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AUTOMATIC CONTROL OF BASE CUTTER HEIGHT ON SUGAR CANE HARVESTERS.

Thesis submitted by

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in May 1983

for the research Degree of Master of Engineering Science in the Department of Electrical and Electronic Engineering of the James Cook University of North Queensland.

(0010)

DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

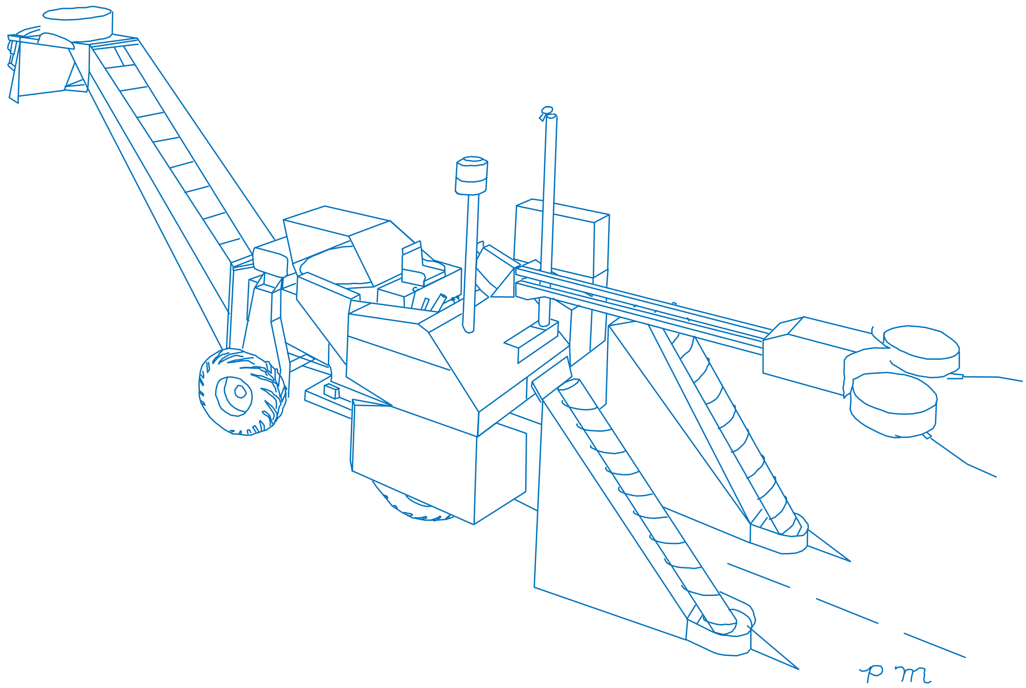
P.C. Musumeci

11th May 1983

ABSTRACT

This thesis studies height estimation techniques necessary to achieve automatic control of the base cutter height on sugar cane harvesters and, in particular, those techniques analysing the hydraulic oil pressure drop across the base cutter hydraulic motor. Signal processing of pressure information leads to the proposal of pressure variance as a height quantifier. As harvesting conditions are non-stationary, an asymptotically unbiased variance estimator using an exponential data window and possessing adjustable tracking and noise smoothing characteristics is devised, implemented in a real-time microprocessor system and tested.

Cane Harvester



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Chapter 1

1.0 Introduction

The efficiency and international competitiveness of the Australian Sugar Industry is maintained by active research and development directed at various levels of the industry including Plant Breeding, Farming, Harvesting, and Milling. In particular, Australian cane harvesting is now fully mechanised and improvements in harvester control will lead to an improvement in yield.

For the purposes of harvesting, the sugar cane plant can be divided into three sections i.e. the root section beneath the soil surface, the stem or stalk section which stores the sugar, and the leafy top which is producing the sugar. During the growth stage, dead leaves are left clinging to the stem or fall down onto the ground near the base, or stool, of the plant. This dead foliage in combination with weeds and vines, and secondary growths of the cane plant, can shield the soil surface at the stool from view during green cane harvesting or when harvesting poorly burnt cane.

Figure 1a shows a mechanical chopper harvester. It must remove the tops with the topper, lift any fallen cane stalks with the augers, cut the stalk off at ground level with the base cutter, chop the stalk into small lengths or

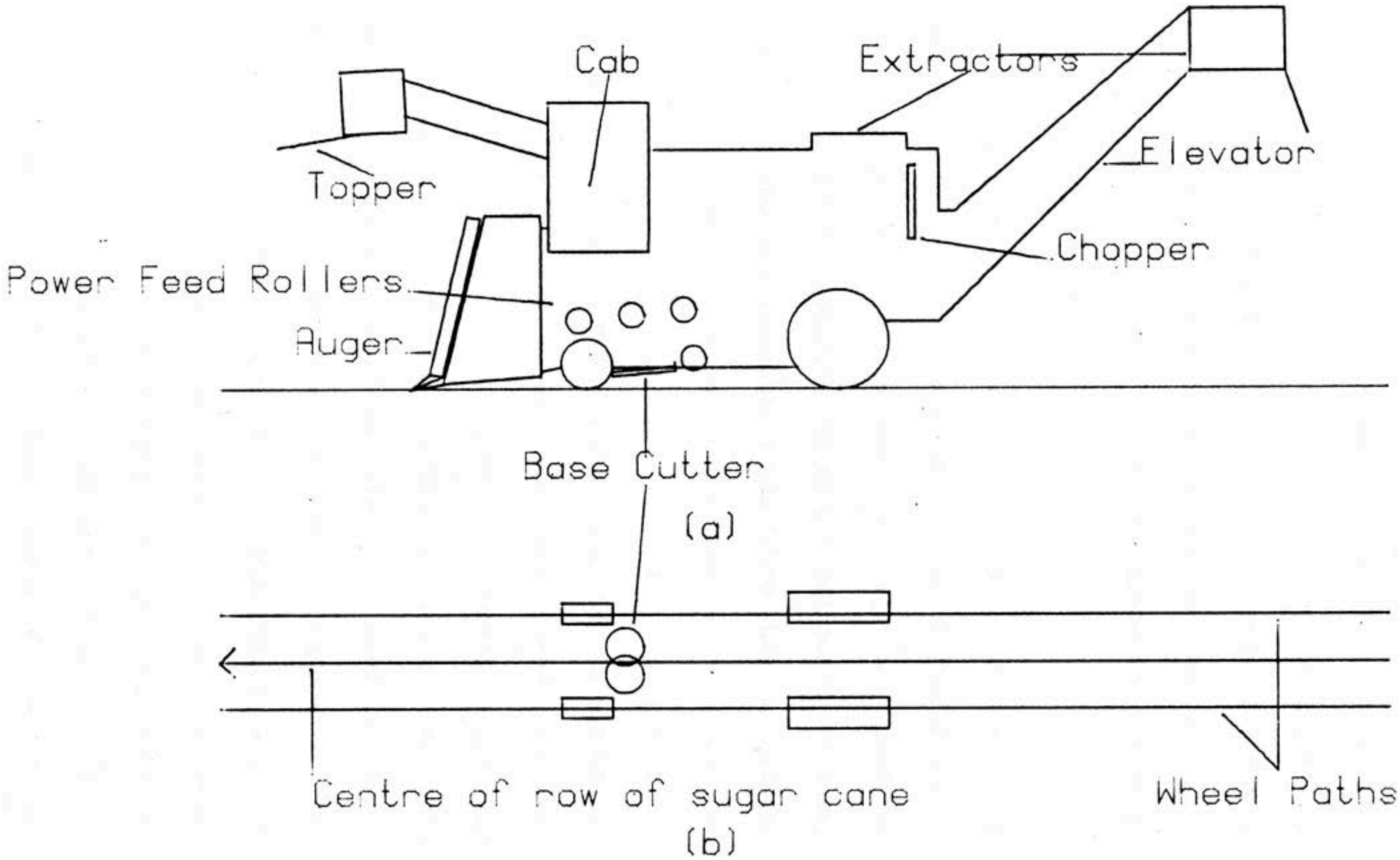

Cab
Extractors
Topper
Elevator
Chopper
Power Feed Rollers
Auger
Base Cutter
(a)
Centre of row of sugar cane
Wheel Paths
(b)

Figure 1

billets with the chopper, remove some extraneous dirt and leafy matter by extractor fans and elevator sieves, and transfer the sugar cane into a bin for transport to the Sugar Mill. The cane harvester operator is usually positioned in a cabin located at the front of the harvester. The cane harvester travels along the row of cane as shown in figure 1b. Its vertical position depends on the condition of the inter-row soil which can suffer washouts and provide an irregular wheel path.

The demand on the operator to adjust cane harvester parameters such as topper height, base cutter height or depth, auger position, ground speed, and elevator position can vary greatly according to crop conditions. In ideal harvesting conditions where the sugar cane has a regular stem length and top height, the topper height would need little adjustment. Also, if the soil surface at the stool is a constant height above the wheel path of the harvester, then the base cutter height does not need constant adjustment. However, ideal harvesting conditions are very uncommon and the operator is very busy adjusting: the cane harvester's ground speed as the crop density varies according to field conditions; the topper height as the average stem lengths change; and the base cutter height as the shape and height of the soil at the base of the stalk varies according to the washouts of the wheel paths and erosion of the stool region that may have occurred since the last cultivation. Of these control variables, base cutter height adjustment can present the highest demands on the operator because of the difficulty associated with accurately gauging performance, and because rapid field condition changes can apply other heavy control loads on the operator.

As mentioned earlier, the stool region of the plant can be shielded by foliage. The operator's view of the base region is also inhibited by the cane stalks and the harvester's geometry. These factors, plus the additional stress placed on the operator by the demands of controlling the other functions of the harvester, and by the presence of airborne dust and other extraneous matter produced by extractor fans and the base cutter, make adequate control of the base cutter height difficult to attain.

