Implementing the TMS320C26 DSP as a Rib Counter

Authors: R. Normand, L. Cordesses, P. Tournayre, J.L. Damez

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CONTACT INFORMATION

US TMS320 HOTLINE	(281) 274-2320
US TMS320 FAX	(281) 274-2324
US TMS320 BBS	(281) 274-2323
US TMS320 email	dsph@ti.com

Contents

Figures

Implementing the TMS320C26 DSP as a Rib Counter

Abstract

This application report describes the development of an automated system to control the cutting of ribs during the boning process of bovine carcasses using the Texas Instruments (TI™) TMS320C26 digital signal processor (DSP). Operating costs in meat processing plants encourage the use of automated equipment such as robot saws. To precisely cut the forequarter and hindquarter of a side of beef, the robot saw must stop movement when it cuts the desired number of ribs.

This document was part of the first European DSP Education and Research Conference that took place September 26 and 27, 1996 in Paris. For information on how TI encourages students from around the world to find innovative ways to use DSPs, see TI's World Wide Web site at www.ti.com.

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Introduction

The Clermont-Ferrand/Theix Centre is one of 22 centres of the National Institute for Agricultural Research (INRA). It currently employs 745 people, including 300 graduates (Scientists, Researchers, Engineers, and Lecturers). The weight and originality of the studies conducted at the Centre are based on a wide range of approaches, from molecular and cellular biology to the systems, via organism biology. Likewise, research on the production of meat and milk, on the quality of human foodstuffs and seeds and plants, has taken increasing amount of the needs of the food and farm industry: development and quality of raw materials, production cost control, processing techniques, product usage and health value of foodstuffs for man. Meat quality can now be measured, thanks to the development of new methods of objective product characterisation: instrumental measurements, sensory analysis, modalities of consumer's sensory perception of texture, consumer behaviour analysis. To control the transformation processes, studies are conducted on slaughtering physiology and cell death, to solve the ethical problem facing the industry, in accordance with its economic constraints on process engineering: robotics and smart tools, heat and mass transfer (process and product modelling), which have the principal role for our team.

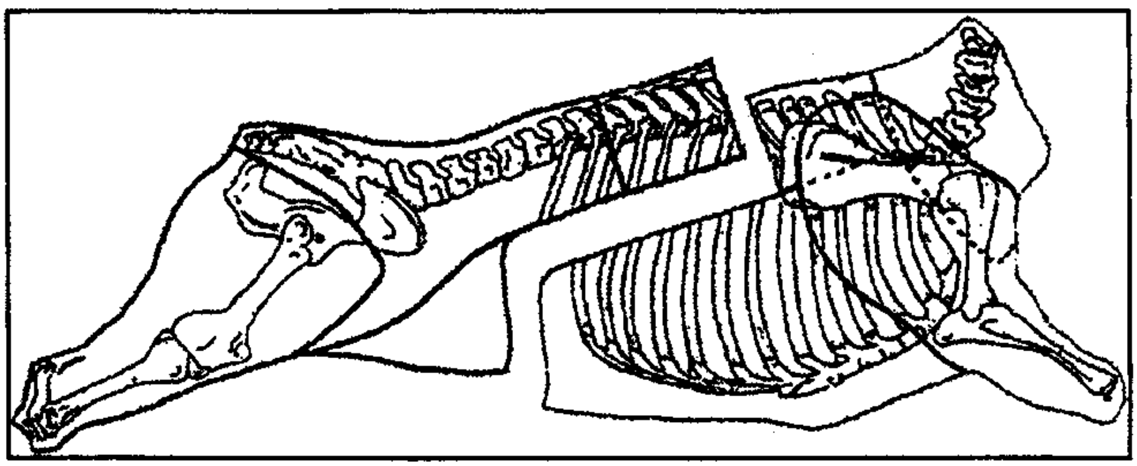
The Beef Cutting Project

The Half Carcass Beef Splitting Prototype

Within the European Eureka project EU 1032:"ABCD", INRA, Durand International, and Interbev develop two industrial prototypes: one will separate automatically a beef side into forequarter and hindquarter, the second will make three pieces from the forequarter (shoulder, neck, and breast). This project results from previous projects led by INRA[1], with the cooperation of ADIV and Cemagref, and aimed first at proving the feasibility of robotized cutting of a beef forequarter.

