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ROBOTIC HARDNESS EVALUATION FOR NATURAL MATERIALS

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A b s t r a c t. The automated processing of natural products demands advanced sensing capabilities combined with well tuned responses. Many processes often require textural and positional information. In handling applications and in situations where guidance of a tool is required softness of the object plays an important role.

This presentation reports on the development of a prototype sensor for hardness estimation. A relatively simple concept has been employed to probe the material. Measurements of a wide range of natural and flexible objects directed the design of the sensing head. The concept involves a dual tactile probe with selectable compliance to cover different ranges of hardness.

Initial trials with a stationary sensor showed encouraging results. The sensor system has been mounted onto an industrial robot to examine continuous measurements during motion. The sensor data are fed back to the motion controller to guide the robot over a soft surface with a pre-selectable constant force. Experiments were conducted on flat and curved test beds with a variety of rubber-based materials. The results obtained showed good potential for force-controlled contour following applications.

The major advantage of the sensing system is the capability to continuously identify the hardness range of an object as a function of the current position. Future developments are focusing on miniaturisation of the prototype sensor for 'real-world' applications and automatic orthogonal orientation of the sensor.

K e y w o r d s: robotic evaluation, natural materials, hardness

INTRODUCTION

Traditionally, robotic automation has been applied to artificial and rigid objects mainly in the manufacturing industry. The development of advanced sensing capabilities and motion control capabilities made the advancement of more complex operations possible. The increasing demand for automated processing of natural products including meat, fish and agricultural products prompted the development of methods to cope with the variation inherent to natural products. Soft objects with their variance are difficult to handle and require advanced sensing and motion capabilities particularly where the guidance of a tool is required.

Processing of soft objects is a challenging task because of their individualism and deformability. These properties require adaptive control mechanisms with sensors to detect any deviations from preprogrammed motions. For example processes with a constant force requirement as in cutting operations require some form of positional information (e.g., distance) to cope with the position changes of deformable objects. These contour following operations have been in use in manufacturing applications such as welding and deburring [1].

Examples of novel applications in processing of natural products include the deboning of beef forequarter and foreleg [2] and the automated sheep shearing [3]. The deboning process involves a force feedback technique to follow the contour of the bone and to enable a cut close to the bone. Touch sensors maintain the contact with the meat surface. In the sheep shearing project a combination of contact and non-contact sensing has been applied to track the body of the clamped sheep during the shearing process. Resistance sensing was used detect penetration of the skin by the comb and capacitive sensing was employed to keep the cutter at a predetermined constant distance. In other processing situations such as sheep dressing the hardness of the product is of prime importance to avoid wastage of prime product by cutting too deep.

This requirement prompted the development of a sensing device capable of distinguishing hard and soft parts. In order to gain an understanding of the hardness ranges involved in natural products a comprehensive testing cycle with artificial and natural products was conducted using an INSTRON testing machine as a reference. For sensor feasibility trials artificial soft materials have been used in order to keep the same condition for the various experiments.

SENSOR PRINCIPLE

Hardness or firmness can be evaluated by the rate of applied force over the rate of deformation. For simplicity an uniform material with a spring-like behaviour is assumed. Exerting a force onto a soft material will depress the material to an extend corresponding to its hardness. Assuming linearity the material can be described as:

$$f = k_m x_m \tag{1}$$

whereby f - force, k_m - material constant, x_m - material displacement.

Using a spring probe to apply a force causes two displacements x_1 (spring depression) and x_{m1} (material depression) with the equal force, so that:

$$k_1 x_1 = k_m x_m \tag{2}$$

Similar for the second probe using k_2, x_2, k_m and x_{m2}.

It can be shown that:

$$k_m = \frac{k_2 x_2 - k_1 x_1}{x_1 - x_2} \tag{3}$$

The material (spring) constant is therefore equal to the force difference over the displacement difference. Consequently if the spring constants of the probes are known then the spring constant or firmness of the material can be evaluated from the differences of the measured probe displacements. Assuming linear material behaviour the firmness can then be measured by positioning the probe only once with a predetermined force. The force value should ideally be independent of the object hardness but within practical limits of the particular material.

A prototype sensor has been constructed with rounded tip probes. The appropriate selection of springs, spring constants (Fig. 1) and ratios ensures a medium measurement range of 30 to 70 Shore A hardness. The probes, springs, and transducers are housed in an aluminium casing which is fixed to a robot arm. The robot arm moves the sensor to a pre-programmed position probing the object. A calibration procedure ensures mechanical alignment of the tips, appropriate adjustment of conversion factors and offset values (Fig. 2), and taking other parameters into account including a zero reference and spring pre-compression rates.

