors exploit the acoustic vibration generated by parts contacting in a robot work space during assembly. Even if the air-borne sound is weak, the sound propagated through the robot working table or through the robot gripper may be strong enough to provide useful information. We developed two variations: the Table sensor and the Noise cancelling sensor. These were then combined into one virtual sensor, the Clunk sensor.

An RTX robot with two different kinds of work table (15 mm thick wooden and 4 mm thick metal) and an Adept1 robot with a massive metal surface table were used for experiments. The experiments focussed on aspects of the characteristics of the PVDF films, vibration properties of the robot working tables, the noise from the robots, and the signal patterns. Power spectral density analysis and filtering simulation using the software package Pro-Matlab [5] were employed.

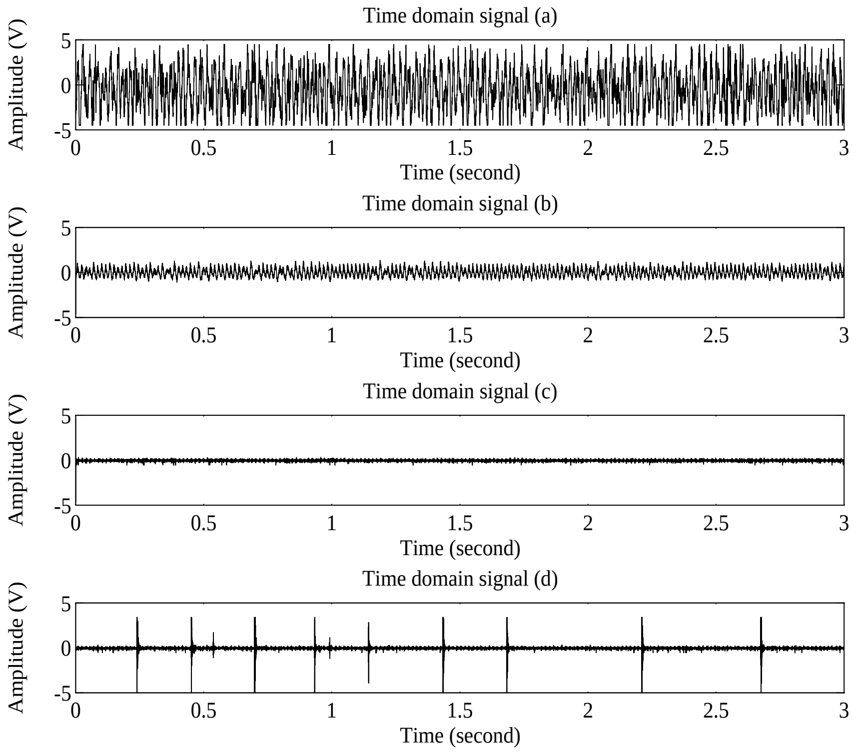
PVDF films were affixed to the robot working table. Noise from the environment and from the working robot was sampled and carefully analysed. In our laboratory, the RTX robot sits on its working table, while the Adept1 robot stands beside its working table. Since the RTX robot sits on the table, an extra plate with acoustic buffering material underneath is required due to the strong mechanical noise that propagates directly from the robot. As a buffering material, squash balls were used which proved to be very effective, attenuating 6/7 of the noise. However, the noise was still so significant in contrast to the signal that it then had to be filtered electronically. The dominant frequency of the noise from an RTX robot is near 120 Hz. A 4^{th} order Butterworth high pass filter with a 200 Hz cutoff frequency was used to attenuate the noise further, while preserving most of the useful information. A simple acoustic amplifier with a gain of 600 was built using CMOS op–amps of high input impedance. There was no significant difference between the wooden table and the metal table as an RTX working table. However, the metal table is more springy than the wooden table, which results in the vibration remaining long after an impact. Hence, the metal table needs more damping. For both kinds of table, the sound (clunk) from dropping a piece of thin soldering wire (1 cm long) from 2 mm above the table can be detected.