On the first prototype, the cutting path (Figure 1) is achieved by a special tool designed around a rotative saw handled by a robot. The saw is used to cut the ribs and an other part of the special tool is used to seam the meat.

Figure 1. Fore and Hindquarters

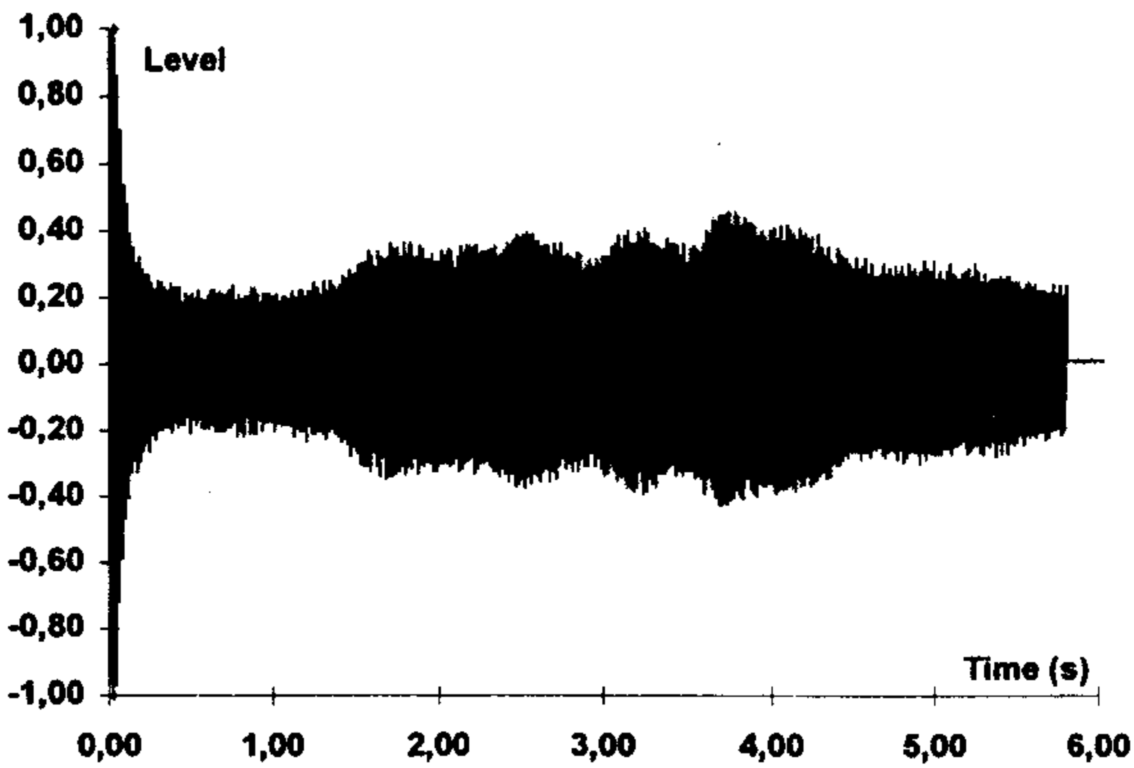


It is really complex to perform this action, as the incidence of biological variability is tremendous. We have made some trials by using home-made morphometric models linked to anatomic parameters but the only way to solve this problem seems to use a feedback control from parameters coming from the tool itself.

The Cutting of the Rib Cage

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 can easily extract the rib position but it is very dependent on the surrounding installations, especially in a noisy plant like an abattoir. The vibrations of the saw can also be used but 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 motor. An increasing amplitude represents the cutting of a rib while the meat in an inter rib space is represented by a lower amplitude. But this signal (Figure 2) is very noisy and must be significantly processed.

Figure 2. Raw Current Signal



Procedure Used

From Analog to Digital Processing

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.

Texas Instruments gave us the opportunity to evaluate at low coast ,a DSP solution.[2] We obtained the affordable TMS320C26 DSP Starter Kit (DSK) and developed a first software based primarily on the analog solution previously tested.[3]

Three block functions were realised:

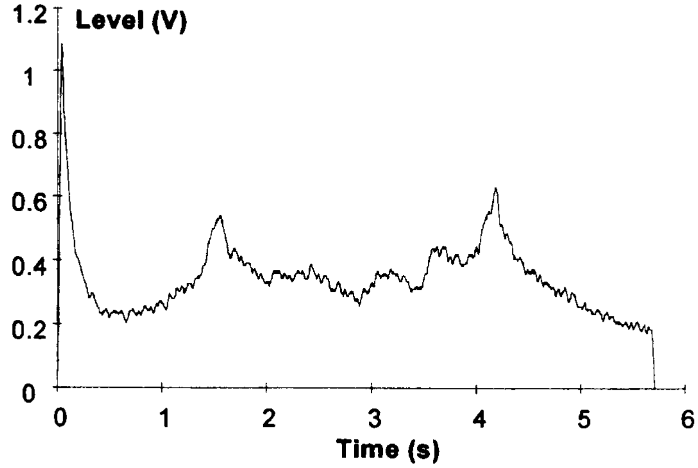
- The first one was an A.M. demodulation.
- The second one was a threshold which extracted the parts of the signal containing cut ribs.
- The third one was a rib detector using two sliding windows and comparators.

Figure 3 illustrates the results after each step of the process.

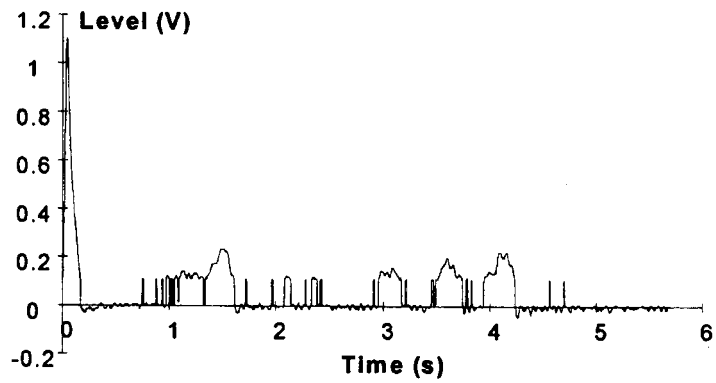
We have been limited by the amount of available memory and the lack of digital Input/Output lines. So an add-on board including extra memories and interface circuits was developed. Moreover this card was aimed at running without any external computer.[4]

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

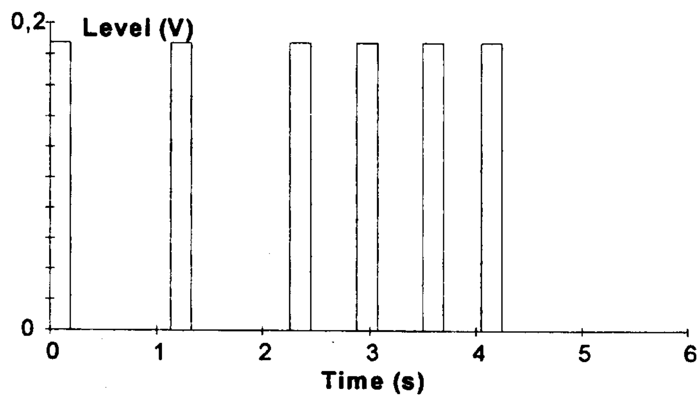
Figure 3. Signals During the Digital Processing



Signal after demodulation



Signal after thresholding



Signal after windowing

The Stand Alone Card

Specification Sheet

The rib counter must be seen as an Input/Output black box as shown in Figure 4.

As the previous software was too huge to fit into the internal memory of the TMS320C26, we added some fast external static RAM. The amount was fixed by the knowledge of the sampling frequencies and the spectrum of incoming signal. As a typical signal lasted about 6 seconds and the sampling frequency was 1000 Hertz, that gave us a memory size of 8 KO.

We chose the EPROM, TI TMS27C256 DSP, as program memory because of its low price and availability. However due to its long access time in regard to the DSP memory access timing we designed a wait state generator.