This parameter has a great influence on the farmer's returns. Base cutting too high leaves sugar bearing cane in the field thus reducing earnings. These butts protruding up from the stool soil surface can also foul cultivation equipment as the next ratoon crop is farmed. Additionally, the farmer may incur extra expense in cutting these butts off. Base cutting too low also has many disadvantages. The base cutter dislodges the soil around the stool and some of this soil enters the harvester where it increases abrasive wear on extractor fan blades, plate metal surfaces such as elevator walls and extractor fan shrouds, and, in some instances, elevator chains. Dislodging this soil also increases the fuel consumption of the cane harvester and decreases the life of the base cutter blades. Since some of this soil finds its way to the Mill, the farmer and/or harvester owner usually pays penalties imposed by the Mill because the soil makes sugar extraction more difficult. Cutting extremely deeply can adversely affect future crops because the root stock which can produce up to three or more future crops can be disturbed so that future tonnages are reduced or the farmer again incurs extra expenditure when paying for the replanting of the field.

The central problem is to improve the sensing of the actual base cutter height above the stool soil surface so that either the present control loop which includes a human operator will work more effectively, or an automated height control system may be implemented. Ideally, this height information should refer to the crop in front of the harvester so that the operator or a fully automatic system could use a priori knowledge of the harvester's height.

1.1 Review of Previous Work

Early mechanical cane harvesters used mechanically driven base cutters. In 1968, Giardina [1] filed a U.S. patent which described the height adjustment system shown in figure 2. Any increase in load on the rotating cutter blades causes an increase in the mechanical energy

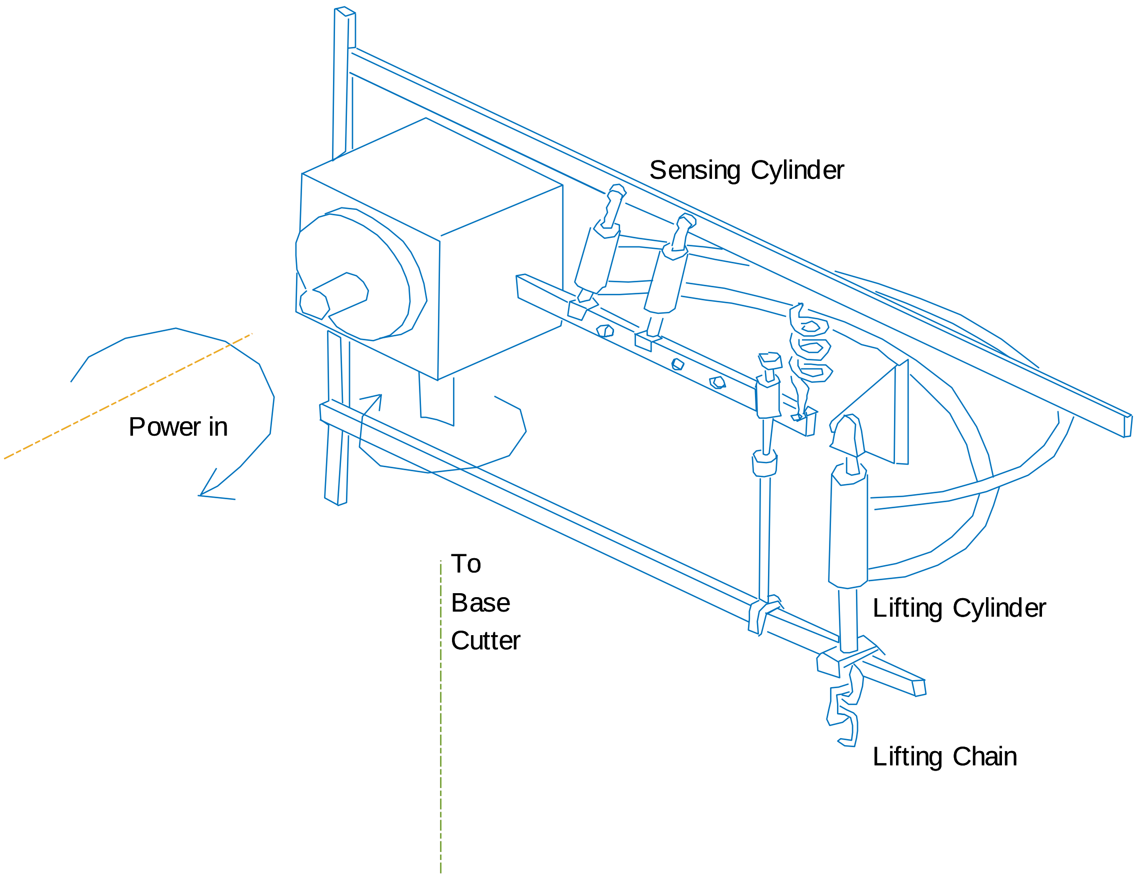


FIGURE 2 Giardina 1968

transferred through the gear box. The change in torque applied to the gear box causes it to rotate slightly causing a fluid flow between the load sensing cylinder and the height adjustment cylinder resulting in the lifting of the cutter blades. Giardina shows how this device would be mounted in a whole stick cane harvester in the patent. Most recent mechanical cane harvesters that deliver billetted cane now have hydraulically driven base cutters so similar ideas to Giardina's have been applied to these machines thus spawning a number of similar height sensing techniques. We shall consider some of these products that were tested.

In 1969, Suggs and Abrams [2] described a base cutter height controller that sensed the energy useage of the hydraulic motor driving the rotating base cutter blades as shown in figure 3. In this mechanism, an increase in cutting depth of the base cutter causes an increase in the load on the hydraulic motor. Assuming that the oil flow rate through the motor does not change appreciably, an increase in the hydraulic oil pressure drop across the motor occurs. This results in an increase of P_{in} causing the hydraulic ram to lift the floating assembly until the lifting force F achieves equilibrium with the downward force due to the spring G and the mass of the floating assembly. (As the assembly rises, the motor load decreases so that force F decreases. Simultaneously, force G is increasing until, at equilibrium, rising halts). This feedback system does not contain any integration elements so that the

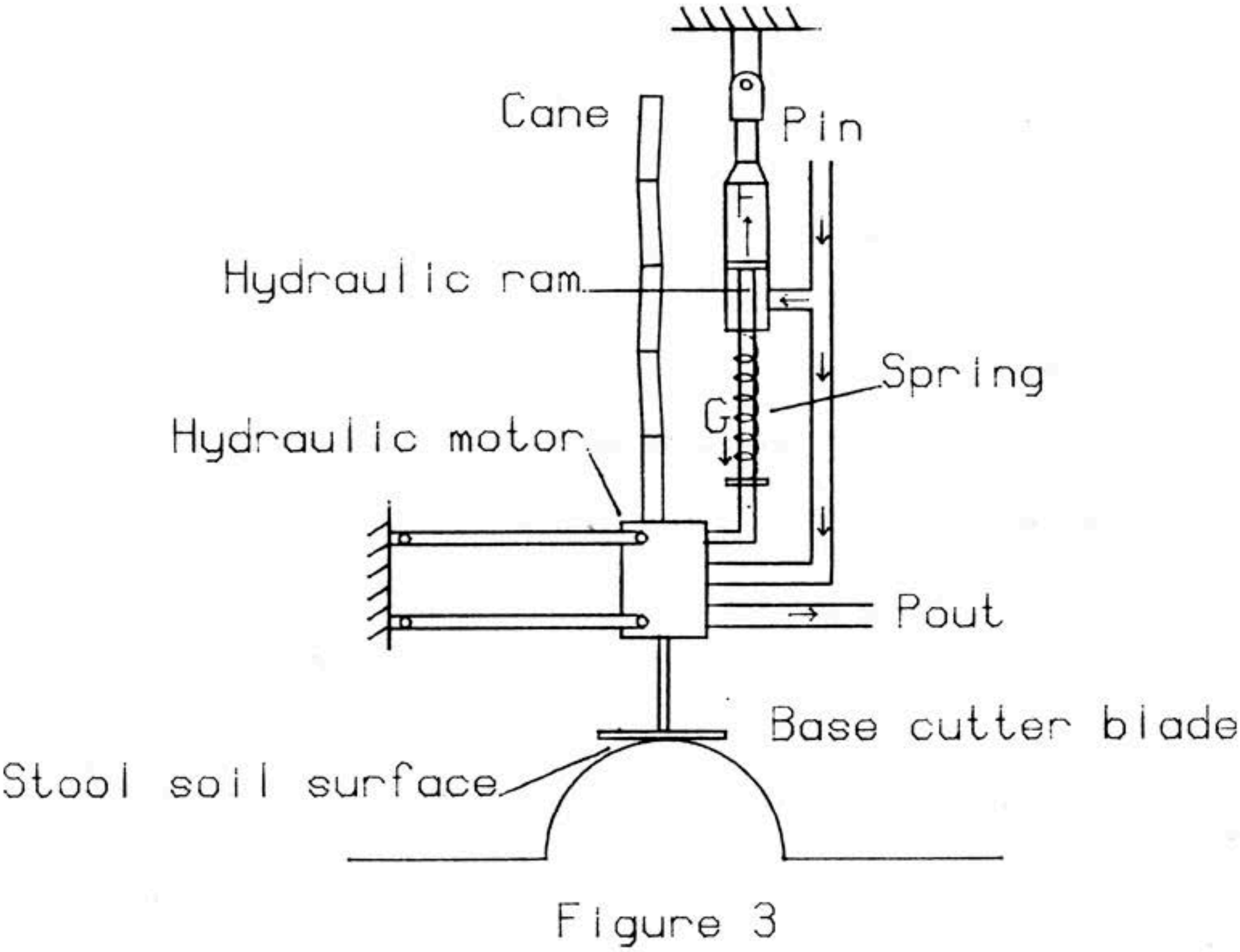

Cane
Pin
F
Hydraulic ram
Spring
G
Hydraulic motor
Pout
Base cutter blade
Stool soil surface

Figure 3

equilibrium position obtained will always contain a residual error with respect to the soil surface near the stool. Careful choice of the lifter ram's piston area and of the spring's characteristics can theoretically give a relatively small residual error when a large absolute change occurs in the soil surface position.