In the case of the Adept1 robot, (under our laboratory conditions), although the robot is mechanically separated from the working table, the electrical noise induced by the robot in the sensor circuitry is so strong and of such high frequency that a high pass filter with a much higher cutoff frequency had to be used to block the noise sufficiently. 1500 Hz was used as the cutoff frequency with 5000 as the amplifier gain. Due to this significant electrical noise, sound generated from dropping a 25 mm metal cube from 5 mm high can be detected, but smaller objects could not. This still was enough for a useful event signature sensor. A method of reducing this noise is being investigated.

We call these **Table sensors**.

Because the table sensor transducer is attached to the table one problem with them is that they become less sensitive as the the distance between the table and the site of the event (clunk sound) becomes greater. The virtual Clunk sensor solved this kind of problem, by incorporating an additional sensing element in the gripper.

In the gripper the robot's mechanical noise affects the sensor directly. Buffering materials, such as sponge or cloth, are not very effective in blocking noise, because the robot will compress them when it grips the object firmly. A noise cancelling method was used to reduce the noise instead. Two PVDF



(a) shows the noise from the shoulder of the RTX robot sampled from one film. By subtracting the output from a sensor at the finger, the noise is reduced by approximately 1/4, as shown in (b). This is further filtered by a 4^{th} order Butterworth high pass filter which resulted in (c). The signal (d) is the result of subtracting and filtering of the signal from soft tapping of gripped parts without noise. The impulse-like signal is much stronger than the noise in (c).

Figure 2: The effectiveness of the Noise cancelling sensor

films were placed on the surface of a robot finger with stiff plastic sponge as a compliant material between them. The film which is closer to the robot finger detects more noise and less signal than the other which is farther from the finger surface and closer to the gripped object. Signals from both films were tuned for optimal cancellation and subtracted using a differential amplifier. The effectiveness of cancelling noise is displayed in Figure 2. The noise was reduced by more than 3/4.

This sensor is called a **Noise cancelling sensor**. The output from both the Table sensor and the Noise cancelling sensor were summed, forming a virtual sensor called a **Clunk sensor**.

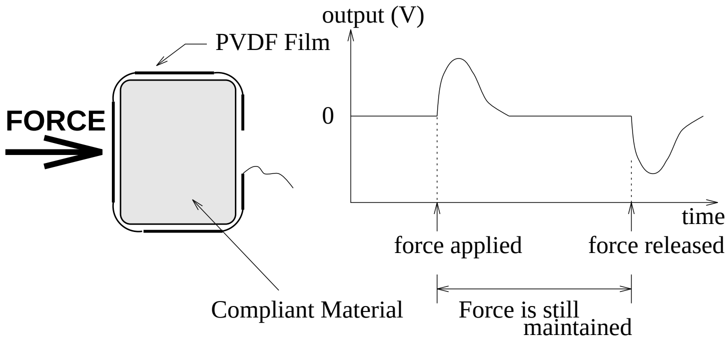


Figure 3: An example of Force sensor and its output

The Development of the Force sensor

An interesting low frequency characteristic of PVDF film was exploited. A PVDF film was wrapped around some compliant material (sponge), the signal amplified 80 times, and filtered by a simple RC low pass filter with a cutoff frequency of 1.6 Hz (R = 100KΩ, C = 1μF). The output is proportional to the rate of change of force applied to the sensor. In Figure 3 an example of the Force sensor and the output is shown. This is basically a force sensor, because it provides an output proportional to the force change applied to the sensor body.

One Force sensor was mounted on an outer surface of a robot finger and used as a touch sensor to find the location of a part. This was named a **Bump sensor**. Another Force sensor was affixed to the inner surface of the finger and contacts gripped objects. This was named a **Push sensor**. Rubber was used as the compliant material for the Push sensor, which can still maintain useful compliance under the gripping force of the robot. The Push sensor is sensitive to a bump applied to the gripped part. It is so sensitive that part contact occurring at the speed of 0.5 mm/sec can be detected. Also, it is very insensitive to any kind of noise since only low frequency variation (less than 10 Hz approximately) is considered.

To date, the outputs from the Force sensors are thresholded, making them binary touch sensors. We are investigating the use of analogue information from them, and using more than one Push sensor, for example to detect the direction of an applied force.