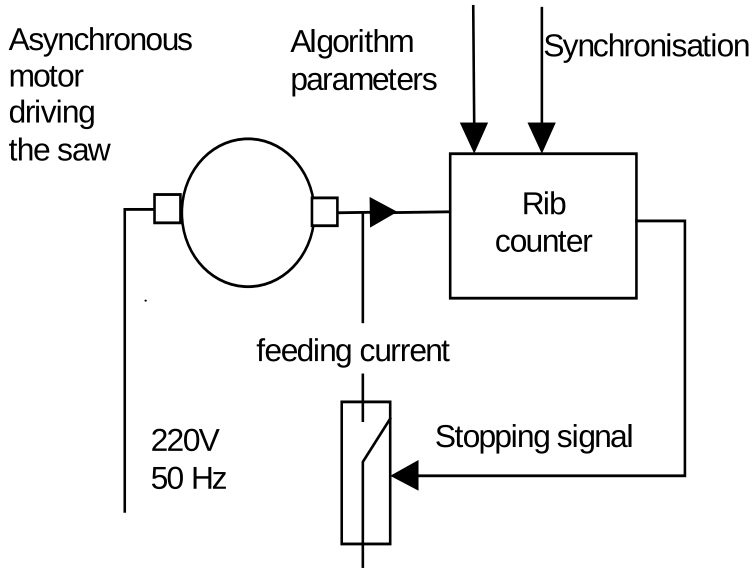
A classical glue logic has been preferred to a high integration circuit (like a PAL) because it is easier to maintain or repair in an industrial context.

The digital Output lines are latched and buffered using one Darlington array (ULN2803). One of these lines is used to send the stopping signal to hardware that drove the movement of the saw.

The digital Input lines allows one to enter the number of ribs to be cut and to adjust the sensibility of the algorithm.

The analog I/O uses the same analog interface circuit (AIC) (TLC32040) as the DSK for compatibility.[5]

Figure 4. Rib Counter Environment



Board Design

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

We bought a set of software for schematic design and printed circuit board, including auto-route.

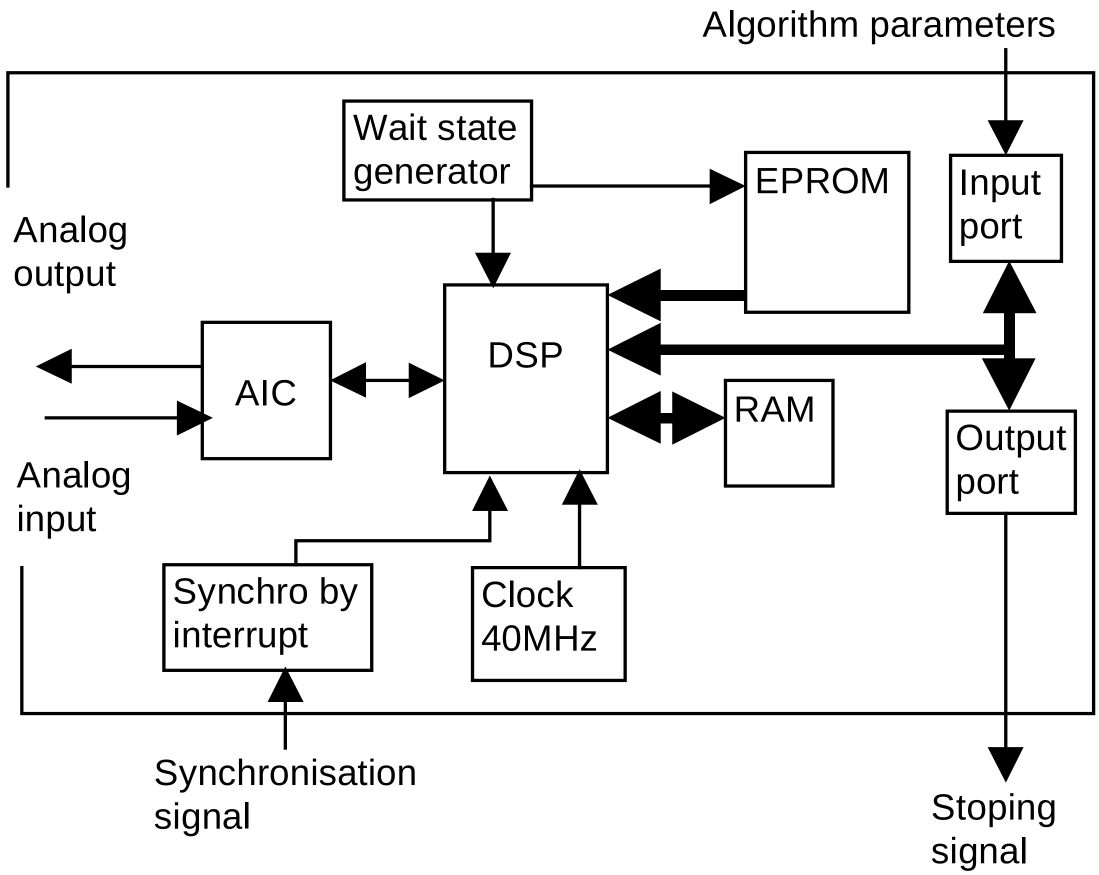
This single size board, with two layers, has two main advantages:

- 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 flexibility.
- 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.

