Sensors for automated cutting machines.

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INTRODUCTION

The objective of the work presented here is to perform fundamental research into design and use of intelligent sensors for meat cutting robots. The overwhelming need for robotics and automation research for the food industry make this extremely desirable.

In preliminary studies carried out at I.N.R.A. Station de Recherches sur la Viande, we have established that sensors are required to provide information about the process and the surrounding environment during the robot task [1]. Global positioning and path driving of the robot can be performed by a modellisation from a conformation data base (carcass geometry and surface characteristics) adjusted with parameters derived mainly from a vision system; local information has to be provided by sensors to adjust the movements of the tools along the previously defined path.

The first described sensor is a microwave multi-sensor included on a specific blade.

We used the sensors in two methods: a measurement on each side of the knife to obtain the lateral information, and from the both sides to obtain the axial information.

The second described sensor has been developed in order to stop an electric saw during rib cage cutting when the desired number of cut ribs is reached. The method consists of acquiring and processing the feeding current of the asynchronous engine which drives the saw.

A microwave multi-sensor for interface tissue tracking and bone detection.

The main purposes of this study are:

* to know the nature of surrounding tissues in "real time".

* to carry out real time cutting operation, for a local movement control or to provide warning information to stop the machine. * to control a process by giving characteristics during the process.

The sensor must provide information both in the cutting axis and on each side of the blade. The lateral information coming from tissues surrounding the blade is necessary to follow meaVfat and meaVbone interfaces. The axial information is needed to avoid a collision with a bone during cutting movements. Furthermore, the sensor integrated in the tool must be sufficiently for a non - thickening of the blade.

A number of antenna have been investigated: open ended coaxial lines, microstrip patch antennas and microslot antennas.[2][3]

The required radiation field, the surface evenness of the tool and the limited thickness of the sensor require a coplanar antenna with an adapted geometry. The coplanar structure is chosen preferably to the coaxial structure because it integrates a more important scattered volume. Indeed, coaxial guides studied (UT47) take into account only a small volume (that can be assimilated to a 2mm radius half sphere) facing the heterogeneous micro structure of biological tissues.

An original antenna geometry has been developed in order to respond to the double criterion axial and lateral detection. Such a microslot antenna is implanted on both sides of the blade. Each antenna detects the nature of tissues with which it is in contact. Furthermore, by coupling the two antennas situated back to back on the blade, the presence of a close bone in front of the blade during the tool displacement can be detected. A number of probe configurations have been investigated and the basic probe configuration which has been used most, extensively is schematically illustrated in Fig.1 The fields scattered needed for the detection impose constraints on:

· dimensions and geometry layout: electromagnetic waves in the microwave domain are linked to the geometry and to dimensions of scattering element.

· the nature of the metal-clad and substrates: the design of microwave circuits requires the kind of substrates and metal knowledge. Dielectric characteristics both of the substrate and feeder have an essential influence on theantenna performance.The thickness of metal must be constant and this thickness integrated in the antenna layout parameters. In order to obtain edges with perfectly definited tracks, we have undertaken a mechanical engraving of the slots.

Various attempts were made to match the sensors to a 50Q impedance while they were submerged in the phantom material. The first prototypes had dimensionsslightly too important for the envisaged application. In order to reach a more elaborate miniaturization the necessary solution is to increase the frequency and to change the nature of the substrates. An increase of the frequency would decrease the depth of detection, the wave length being linked to the depth of penetration. Calculations and line adaptation, splits and geometry layout of the antenna have been realised thanks to dedicated softwares. SERENADE and SUPER COMPACT from Compact-Software were used to undertake the electrical drawing and the behaviour simulation of designed circuit facing impedance adaptation problem. All these softwares were designed to make calculations for free space antennas. As we work in lossy material with average relative permittivity near 50, the velocity of propagation and the wavelength is reduced by $\sqrt{50}$. The antenna was designed to work in a frequency band from 2 to 4GHz, thus we applied all the calculations for a sensor reduced to the size of an antenna operating in free space from 14 to 28GHz. An electromagnetic simulation has been realised with EXPLORER in order to determine the radiation lobe of the coupled probe antennae. Performances of our multisensor system have been measured on a laboratory stand with phantom materials. We used gelatine with different water content as a lossy host medium and a shaped part of bone as buried target. Measurements of the reflection coefficient have been performedusing one or two antennas, as illustrated in Fig.3, simply by measuring the power amplitude of the reflected and transmitted signals. The incident power (P') is partly reflected (Pr) and partly dissipated so that $Pr = I \Gamma I^2 P_i$ where Γ is the reflection coefficient

Measurements were compared with reflected signal (Sii) made by an HP 8753c network analyser over the frequency range centred around the antenna resonance.

Results obtained from the experiments agree with the precision required in terms of depth detection and beaming. A bone can be detected at a distance of 3mm in front of the blade, and at a distance of 5mm on both sides of the blade.