Problems occur when cutting just below the stool's soil surface where sensor signal to noise ratio is small. Similarly, sensor information obtained when cutting just above the surface would also be unreliable because the cutter load would be randomly changing depending on sugar cane stem density. The transient response of this system cannot be changed after construction so that changing soil characteristics and variable crop density will result in non-optimal operation. Furthermore, adoption of this system in current Australian cane harvesters would require a major redesign of the cane gathering mechanism. Harvesters presently feature rigidly mounted base cutters, power feed rollers, and butt lifters which are arranged for the task of crop collection. This point, in combination with the expected poor performance in the important cutting region just below the soil surface, rules this device out (for Australian conditions).

A more recent analysis of the possibility of using base cutter hydraulic motor pressure drop as a measure of cutting depth was undertaken in 1979 by Reidenbach et al [3].

Hydraulic oil pressure transducers were connected to the input and output hydraulic lines of the base cutter motor and the chopper motor. This produced voltage signals proportional to the base cutter load and the cane flow rate through the cane harvester. Postprocessing of the data gave the mean base cutter load due to cutting into the soil for a number of trials with constant ground speed and cutting depth. As expected, cutting more deeply into the soil did increase the base cutter motor hydraulic pressure drop. This pressure signal is particularly noisy and statistical postprocessing is needed to estimate the height. As figure 4 shows, a cutting depth greater than 60 mm is required before a significant discernable pressure increase is observed. This has been verified by Musumeci and Bitmead [4]. Base cutter height estimation via the energy useage criterion is essentially infeasible because a small change in height produces a negligible change in pressure and this signal is embedded in large variance noise.

Studies by Henkel, Fuelling, and Ridge [5] showed that "The quantity of dirt in the cane supply increased appreciably when cane was cut 50mm below ground rather than at ground level". Real-time mean estimation of the base cutter hydraulic motor pressure drop is therefore inadequate as a cutting height sensor because the cutting height can be allowing significant soil in with the cane before any pressure signal change occurs. Information when cutting above the soil surface would be misleading because figure 4

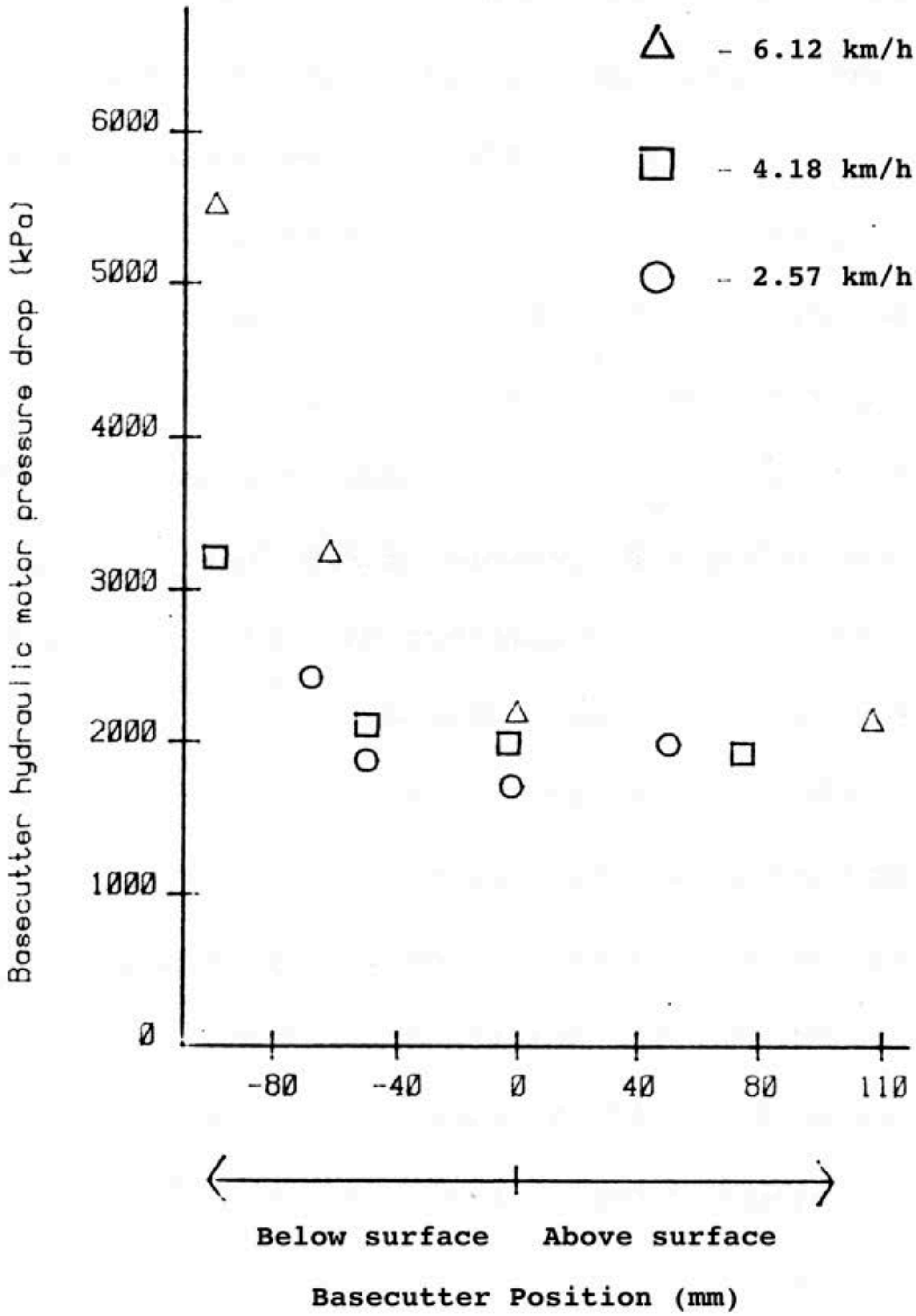

△ - 6.12 km/h
□ - 4.18 km/h
○ - 2.57 km/h
Basecutter hydraulic motor pressure drop (kPa)
6000
5000
4000
3000
2000
1000
0
-80
-40
0
40
80
110
Below surface
Above surface
Basecutter Position (mm)

Figure 4

shows the base cutter hydraulic pressure increasing as height increases, with the minimum occurring in the region located 0→80mm below the soil surface.

The possibility of trailing multiple arms behind the cane harvester and across the row to detect the presence of protruding residual cane stalks has been investigated by Ruff et al [6] in 1977. The estimate of stalk height above the stool soil surface was based on the movement of the arms, and the duration of movement. In contrast to the base cutter hydraulic pressure systems, this method of sensing the cutting height would only work when cutting above the soil surface. The information obtained would be dependent on the uniformity of the stalk density along the row. Further disadvantages are that the trailing arms could foul up with thrash etc. which would probably be present if the base cutter was cutting slightly above the soil surface; the device would complicate the rather simple techniques used to raise and the lower the present harvester mechanism as this device would also require raising and lowering at the opposite end of the harvester; some of the crop would still need to be left in the field; and the physical displacement between the arms and the base cutter produces a possibly unacceptable time delay.

In 1974, Paulson and Strelioff [7] developed an ultrasonic depth sensor for use in wheat farming on the Canadian prairies. This system successfully detected the flat surface in a crop of wheat by using a hardware based fixed transmit signal sonar system with a simple return signal amplitude threshold detector to determine cultivation height. Adaptation of this simple sonar system to the sugar cane harvester is difficult because the crop in front of the harvester is much thicker and concentrates in the region of interest, the stool soil surface. This has led to the Coad et al [8] 1979 work on a microprocessor based ultrasonic height sensor aimed at the stool soil surface behind the harvester. This system attempts to discriminate between the acoustical reflections caused by the sugar cane stalk butts and the actual stool soil surface. While laboratory tests have been successful, height detection still relies on some sugar cane being left in the field. Any height controller using this information source would also contain an inherent delay making control difficult.

Investigations with an acoustical ranging system that used a programmable transmit signal have been performed by Musumeci and Bitmead [9]. Measurements of background machinery noise directly in front of the cane harvester gave sound pressure levels greater than 110dB. Given that the acoustical channel through which the vibrational signals must pass contains crop and leafy matter that has a range of physical dimensions similar to the wavelengths used, a simple time-of-transit sonar system is considered inadequate.

Radar techniques offer another approach for the development of a ranging system. The radio channel will again contain foliage with sugar cane dominant. Sugar cane contains 70% H_2O [10] so that the crop could offer a reflection co-efficient of approximately -0.8. This is much larger than the expected reflection co-efficient of soil which is approximately -0.43 [11] resulting in much stronger reflections from the vegetation in the channel. Simple tests conducted at ≈10 GHz have shown that one legume leaf can easily produce a reflection larger than that of soil. Furthermore, given variable soil characteristics such as moisture content, any RF signal reflected from the region at the base of the stool would not necessarily originate from the visual soil surface but could originate from other soil levels. (This contrasts with the acoustical ranging system where the transmit signal is a pressure disturbance propagating through the air.) All the distortion factors mentioned for Radar would also present serious difficulties for the phase encoded continuous RF ranging techniques.

The height estimation techniques can be divided into three classes according to when the height estimate is delivered in relation to the base cutting. Techniques that provide information after the base cutting present difficulties from the control implementation viewpoint, and so have been disregarded as sole information sources. Techniques that obtain terrain information ahead of the base cutter possess advantages from a control aspect, but may be very complex because of difficulties in penetrating the crop - mechanical devices cannot distinguish between the soil surface and the rigid crop. Equally, electromagnetic and acoustical ranging systems need protection. The base cutter energy useage systems provide information at the instant of cutting which is reasonable for the purposes of control. They are relatively simple, but presently lack resolution.

1.2 Approach and Contribution of this Thesis

The approach adopted in this thesis is to produce better and more flexible methods of height sensing. In particular, research has concentrated on statistical processing of the base cutter motor hydraulic pressure drop signal to derive height measures. Experimental evidence shows that the variance of this pressure signal can provide a useful quantifier of height which is more sensitive than analysis of the mean of the signal.

A novel adaptive relaxation estimator of variance is derived and its properties studied both in a theoretical framework and when applied to actual cane harvester data. The effects of altering each of the two relaxation parameters of the estimator are studied with an aim of providing useful feasible working ranges. While this method was chosen because of its implementability, it is demonstrated that it provides a possibility of simple detection of height changes, for control purposes, through the application of the F-test.