Figure 5. The Board Architecture



Modification of the Existing Software

In order to use the extended possibilities of the new hardware, we had to write some other functions: the auto-boot, and memory greedy procedures.

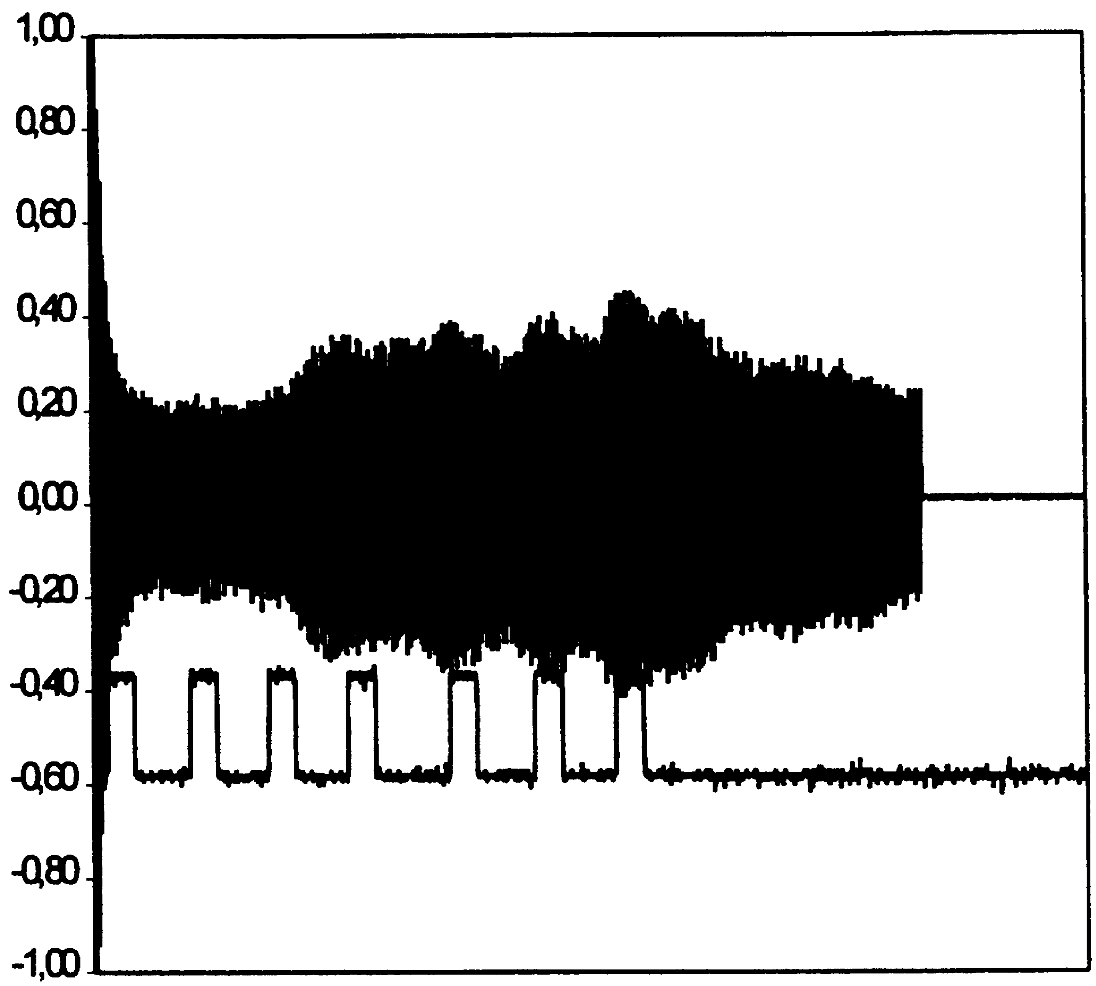
The aim of the auto-boot is to self-initialise the TMS320C26 and to load the EPROM content into the fast internal RAM. The program is then run as on the DSK. The external fast SRAM is used as data memory to let all internal memory free for program code. Furthermore, as it is a standalone system, the program has been modified to send a 200 ms pulse via the unused output of the AIC for an easy control on a scope.