Initial trials using artificial, agricultural and meat products have resulted in a reasonably

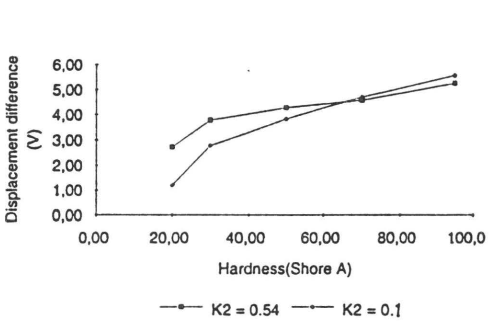

Fig. 1. Compliance calibration.

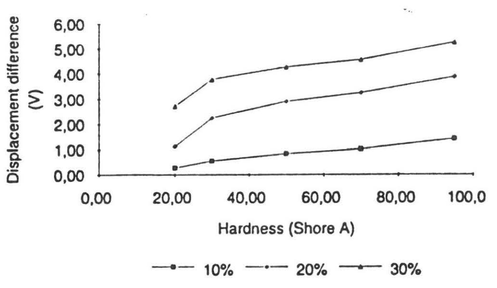

Fig. 2. Hardness calibration.

realistic list of hardness. Figure 3 shows the results of artificial materials, Fig. 4 refers to agricultural products and Fig. 5 deals with results of meat products.

CONTOUR FOLLOWING TESTS AND RESULTS

The concept of discrete and stationary probing has been extended to continuous testing with a moving probe. In the stationary case the probing position can be pre-programmed and deviations related to physical

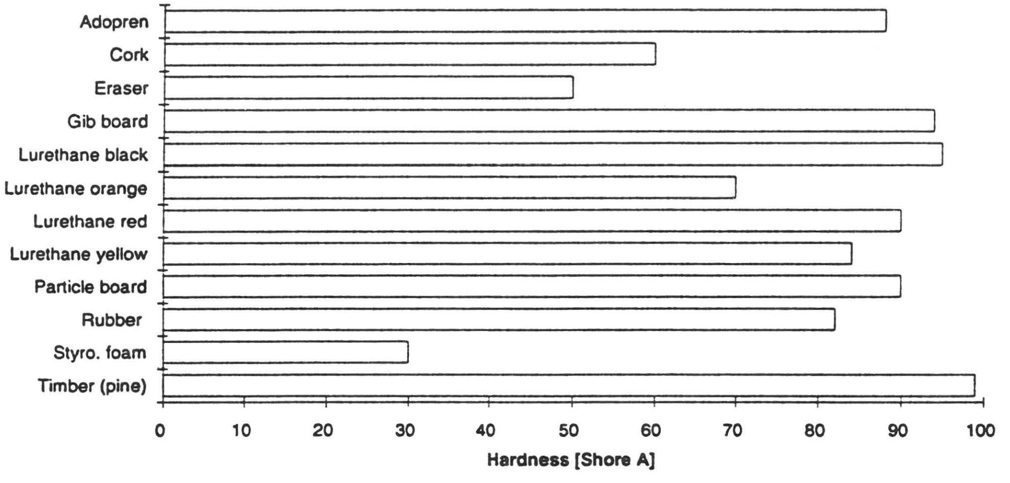

Fig. 3. Hardness of artificial products.

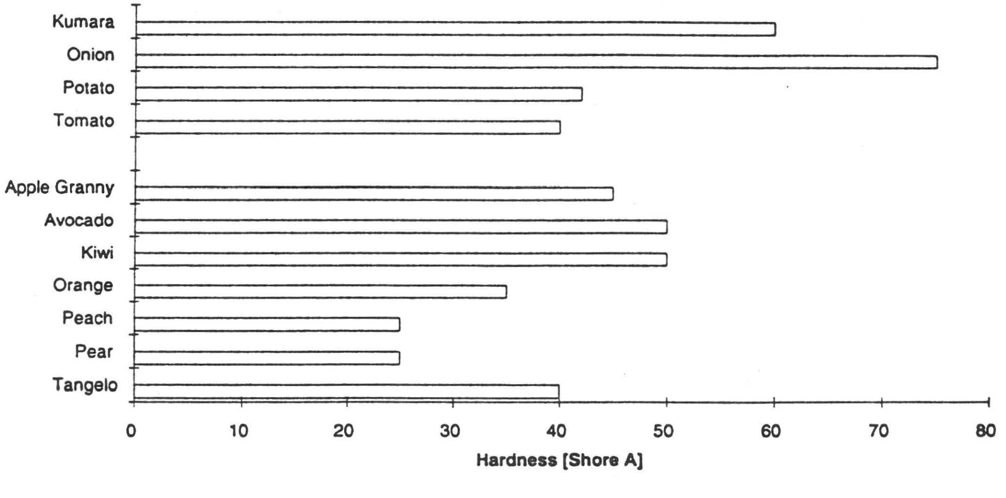

Fig. 4. Hardness of agricultural products.