The approach to experimental evaluation has been to develop a real-time microprocessor (μP) system which provides the means for field testing, data logging and system development. Novel hardware features include a 9600 baud cassette tape data interface, the pressure signal interface, and the design of the dedicated μP system. The μP system's software includes a local monitor with remote host computer communication and object code download facilities, and concurrent programming techniques for running user application programs. Mainframe software includes PASCAL and FORTRAN programs which perform signal processing and estimator relaxation variable design.

1.3 Outline of Thesis

Chapter 2 describes the initial field tests leading to the proposal of the variance of the oil pressure drop signal measured across the base cutter's hydraulic motor as an estimate of cutter height. The properties of this pressure signal are discussed in Chapter 3 with two possible variance estimation algorithms analysed. An adaptive variance estimation algorithm is chosen and it is shown to possess asymptotically unbiased estimates. Chapter 4 describes the software and hardware development associated with this project. A conclusion and description of future work is given in Chapter 5.

Chapter 2

2.0 Base Cutter Hydraulic Pressure Drop & Soil Surface Roughness Techniques

The research of Suggs and Abrams [2] stimulated interest in base cutter hydraulic motor pressure drop measurements. Simple tests conducted with a TOFT 6000 cane harvester showed that the oil pressure drop across the hydraulic motor increased from around the 1800kPa level to around 2300kPa when cutting into firm soil. This corresponded to the findings of [2] and [3], but still left an information gap when cutting occurred above the stool soil surface.

Independently of the work described in reference [6], consideration was given to measuring the roughness of the soil surface after cutting by the base cutter since, as noted in chapter 1, roughness information would appear to complement the energy useage information. Two systems were considered:

1. The first system would use a cross-row scanning radar searching for the presence of residual stalk material. Whenever short lengths of stalks called butts were present, their high co-efficient of reflection for RF energy would result in good reflections, as shown in figure 5. Alternatively, if a clean cut was performed,

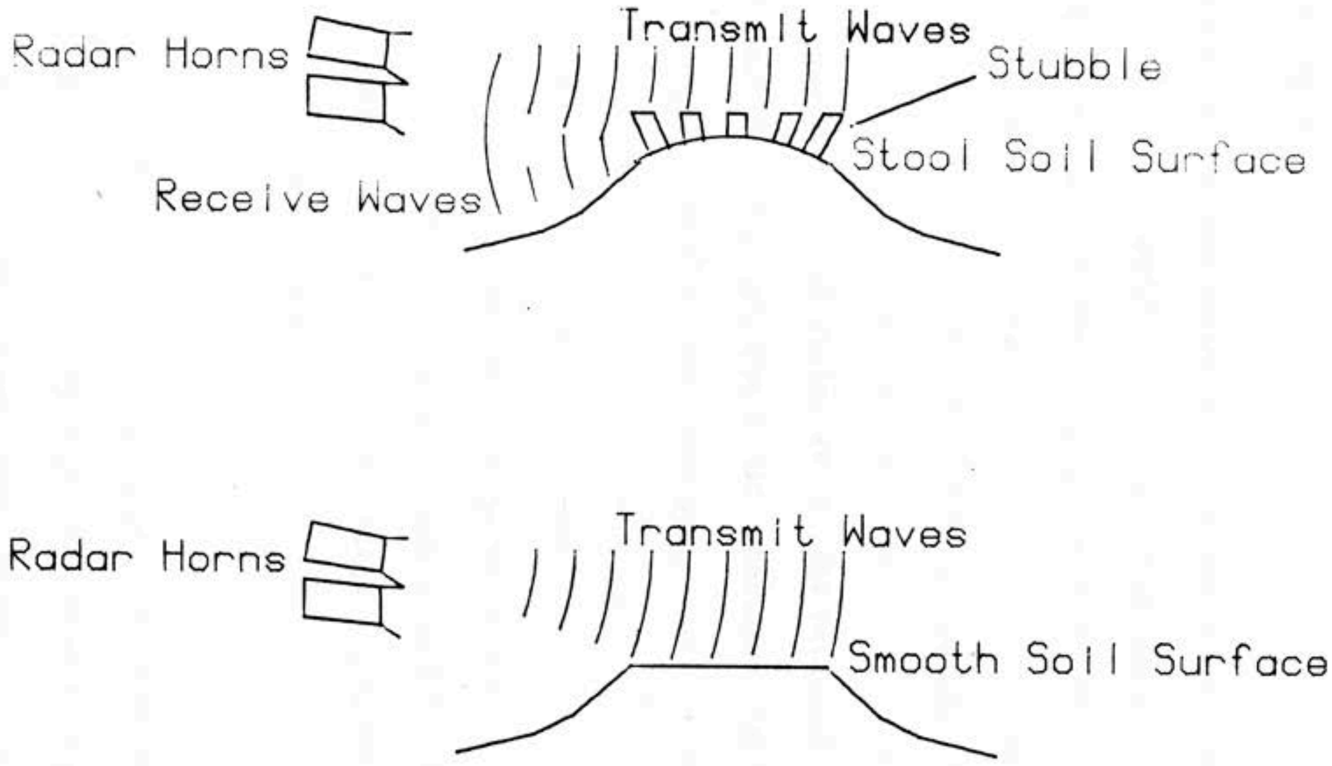

Radar Horns
Transmit Waves
Stubble
Stool Soil Surface
Receive Waves
Radar Horns
Transmit Waves
Smooth Soil Surface

Figure 5

this RF energy would be expected to skim the stool soil surface providing little reflections. As noted earlier, system complexity and the possiblity of spurious reflections from beneath the visual surface were serious disadvantages.

2. The second system was based on a sugar cane farming implement called a scratcher. A scratcher consists of a number of vertical lengths of spring steel arranged in a fashion similar to a rake and used to cultivate growing sugar cane. In normal use, the vertical spring steel arms (or tines) are passed along the row and dislodge small weeds etc. while giving way to the sturdier cane plant shoots. The principle of operation here was similar except that the tines were positioned to provide maximum contact area with oncoming cane stubble, and the common three point linkage contained a spring steel member. A strain gauge was to be glued to each side of the vertical member, as shown in figure 6, and connected to a bridge circuit to provide a voltage signal related to the forces at the base.

The second system was chosen because it was already in common use throughout the industry, was simple, and was cheap to construct. Some sugar cane belonging to the Queensland Bureau of Sugar Experiment Stations was manually cut at various heights and the device's operation was