Results

Graphs

The tests were conducted on forequarter with only five ribs to cut. Moreover, we could not make a great number of tests because of the expensive cost of bovine carcasses. During these tests, four cut ribs were each time detected. The fifth one was not always detected. An example of a typical graph obtained is shown in Figure 6:

Figure 6. A Typical Graph



Comments

The study of these graphs and the different tests highlight four essentials points:

- The last four pulses correspond to the four cut ribs. So the detection with this software is quite good.
- Sometimes cut ribs are not detected or the algorithm detects some rib which does not exist (for instance the third pulse). This problem is due to a lower or higher sensitivity of the software.
- The first pulse corresponds to the starting of the engine but is also considered as a cut rib.
- The second pulse corresponds to the beginning of the cutting of the meat surrounding a rib, and the raising of the torque is detected by the software as a cut rib.

As a consequence, the detection must only begin when the saw is in the meat of the carcass, which could avoid the appearance of the two first pulses. This synchronisation signal must be planned in the formal automatic cutting device. The hardware of the rib counter is already designed to receive this signal.

The two first observations show the limits and the defaults of the software, even if the detection is, most of the time, quite good.

Limits and Defaults of the Software

The detection is not systematic on all carcasses. Sometimes we need to modify the sensitivity of the algorithm. This is the essential default of the software. Indeed, the fact that the user settles the sensitivity, does not allow an automatic industrial utilisation of the detection algorithm.

Moreover, the tests were not carried out in an industrial environment. So, the input signal was quite clear. However, in an industrial environment, the signal could be more noisy and could perturb the detection because of the demodulation. In fact, the demodulation gives an accurate reproduction of the cover signal without decreasing the noise. So, the perturbations are present in each part of the processing.

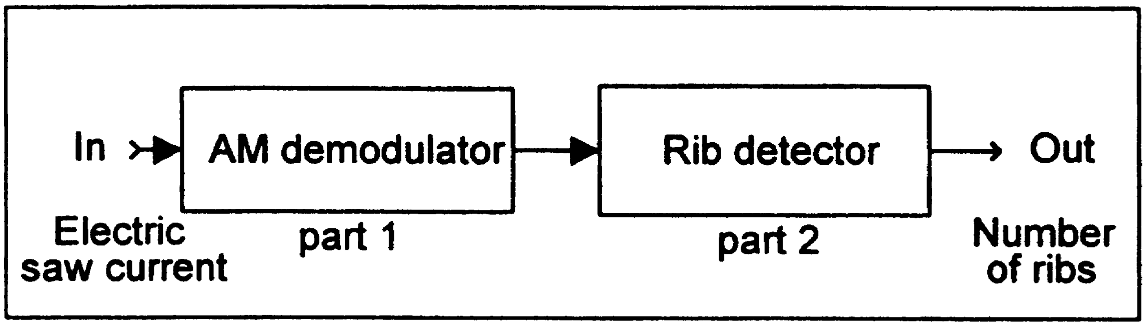
For an industrial utilisation of the rib counter the software ought to be improved.

A New Approach

Overview

The first software was based upon the analog system previously designed. In order to achieve better results with the same hardware, we decided to study the signal produced by the electric saw. Then we optimized each part of the software (Figure 7)[67].

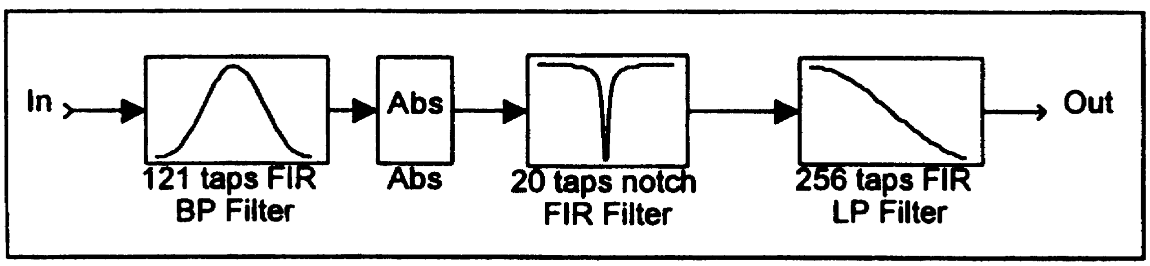
Figure 7. Block Diagram of the Rib Detector