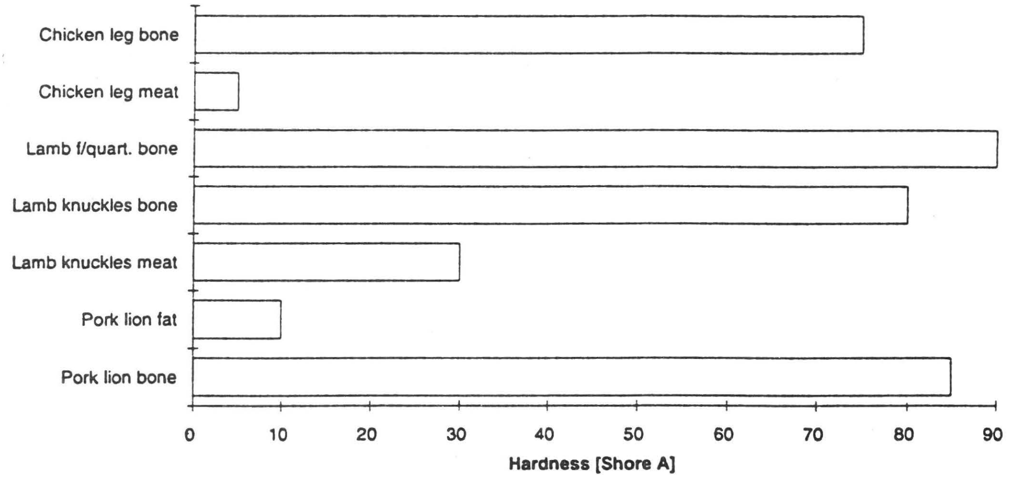

Fig. 5. Hardness of meat products.

variations of the object are not significant due to the assumption of firmness linearity. In the case of a continuous motion however the contact of the sensor with the object has to be ensured within a useful force range. In order to maintain a given force during motion one of the transducer signals can be employed as feedback signal to the robot controller. In such a way contour tracing can be realised with some inherent limitations in respect to accuracy and tracing velocity. Selecting a signal reference determines the amount of force applied to the object during contouring. This feedback signal then regulates the current path so that the machinery is able to deviate from its pre-programmed path.

An industrial robot (ASEA 2000) was used to test three different rubber-based materials on a level test bed. Trials with materials in the hardness ranges of 30, 50 and 70 Shore A hardness showed encouraging results and confirmed the basic suitability of this approach. The material has been lubricated to keep friction factors to a minimum. For simplicity reasons no compensation was made for changes of the probe area under pressure during motion in the trials.

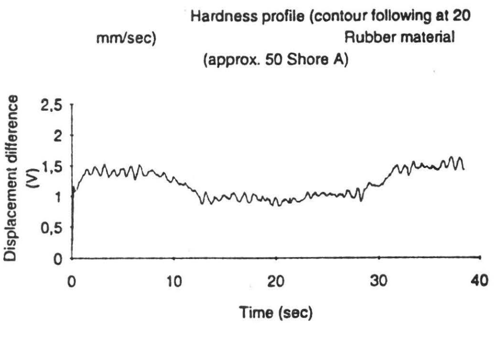

Fig. 6. Continuous hardness measurement at 20 mm/s.

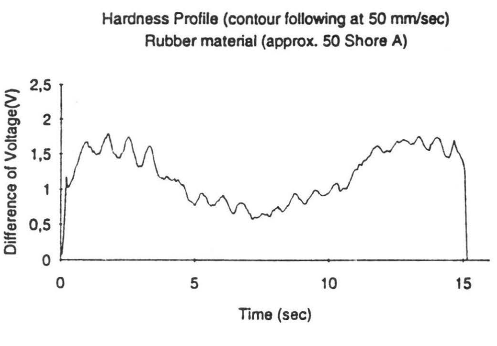

Fig. 7. Continuous hardness measurement at 50 mm/s.

In the second stage a curved test bed shaped similar to sine wave has been constructed. The results of a medium hard rubber material (approx 50 Shore A) using two different velocities of 20 mm/s and 50 mm/s are shown in Figs 4 and 5, respectively. An oscillation overlaying the hardness signal of approximately one Hz is suggested to be caused by the servo algorithm. The limitations of the system to follow a contour at higher velocities is produced by a large time constant in the servo control system.

CONCLUSIONS

In summary, a prototype sensor to evaluate hardness of natural object was introduced. Stationary tests on artificial and natural products showed encouraging results. As an extension the sensor was successfully employed to continuously measure hardness. An industrial robot utilised the sensor signal as feedback to follow the contour of an object along a coarsely defined path.

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