These four variations of two kinds of sensors were used with an Adept1 robot. The table sensor was affixed to the working table and the others were mounted on both the robot fingers. On the contact surface, two pieces of fibrous pot scourer were used to provide higher friction and at the same time to detect slipping of the gripped object, by producing sound. The sensor

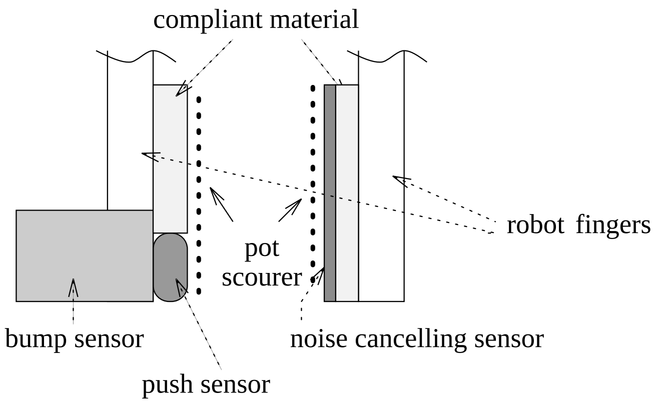


Figure 4: The designed fingers and sensors on them

mounted finger is drawn in Figure 4.

In summary, the sensors developed are described briefly below:

- **Clunk Sensors:** This kind of sensor detects sound generated when the gripped part touches another part or the table. Two sensors of this kind were developed:
  - **Table sensor:** A PVDF film is affixed to the working table as a microphone, so that it detects sound propagated through the working table.
  - **Noise cancelling sensor:** Two PVDF films are fixed to the gripper, one detecting the noise from the robot while the other detects both noise and signal propagated through the gripper. The outputs from the films are subtracted, so that a clearer signal can be detected.
- **Force sensors:** This kind of sensor exploits the low frequency characteristics of the PVDF films. Films are wrapped onto compliant materials, and detect the change in shape (deformation) of the sensor body. Hence, they detect force changes applied to the sensor body. Sensors of this kind are:
  - **Push sensor:** A Push sensor detects the change of force applied to the gripping surface of the finger. Hence, it detects when the gripped part touches other objects.
  - **Bump sensor:** A Bump sensor is mounted on an outer surface of the finger, and is used for exploring the location of the objects. When this sensor touches something, it signals the event.

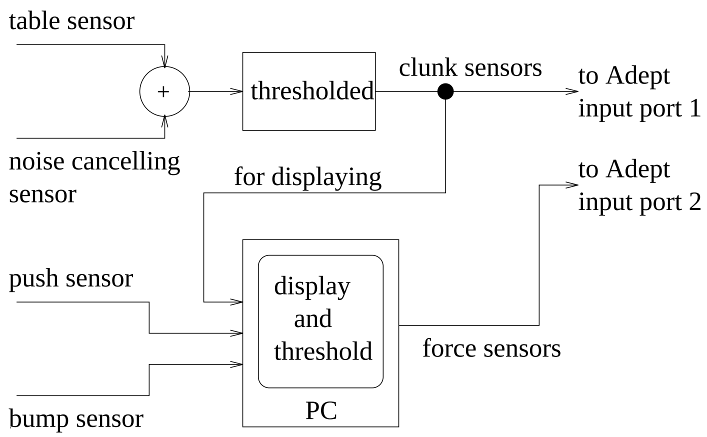


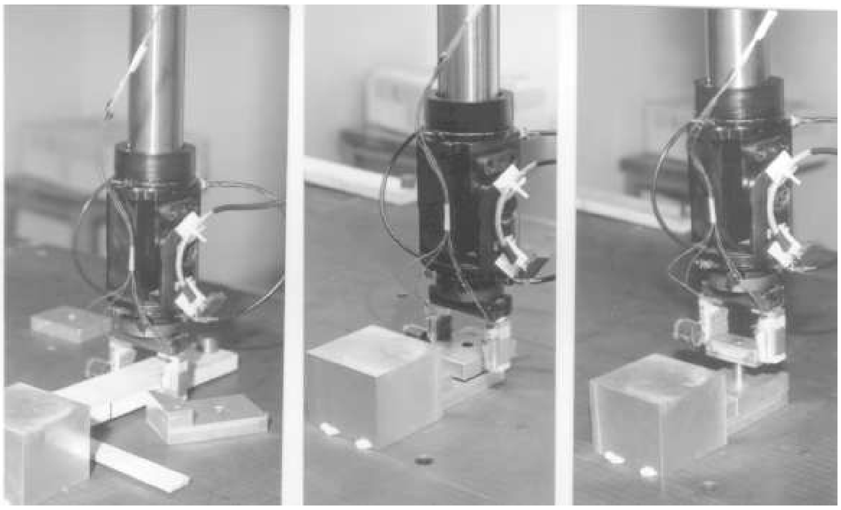
Figure 5: Interconnections of sensors and Adept1 robot