Amplitude Demodulator

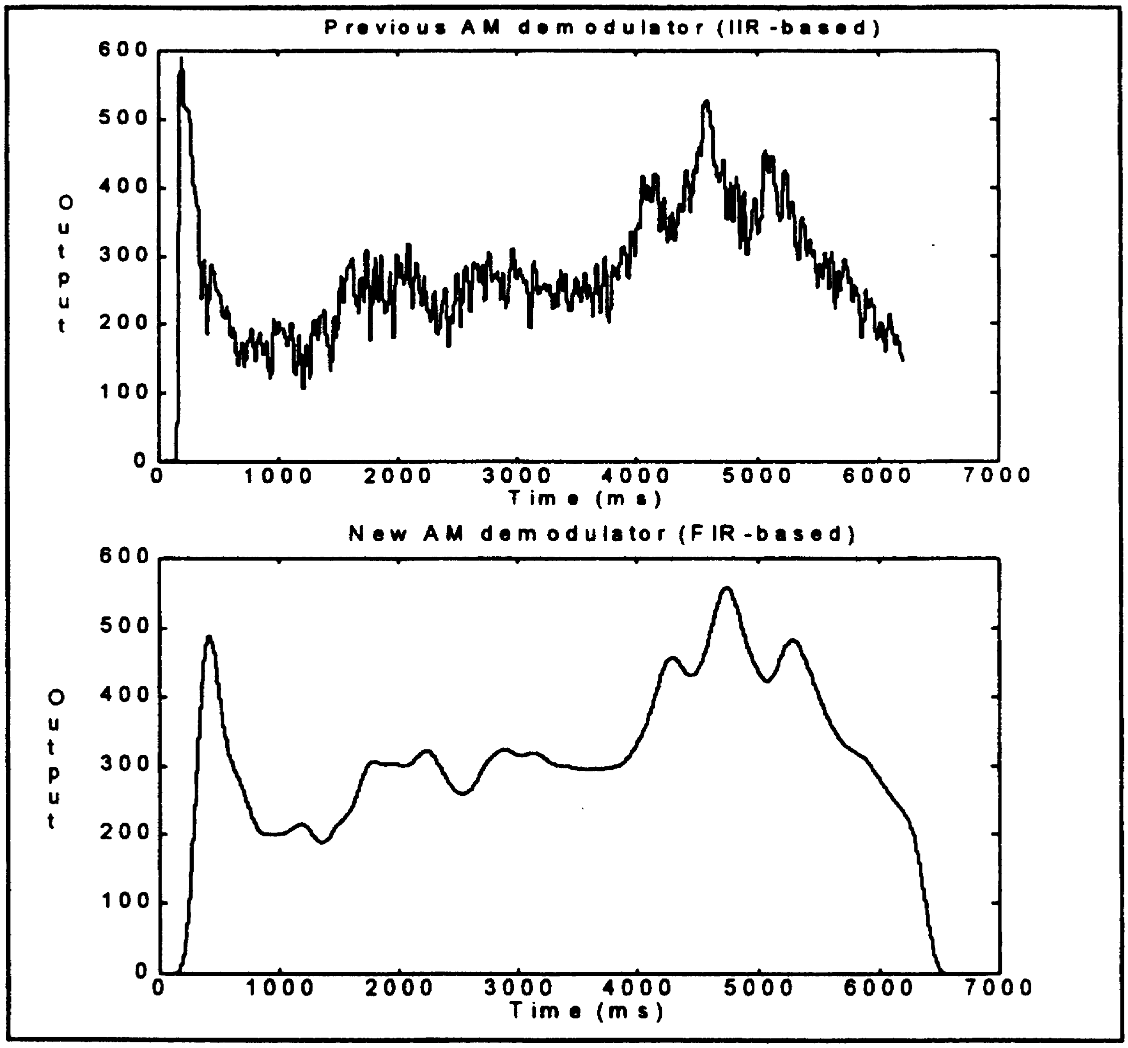
We decided to use the FIR (Finite Impulse Response) filters instead of IIR mainly because they are stable[8], even on a fixed-point device. The block diagram in Figure 8 illustrates the new demodulator.

Figure 8. New Demodulator for the Rib Detector



The 121 taps FIR (f0=50 Hz) filters the incoming electric saw amplitude-modulated signal[9]. Then the software detects this signal, taking the absolute value and rejects the 100 Hz carrier using the 20 taps notch filter. We chose 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 provides excellent results and fc=2.1 Hz. A comparison between the old and new demodulators is shown in Figure 9.