A sensor to control rib cutting

Within the European Eureka project EU 1032:"ABCD", INRA, Durand International and INTERBEV study industrial prototypes to separate automatically a beef side into forequarter and hindquarter. This project results from previous projects lead by INRA [1], with the cooperation of ADIV and CEMAGREF, and aimed at proving the feasibility of robotized cutting of a beef forequarter. On this prototype, the cutting path (Figure 4) is achieved by a special tool designed around a rotating saw handled by a robot. The saw is used to cut the ribs and another part of the special tool is used to cut the meat. It is really complex to perfomm this action as the incidence of biological variability is | tremendous. We have made some trials by using home-made morphometric models linked to anatomic parameters, but the only way to solve this problem seems to require a feedback A/ -control from parameters coming from the tool Itself. During forequarter and hindquarter splitting it is necessary to stop the movement of the cutting saw when the desired number of ribs is reached. To achieve this, we tried to use video image analysis but all ribs cannot be detected on each carcass because of the presence of blood, fat, etc Therefore it is judicious to use a signal directly linked to the saw, like sound frequency variations, vibrations or amplitude variations of the feeding current of the saw. The sound frequency variations due to the cut seem to be a signal from which we easily extract the rib position but it is very dependent on the surrounding installations, especially in a very noisy place like an abattoir. The vibrations of the saw can also be used rib it is necessary to adapt specific sensors on the equipment. As the current is very easy to obtain, even on an industrial equipment, we have chosen this signal. Moreover, it is not dependent on the surrounding equipment contrary to the sound signal. This signal is directly proportional to the torque of the asynchronous saw engine. An increasing amplitude represents the cutting of a rib while the meat in an inter rib space. But this signal is very noisy and must be significantly processed. Our first approach to check the feasibility of a rib detector consisted in designing an analog prototype. This gave promising results but it quickly reached its limits, as it was necessary to perform some manual adjustments. So we decided to investigate the possibilities of a digital signal processing. We evaluated a low cost DSP solution and developed a software mainly based on the analog solution previously tested [4].

Three block functions were realised:

· The first one was an A.M. demodulation

· The second one was a threshold which extracted the parts of the signal containing cut ribs

· The third one was a rib detector using two sliding windows and comparators.

Figure 6 illustrates the results after each step of the process.

The whole system (hardware and software) gave such interesting results that we chose to design a stand alone single board.

Board design

The aim was to build a single size board with classical tools for a small laboratory.

This single side board, with two layers, has two main advantages:

· Its design allows an evolution of the final system. Indeed, the EPROM allows to change easily the software on the board. So, if another detection method is chosen (for example a sound detection), the hardware will remain functional because of its general purpose.

· The memory capacity obtained with the RAM allows the use of more powerful algorithms.

Moreover, the system is easy to use and to connect to the cutting device.

The power supply and the current sensor stand on a separate card to avoid EMC problems.

Overview .

The software developed was based upon the analog system previously designed.

We decided to use FIR (Finite Impulse Response) filters instead of IIR mainly because they stable [6], even on a fixed-point device. The block diagram in Figure 7 presents the demodulator.

The software detects this signal, taking the absolute value and rejects the 100 Hz carrier using the 20 taps notch filter. We tested the 256 taps lowpass filter thoroughly with a trial and error process in order to kill glitches and noise, and to allow the rib waveform to go through the demodulator. A Kaiser window detector provides excellent results and fc=2. 1 Hz. The 121 taps FIR (fO=50 Hz) filters the incoming electric saw amplitude-modulated A new kind of model has been developed under Matlab and then translated into TMS320C26 assembly language. The directions we have investigated are:

· a rib shape waveform-based detector

· a memory-based method storing parameters of the previous rib

· a probability function for rib prediction .

The model saves into RAM the shape of the last rib. The last function indicates if a rib is likely to come away or not. We found that a single method does not produce accurate results. This is the reason why the final algorithm takes into account the three methods.

Results and discussion.

The software provided very good results and a very accurate time localization of the ribs.

The upper window is a typical electric saw current. The lower window shows the processed signal at the input of the rib detector (smooth curve) and the pulses generated by the rib detector when a rib is found. The simulation (Figure 8) and the DSP implementations produce the same results.

Moreover, There are already ways to improve this system. The algorithm will store all the samples of the intensity signal. Thus it will be able to process the data twice:

· once in real time, as described above

· the second time after the fourth or fifth rib. This will allow to validate the results of the detection algorithm, making use of the complete shape of the rib instead of the beginning of the shape.

Another research area is wavelet processing of the incoming data [71. Some experiments conducted under Matlab proved that waveless are more powerful for the rib signal than classical digital filtering (this is due to the time-frequency description of the signal).

CONCLUSION

Information is needed for local real time driving of cutting devices by robots in automatic meat cutting processes. We have presented, in this paper, a multi-sensor system to provide information both in the cutting axis and on each side of a blade. This multi sensor system is able to send parameters to adjust tool movements along the previously defined path and avoid collisions.

An automatic system to control the cutting of ribs during a boning process of bovine carcasses discussed in this paper was developed in a five months engineer training period. This system is based on the real time analysis of the feeding current of a rotative electric saw. Our choice of the DSP to carry out this operation is focused on the TMS320C26. A versatile single size board has been designed. Discussion was done on the use of FIR filters instead of IIR filters, and openings with waveless processing. Such improvements will be carried out using a stronger assembler and perhaps a floating-point device.

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