3 Application to an Assembly task

Two sensor input ports of the Adept1 robot are used. One, the Clunk sensor, is connected to the output of the summed Table and Noise cancelling sensors thresholded by a Schmitt trigger, and the other is connected to the signal, thresholded by a PC, which represents two force sensors. The output of the Clunk sensor is connected to the PC only for displaying the status of the sensor. The interconnections between the sensors and the Adept1 robot are illustrated in Figure 5.

Some robot assembly problems with at least 1 cm uncertainty on part location were tried. Tasks such as measuring the part size, locating parts, moving parts, fitting parts side-by-side (horizontal placing), putting parts down (vertical placing), and peg-in-hole were performed, since these arise frequently in a real assembly tasks. Hence the applicability of the sensors to real assembly tasks was established. Some pictures taken while the robot performs an assembly are displayed in Figure 6.

The robot program was written in a modularised and generalised manner according to what we call the **Behaviour–Based Approach** to assembly [6] [4]. Each module represents a purposeful behaviour in the assembly task, incorporating the sensory information within itself. Hence, they are relatively independent of one another and can be used for other purposes as well, with minor modification. This kind of re-use makes for convenience and simplicity in programming new tasks, and the incorporation of sensing in most part movements makes for robust programs.



(a) (b) (c)

(a) The Adept1 robot locates a part using a sweeping tool under control of the signal from the contact of the tool and the part. Also, using the sweeping tool, part size and shape can be recognised by probing action. (b) The robot assembles a part onto another with the ambiguity of the height – guarded motion. (c) an example of peg–in–hole. The robot explores the end of hole.

Figure 6: Pictures taken during the benchmark assembly

4 Conclusion and Future Work

The event signature sensors developed have proved to be robust, sensitive, and economical sensors which significantly contribute to enhancing the performance of a robot under uncertainties in dimension. For instance, achieving guarded motions has previously been expensive, *e.g.* using vision or conventional force/torque sensors used in guarded motion. These event signature sensors enabled the robot to locate the parts, measure the part size, and know when the gripped part contacted the assembly. These competences are important for assembly robots, since given these abilities, many assembly problems can be solved. Apart from these general uses, the flexibility in design of these sensors will easily permit a wide variety of applications.

The Clunk sensors are prone to both electrical and acoustic noise. They are easily used where relatively large size and heavy parts generate large signals. If the environment can be carefully adjusted, so that less filtering is necessary, the Clunk sensors can be much more sensitive and informative. By employing extensive signal processing, they can be used for discriminating parts according to the kinds of material they are made of. Also, the Clunk sensors could be used to monitor an assembly, notifying an erroneous assembly where the clunk pattern of the assembly differs significantly from one recorded during a good assembly which represents a regular and repetitive assembly pattern.

The Force sensors are very robust to noise and relatively easy to build. They can discriminate the direction of force applied. With a view to maintaining this desirable cheapness and simplicity we are investigating the use of limited discrimination combined with context to provide more detailed information, in the tradition of dynamic sensing as described by Beni and Hackwood [2].

At the moment, further research is being conducted on both improving the performance of the sensors and investigating methods and system architectures with which to apply these sensors to assembly tasks under the aegis of the Behaviour–Based Approach to robotic assembly, [6] [4].

In summary, this PVDF film has allowed us to construct cheap reliable sensors which can be adapted to sense a variety of the conditions attending part mating: noise, force change, clunk, touch. Combining them into virtual sensors to more reliably note specific kinds of event has proved very helpful. There is considerable scope for further development, which we are pursuing.

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