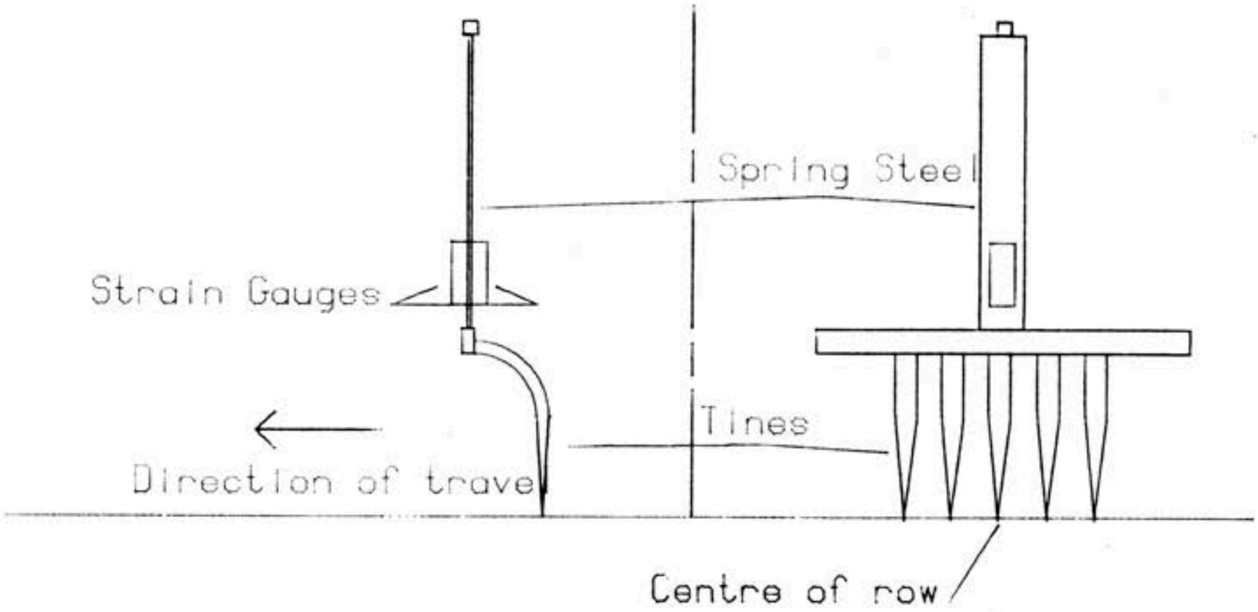


Figure 6 Sugar Cane Plant Scratcher

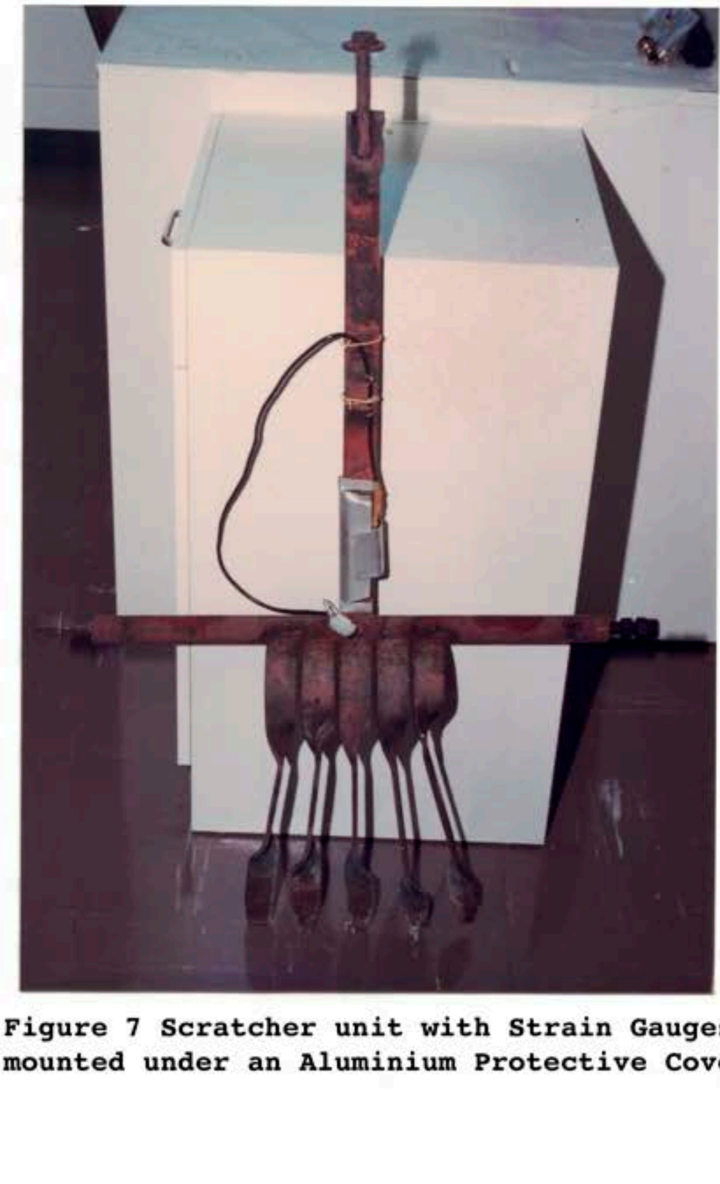


Figure 7 Scratcher unit with Strain Gauges mounted under an Aluminium Protective Cover

verified. A photograph of the final implement is shown in figure 7.

These two successful independent tests led to the formulation of a possible height sensing technique using two information sources:

1. A measure of the base cutter's energy useage when cutting into the soil, and

2. a measure of the roughness of the stool soil surface area following the base cutter (with its inherent time delay).

A microprocessor system (described in Chapter 4) was designed, constructed, and programmed to record the information from sensors mounted on the hydraulic base cutter motor, the hydraulic chopper mechanism motor, the roughness sensor, and a rear mounted fifth wheel measuring harvester displacement.

2.1 Test of Proposed Technique

Field trials were conducted with a TOFT 4000 Cane Harvester in moist, loamy soil in the Tully district. As reported by Musumeci and Bitmead [4], three major tests were performed with constant ground speed and at base cutter positions of ≈+40mm, ≈0mm, and ≈-40mm above the stool soil surface. Typical graphs of the hydraulic pressure drop across the base cutter motor versus time are shown in figure 8. It is apparent that the average hydraulic pressure drop does not change appreciably for the height changes of interest here. Even if it did, a large sample size would still be required to average out the noise (with mean assumed to equal zero) thus resulting in undesirable time delay. Figure 9 includes a graph of sensed roughness versus time. Noise also swamped any information present in this signal. This agreed with visual checks on the operation of the sensor which showed that it rarely stopped bouncing along the surface. The need for a spring to force the sensor down onto the soil surface, and of a damper to dissipate potential energy stored whenever the tines gripped a surface irregularity such as a cane stalk butt was apparent.

In an attempt to detect any interrelationships between the various signals, and therefore any information content, non-circular cross-correlations between the signals from the base cutter, the chopper, and the roughness sensor were performed. In particular, it was expected that a cross-correlation between the base cutter signal and the sensed roughness signal would contain a peak at position

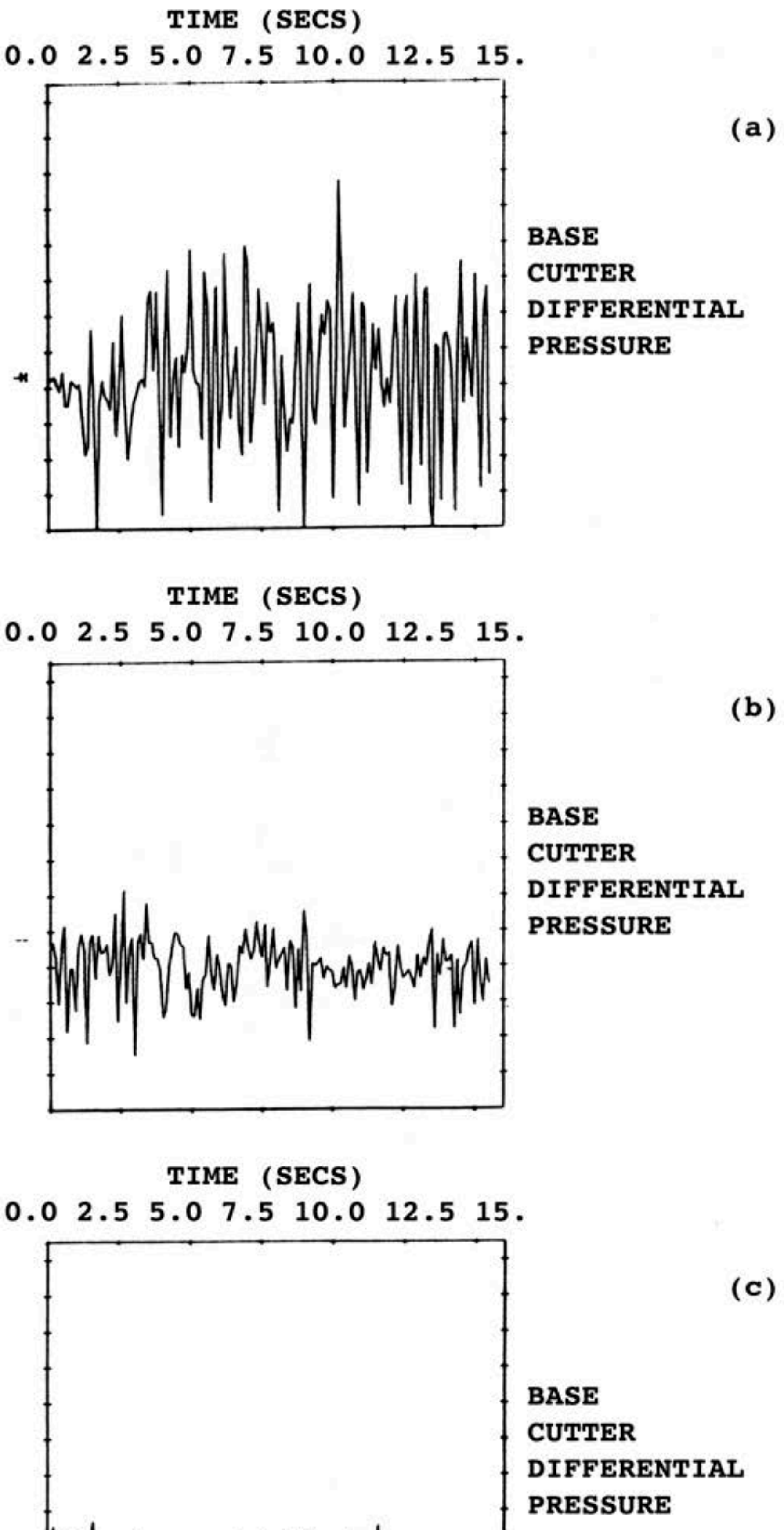


Figure 8 Base Cutter Pressure Signal versus Time
(a) cutting high, (b) cutting at the surface, (c) cutting low

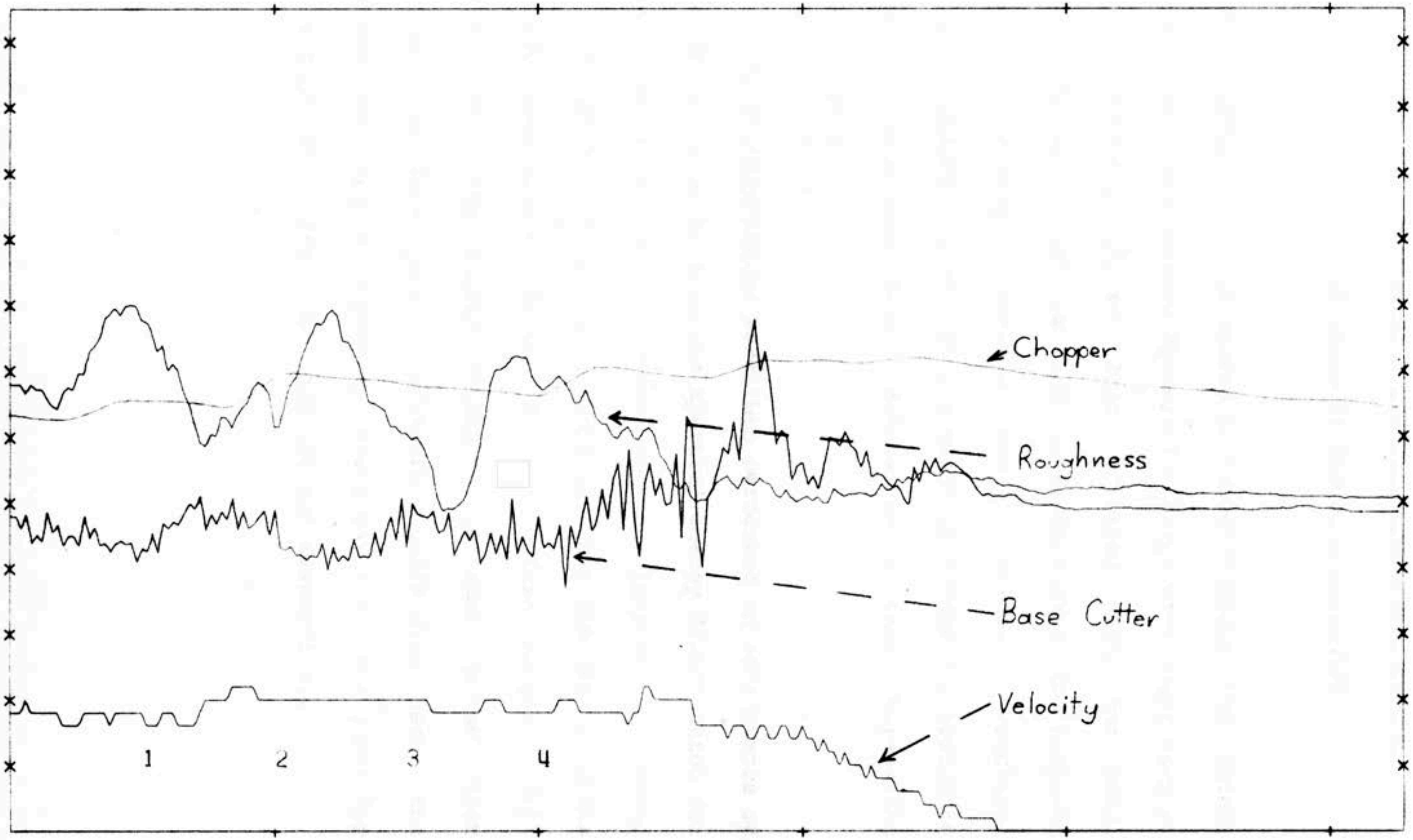


Figure 9 Test Data including Roughness Information

$$\delta time = \frac{\text{distance between base cutter \& roughness sensor}}{\text{ground speed of the cane harvester}}$$

The cross-correlations showed no expected peaks but rather that the cross energy spectra for these particular samples were relatively uniform. This indicated that, for small base cutter deviations and the sensors used, the proposed height sensing technique was invalid. Practical considerations ruled out the eventual successful operation of the roughness sensor device in a cane harvesting environment.