Figure 9. Output of the Old and New Demodulators



NOTE:
The vertical axis is proportional to the output voltage of the demodulator.

The Rib Detector

A New Model of Rib Detector

A new kind of model was developed under Matlab and then translated into TMS320C26 assembly language. The new 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 first model rejects “wrong” shapes; the second 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 formal algorithm takes into account the three methods.

Main Drawbacks

We were limited by the possibilities of the DSK assembler: our assembly source code was too long (more than 36 Kb).

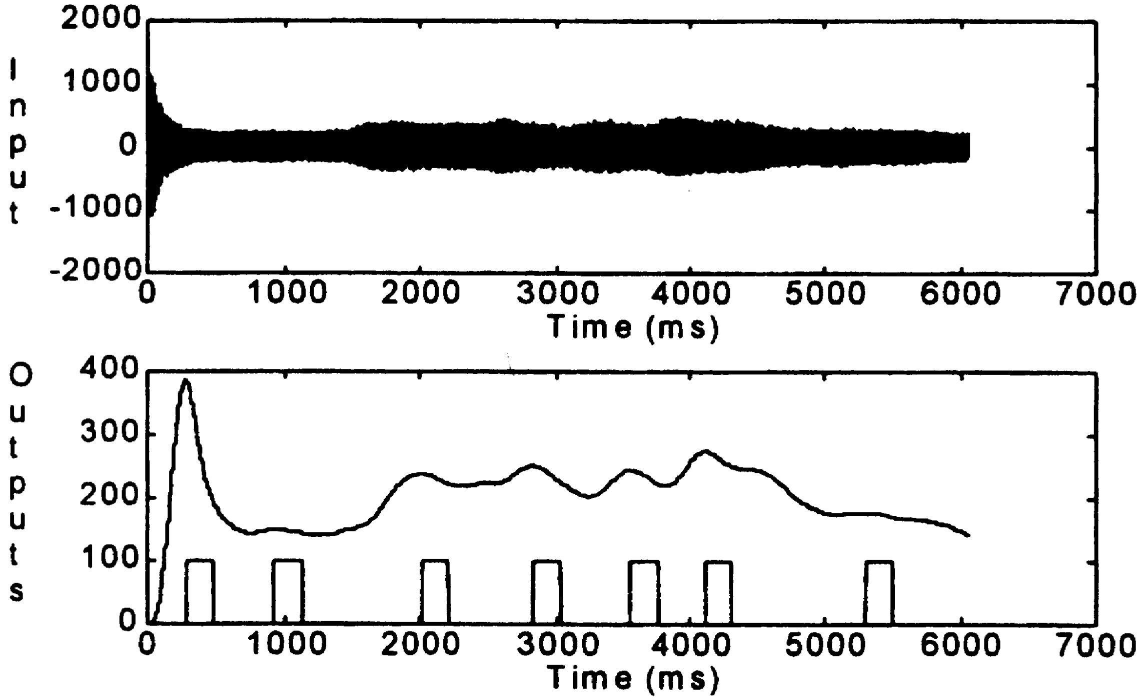
Moreover, we faced two problems during this project:

- The central arithmetic and logic unit (CALU) of the TMS320C26 is a fixed-point device, so we were lacking sufficient dynamic for our calculations and thus we used FIR filters.
- As the TMS320C26 does not have a hardware division, we had to modify our model to cope with multiplication and shift.

Results and Discussion

At the time of writing, the new software provided very good results and a very accurate time localisation of the ribs. It also detected ribs the old software was unable to find (Figure 10).

Figure 10. Input and Outputs of the New Software



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. One noticed that the last rib (t=5400 ms) corresponding to the last pulse was not detected by the old software. We mentioned that the simulation (Figure 10) and the DSP implementations produce the same results.

Moreover, we have some more ideas 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[10]. Some experiments conducted under Matlab proved that wavelets are more powerful for the rib signal than classical digital filtering (this is due to the time-frequency description of the signal). Unfortunately, we lacked time and power processing to implement such a method on the TMS320C26.

Conclusion

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 on this operation is focused on the TMS320C26. A versatile single size board has been designed to be able to support the strongest algorithm the TMS320C26 can handle with the DSK assembler.

Discussion was done on the use of FIR filters instead of IIR filters and openings with wavelets processing. Such improvements will be carried out using a stronger assembler and maybe a floating-point device such the TMS320C31.

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