Auto-correlations were then performed on each sample of pressure data to find the spectral energy distribution for each individual sample. These auto-correlations are shown in figure 10 where it is apparent that the central peaks differ according to the test's base cutter height. This means that the sample variances decrease as the cutter heights decrease. For the pressure signals used here, the normalised sample variances are 3.84, 1.00, and 0.235 for the high cut, surface cut, and low cut respectively.

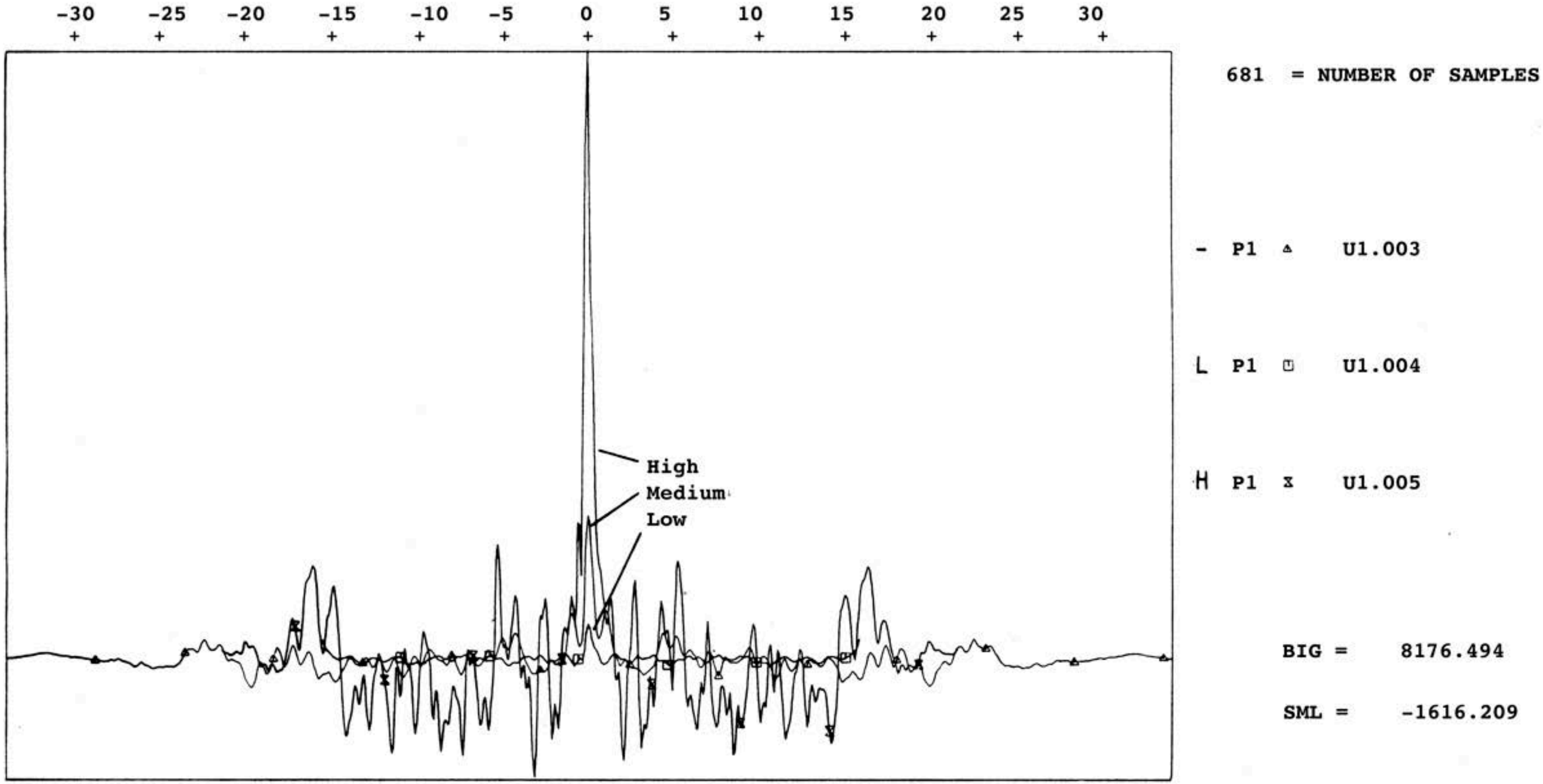


Figure 10 Base Cutter Pressure Signal Auto-correlation

2.2 Variance as a Measure of Height

The base cutter hydraulic motor is usually a toothed type as shown schematically in figure 11. One would expect fluctations to occur in both the pressure drop across the motor and the oil flow velocity through the motor because of the nature of its design. Now consider the case where the mechanical load on the output drive shaft of the motor is also varying. The velocity of the output drive shaft would, under these conditions, vary by a greater degree causing larger pressure fluctations across the motor (there may be some low pass filtering of these variations due to the inertia of the system's external mechanism). Conversely, if the external mechanical load gained a damping characteristic, the pressure fluctations would decrease.

In the application of interest here, it is suggested that base cutting into the soil applies a damping force onto the rotating blades thus reducing the pressure signal's variance. As the base cutter's rotating blades are raised, they intercept a smaller cross section of the stool region's soil as illustrated in figure 12.

The increase in variance as the base cutter is raised is monotonic because the cross section supplying the damping force is decreasing monotonically. When the base cutter leaves the soil, its associated pressure signal variance again increases because of a fundamental change in the load, i.e. a change from cutting through a continuous medium of

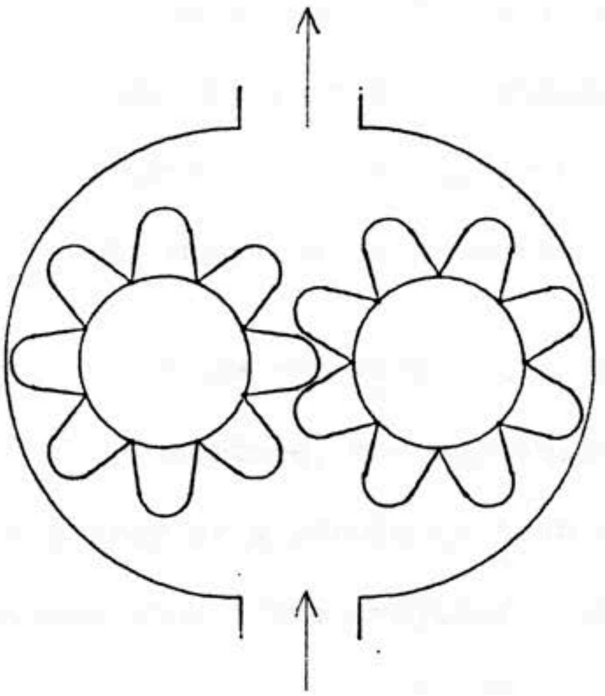


Figure 11

Figure 12

soil to the cutting of irregularly encountered sugar cane stalks.

Close analysis of the experimental results of Reidenbach et al [3] supports this proposition. The model being advanced for the base cutter signal is one of a static load due to the continuous medium of soil together with a persistent impulsive load due to the individual cane stalks. Other vibrational effects of the harvester itself and of stones in the soil superimpose noise onto this signal.

The soil characteristics can vary within a field, as do crop characteristics. Therefore, the mechanical load due to the base cutter will vary as a result of base cutter height and soil characteristics. The variance of the pressure signal is the central second moment of pressure, so that the mean pressure will be required before the variance is calculated. Slow changes in the average pressure are quite likely since the field conditions will not be uniform. The variance should be less sensitive to field condition changes.

2.3 Summary

A proposed height estimation system using the complementary information sources of the average base cutter hydraulic motor pressure drop and the soil surface roughness after base cutting was found inadequate. Further analysis revealed that the variance of the pressure drop signal was related to the cutting height. This relationship was explained in terms of the physical operating conditions of the base cutter, and led to a height estimation proposal based on the variance of the pressure drop signal. Chapter three analyses possible variance estimation algorithms.

Chapter 3

3.0 Variance Estimators

The components contributing to the measured pressure signal are described, followed by a discussion of possible variance estimation algorithms.

The operation of a cane harvester's base cutter mechanism can be regarded as a time invariant system with two parameters under the control of the operator i.e. the harvester's ground speed and base cutter height. The base cutter blade is in contact with the soil which possesses variable physical characteristics.

Due to the cutting load, there is a random pressure signal $p_l(t)$ with statistical properties that are determined by cutting height as well as soil type, crop density etc. Typically, however, the major fast variation in statistical properties will be due to height changes and absence of crop (e.g. at the end of a row). Soil effects should be slowly varying in a field, especially so because of mechanised cultivation.

Under no load conditions (base cutter raised above any matter), a pressure signal $p_m(t)$ will also be measured. This pressure signal is dominantly D.C. with some small periodic component, and will correspond to the losses in the base cutter system, and the series and parallel hydraulic interconnections of numerous rotating devices such as pumps and other toothed motors.

Since $p_l(t)$ and the variation component of $p_m(t)$ are small in magnitude compared to the D.C. pressure signal, and the hydraulic fluid is incompressible, the system is effectively linear in its operation range. By superposition in this linear system, the final pressure signal p(t) will be

$$p(t) = p_l(t) + p_m(t) \qquad ...(3.1)$$

It is the auto-correlation of this signal that is providing an estimate of base cutter height. Further, as this height changes for various reasons, this becomes a nonstationary estimation problem with the need to estimate a slowly time-varying variance.

The auto-correlation function $\gamma_{xx}(\tau)$ of a stationary random process x is defined as $E(x(t).x(t+\tau))$ and, if x is ergodic, may be evaluated as

$$\gamma_{xx}(\tau) = \lim_{T \to \infty} \frac{1}{T} \sum_{i=0}^{T-1} x(i).x(i+\tau)$$

For a finite number of samples, an approximate value of $\gamma_{xx}(\tau)$ is given by

$$\gamma_{xx}(\tau) = \frac{1}{T} \sum_{i=0}^{T-1} x(i).x(i+\tau)$$

for finite T which, for periodic signals, may be evaluated efficiently using the Discrete Fourier Transform (DFT) and, for nonperiodic signals, may be evaluated efficiently using the DFT with zero padding.

An auto-correlation and cross-correlation analysis of experimental cane harvester data was performed to attempt to determine a systematic connection between cutting height, base cutter pressure, trailing roughness, cane throughput and ground speed. The only discernable structure observed was the alteration in $\gamma_{pp}(0)$, that is, the central component of the base cutter pressure auto-correlation, as the height was varied. This may be written as

$$\begin{aligned} \gamma_{pp}(0) &= E(p(t).p(t)) \\ &= var(p(t)) + (E(p(t)))^2 \end{aligned}$$

and, as the mean of the pressure is essentially constant, the variance may be used as the height measure. The variance of p(t) is defined as

$$var(p(t)) = E(p(t) - E(p(t)))^2 \quad ...(3.2)$$

In this application, a measure is required of the damping action of the soil on the pressure signal p(t) therefore it is reasonable to analyse data over a recent, short time period. Since the information is not stationary but slowly varying, an adaptive technique may be necessary. There are various methods of choosing how much data to analyse, and two are considered here.

If the previous n samples of p(t) are considered of equal importance for the calculation of the damping effect, then this is equivalent to passing a rectangular window of size n samples over the data stream as shown in figure 13a. The standard equations to calculate the covariance and mean of n samples of a stationary variable p(t) are given above. For an n sample rectangular window, the mean and variance equations to estimate the (k+1)th estimates are

$$\bar{p}_{k+1} = \frac{1}{n} \sum_{i=k-n+1}^{k} p_i \quad \ldots(3.3)$$

$$V_{k+1} = \frac{1}{n} \sum_{i=k-n+1}^{k} (p_i - \bar{p}_{k+1})^2 \quad \ldots(3.4)$$

or, alternatively, nonoverlapping or partially overlapping data segments can be used.

Implementing equations (3.3) and (3.4) with queues storing n values of $(p_i)^2$ and (p_i) would not require massive computation from a μP. However, in order to provide continuously adaptive estimates, the queues would always be

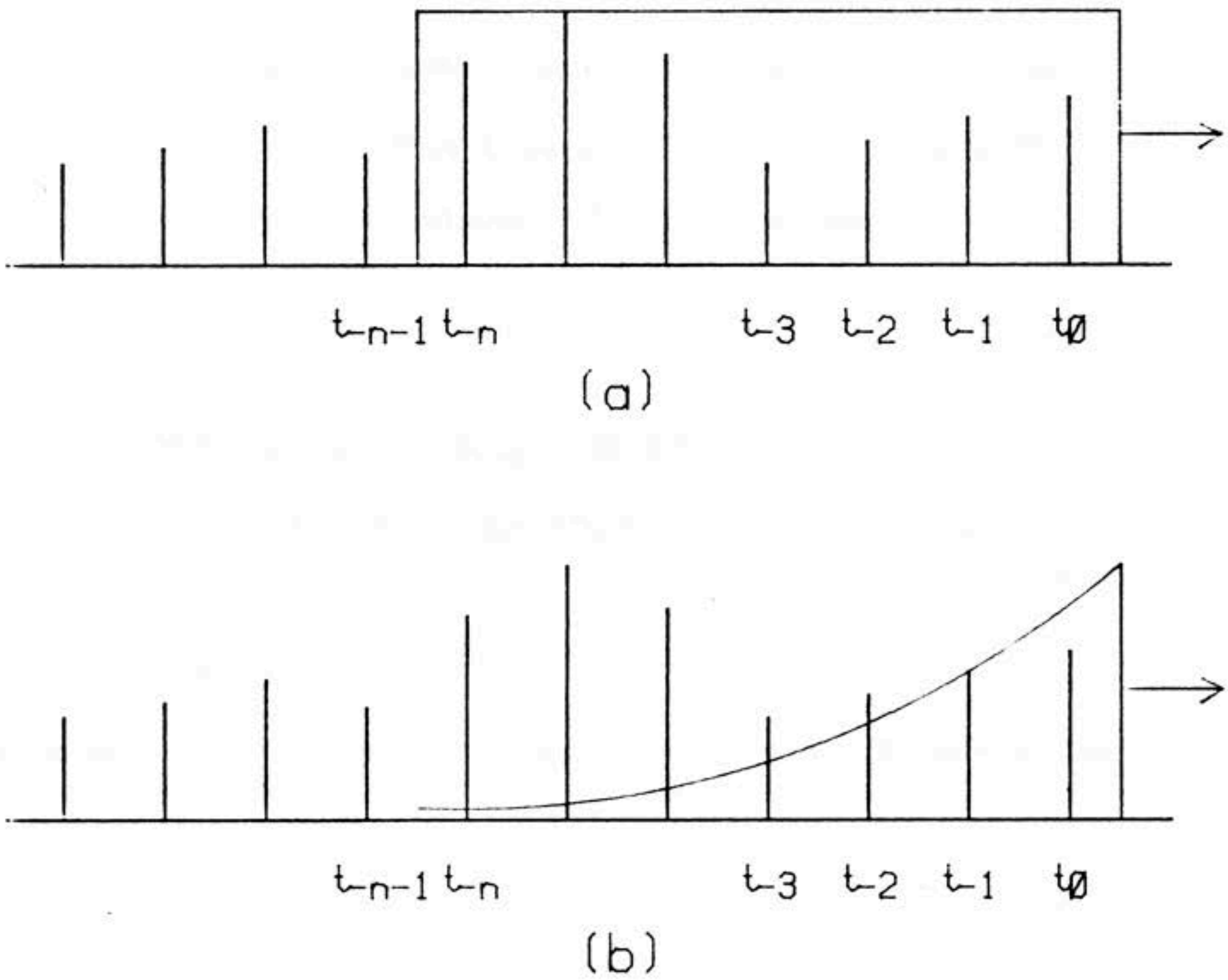


Figure 13

maintained at maximum length. A further disadvantage is that recent samples are weighted as heavily as older samples.

An alternative choice of window function is an exponential window which biases the estimates in favour of new data elements and exponentially decays the weight on past data as shown in figure 13b. The choice of the particular exponential used controls the user's compromise between noise rejection and tracking speed. An exponential mean and variance estimator may be realised with the following equations

$$\bar{p}_{k+1} = (1-\alpha).\bar{p}_k + \alpha.p_{k+1} \quad ...(3.5)$$

$$V_{k+1} = (1-\beta).V_k + \beta.(p_{k+1}-\bar{p}_{k+1})^2 \quad ...(3.6)$$

$$\text{given } 0 < \alpha,\beta < 1$$

The smoothing/tracking characteristics of each recursion are controlled by α and β.

3.1 Properties of Exponential Variance Estimator

The exponential window estimators possess computational and storage advantages which become significant in real-time microprocessor based implementations. From a computational viewpoint, both mean estimation algorithms require a similar number of arithmetic operations while the exponential window variance estimator requires fewer arithmetic operations (in particular, multiplication). From a storage viewpoint, the exponential window estimators do not require two queues but simply the previous estimated value. The rectangular window estimators will therefore be discarded in preference to the exponential window estimators. The choice of α and β will depend on an intelligent judgement of the prevailing field conditions. While the rectangular window has well documented statistical properties for its estimates [13] which show, for example, that the estimates are unbiased, the exponential window may be shown (with a little extra effort) to produce asymptotically unbiased estimates. These properties of the exponential estimator shall now be derived to show that, in practice, it is as effective as the more standard rectangular window.

Consider an independent and identically distributed pressure signal sequence $\{p_i\}$ with mean $\bar{p}$ and variance σ^2. The mean estimate recursion (3.5) may be written as

$$\bar{p}_k = \sum_{i=1}^{k} \alpha.(1-\alpha)^{k-i}.p_i \qquad ...(3.7)$$

$$= (a_k \; a_{k-1} \; a_{k-2} \; ... \; a_1) \begin{vmatrix} p_k \\ p_{k-1} \\ p_{k-2} \\ p_{k-2} \\ . \\ . \\ . \\ p_1 \end{vmatrix}$$

where $a_i = \alpha.(1-\alpha)^{k-i}$.

Taking expected values gives

$$E(\bar{p}_k) = (a_k \; a_{k-1} \; a_{k-2} \; \ldots \; a_1) \; E\begin{vmatrix} p_k \\ p_{k-1} \\ p_{k-2} \\ p_{k-2} \\ \cdot \\ \cdot \\ \cdot \\ p_1 \end{vmatrix}$$

$$= (a_k \; a_{k-1} \; a_{k-2} \; \ldots \; a_1) \begin{vmatrix} \bar{p} \\ \bar{p} \\ \bar{p} \\ \bar{p} \\ \cdot \\ \cdot \\ \cdot \\ \bar{p} \end{vmatrix}$$

$$= \bar{p} \sum_{i=1}^{k} \alpha.(1-\alpha)^{k-i}$$

$$= \bar{p}.\alpha. \sum_{j=0}^{k-1} (1-\alpha)^{j}$$

$$= \bar{p}.\alpha \; . \; \frac{1-(1-\alpha)^{k}}{1-(1-\alpha)}$$

$$= \bar{p}.(1-(1-\alpha)^{k}) \qquad \ldots(3.8)$$

Since $1-\alpha < 1$, then $E(\bar{p}_k) \rightarrow \bar{p}$ as $k \rightarrow \infty$. That is, the mean estimator is asymptotically unbiased.

Next, consider the variance estimate recursion (3.6)

$$V_k = \beta.(p_k-\bar{p}_k)^{2} + (1-\beta).V_{k-1}$$

$$= \sum_{i=1}^{k} \beta.(1-\beta)^{k-i}.(p_i-\bar{p}_i)^{2} \qquad \ldots(3.9)$$

and its expected value

$$E(V_k) = \sum_{i=1}^{k} \beta.(1-\beta)^{k-i}.E(p_i-\bar{p}_i)^{2} \qquad \ldots(3.10)$$

Consider the summands

$$E(p_i-\bar{p}_i)^2 = E(p_i)^2 - 2.E(p_i.\bar{p}_i) + E(\bar{p}_i)^2 \quad ...(3.11)$$

where

$$E(p_i)^2 = \sigma^2 + \bar{p}^2 \quad ...(3.11a)$$

and

$$E(p_i.\bar{p}_i) = E(p_i.\sum_{j=1}^{i} \alpha.(1-\alpha)^{i-j}.p_j)$$

$$= \alpha.\sigma^2 + \sum_{j=1}^{i} \alpha.(1-\alpha)^{i-j}.\bar{p}^2$$

$$= \alpha.\sigma^2 + \bar{p}^2.(1-(1-\alpha)^i) \quad ...(3.11b)$$

and

$$E(\bar{p}^2_i) = E((a_i\ a_{i-1}\ ...\ a_1)\begin{vmatrix} p_i \\ p_{i-1} \\ . \\ . \\ . \\ p_1 \end{vmatrix}(p_i\ p_{i-1}\ ...\ p_1)\begin{vmatrix} a_i \\ a_{i-1} \\ . \\ . \\ . \\ a_1 \end{vmatrix}$$

$$= (a_i\ a_{i-1}\ ...\ a_1)\ \Sigma \begin{vmatrix} a_i \\ a_{i-1} \\ . \\ . \\ . \\ a_1 \end{vmatrix}$$

$$\text{where } \Sigma = \begin{vmatrix} \sigma^2 + \bar{p}^2 \text{ for diagonal} \\ \sigma^2 \text{ for off diagonal} \end{vmatrix}$$

by the independence of p_is.

$$= (a_i\ a_{i-1}\ ...\ a_1)\begin{vmatrix} \sigma^2 & 0 & .. & 0 \\ 0 & \sigma^2 & .. & 0 \\ . & . & .. & . \\ . & . & .. & . \\ 0 & 0 & .. & \sigma^2 \end{vmatrix}\begin{vmatrix} a_i \\ a_{i-1} \\ . \\ . \\ a_1 \end{vmatrix}$$

$$+ (a_i\ a_{i-1}\ ...\ a_1)\begin{vmatrix} \bar{p}^2 & \bar{p}^2 & .. & \bar{p}^2 \\ \bar{p}^2 & \bar{p}^2 & .. & \bar{p}^2 \\ . & . & .. & . \\ . & . & .. & . \\ \bar{p}^2 & \bar{p}^2 & .. & \bar{p}^2 \end{vmatrix}\begin{vmatrix} a_i \\ a_{i-1} \\ . \\ . \\ a_1 \end{vmatrix}$$

$$= \sigma^2 . \sum_{j=1}^{i} (\alpha.(1-\alpha)^{i-j})^2$$

$$+ \bar{p}^2 .(\sum_{j=1}^{i} \alpha.(1-\alpha)^{i-j})^2$$

$$= \sigma^2 .\alpha^2 . \sum_{j=1}^{i} ((1-\alpha)^2)^{i-j}$$

$$+ \bar{p}^2 .(1-(1-\alpha)^i)^2$$

$$= \sigma^2 .\alpha^2 .\frac{1-(1-\alpha)^{2i}}{1-(1-\alpha)^2} + \bar{p}^2 .(1-(1-\alpha)^i)^2 \quad ...(3.11c)$$

therefore

$$E(p_i-\bar{p}_i)^2 = \sigma^2 + \bar{p}^2$$

$$- 2.(\alpha.\sigma^2 + \bar{p}^2 .(1-(1-\alpha)^i))$$

$$+ \sigma^2 .\alpha^2 .\frac{1-(1-\alpha)^{2i}}{1-(1-\alpha)^2} + \bar{p}^2 .(1-(1-\alpha)^i)^2$$

$$= \sigma^2 .(1-2.\alpha+\frac{\alpha^2 .(1-(1-\alpha)^{2i})}{1-(1-\alpha)^{2i}})$$

$$+ \bar{p}^2 .(1 - 2.(1-(1-\alpha)^i) + (1-(1-\alpha)^i)^2) \quad ...(3.12)$$

returning to equation 3.10

$$\text{thus } E(V_k) = \sum_{i=1}^{k} \beta.(1-\beta)^{k-i} .\{\sigma^2 .[1-2.\alpha+\alpha^2 .\frac{1-(1-\alpha)^{2i}}{1-(1-\alpha)^2}]$$

$$+ \bar{p}^2 .[1-2+2.(1-\alpha)^i+(1-(1-\alpha)^i)^2] \}$$

$$= \sigma^2 .(1-2.\alpha).(1-(1-\beta)^k)$$

$$+ \sigma^2 . \sum_{i=1}^{k} \beta.(1-\beta)^{k-i} .\frac{\alpha^2 .(1-(1-\alpha)^{2i})}{2.\alpha-\alpha^2}$$

$$+ \bar{p}^2 . \sum_{i=1}^{k} \beta.(1-\beta)^{k-i} .(1-\alpha)^{2i}$$

$$= \sigma^2.((1-2.\alpha).(1-(1-\beta)^k)+\frac{\alpha}{2-\alpha}.(1-(1-\beta)^k))$$

$$- \frac{\sigma^2.\beta.\alpha}{2-\alpha}.\sum_{i=1}^{k}(1-\beta)^{k-i}.(1-\alpha)^{2i}$$

$$+ \bar{p}^2.\beta.\sum_{i=1}^{k}(1-\beta)^{k-i}.(1-\alpha)^{2i}$$

$$= \sigma^2.(1-2.\alpha+\frac{\alpha}{2-\alpha}).(1-(1-\beta)^k)$$

$$+ (\frac{-\sigma^2.\alpha.\beta}{2-\alpha}+\bar{p}^2).(1-\beta).\sum_{i=1}^{k}(\frac{(1-\alpha)^2}{1-\beta})^i \qquad ...(3.13)$$

$$= \sigma^2.\{(\frac{2-4.\alpha+2.\alpha^2}{2-\alpha}).(1-(1-\beta)^k)\}$$

$$+ (\bar{p}^2 - \frac{\sigma^2.\alpha.\beta}{2-\alpha}).(1-\beta)^k.(\frac{1-(\frac{(1-\alpha)^2}{1-\beta})^{k+1}}{1 - \frac{(1-\alpha)^2}{1-\beta}} - 1)$$

$$= \sigma^2.\{\quad\}$$

$$+ (\bar{p}^2 - \frac{\sigma^2.\alpha.\beta}{2-\alpha}).\frac{(1-\beta)^{k+1}-(1-\alpha)^{2k}-(1-\beta)^{k+1}-(1-\alpha)^2.(1-\beta)^k}{1-\beta-(1-\alpha)^2}$$

$$= \sigma^2.\{\quad\} + (\bar{p}^2 - \frac{\sigma^2.\alpha.\beta}{2-\alpha}).\frac{(1-\beta)^k-(1-\alpha)^{2k}}{1-\beta-(1-\alpha)^2}$$

Taking the limit as $k \to \infty$ to examine the asymptotic properties

$$\lim_{k\to\infty} E(V_k) = \sigma^2 \left(\left(1-2.\alpha + \frac{\alpha}{2-\alpha}\right).\lim_{k\to\infty} (1-(1-\beta)^k)\right)$$

$$+ \left(\bar{p}^2 - \frac{\sigma^2.\alpha.\beta}{2-\alpha}\right).\lim_{k\to\infty} \frac{(1-\beta)^k-(1-\alpha)^{2k}}{1-\beta-(1-\alpha)^2}$$

Now $\lim_{k\to\infty} (1-\beta)^k \to 0$ since $0 < \beta < 1$. Therefore

$$\lim_{k\to\infty} (1-(1-\beta)^k) \to 1$$

and $\lim_{k\to\infty} \frac{(1-\beta)^k-(1-\alpha)^{2k}}{1-\beta-(1-\alpha)^2} \to 0$ if $(1-\alpha)^2 < (1-\beta)$ ‡

Therefore

$$\lim_{k\to\infty} E(V_k) = \sigma^2.\frac{2.(1-\alpha)^2}{2-\alpha} \qquad ...(3.14)$$

Equation 3.14 shows that V_k tends towards the variance scaled by a known parameter, given suitable choices of α and β with $(1-\alpha)^2 < (1-\beta)$. The forgetting factor for the mean $(1-\alpha)$ is thus constrained by the forgetting factor for the variance $(1-\beta)$. This section has shown that the recursions (3.5) and (3.6) can produce asymptotically unbiased estimates of the mean and variance.

Base cutting at different heights produces samples $\{p_i\}$ with various $\bar{p}$s and σs. To distinguish base cutting at these different heights, one must therefore detect when significant variance changes have occurred. For stationary

‡ This condition must be satisfied for equation (3.13) to converge.

data processed with a rectangular window, an F-test may be used to detect when the underlying variance has changed, and with what confidence. To use an F-test, the number of degrees of freedom, or sample size (N) - 1 is required. There is no obvious sample size for the mean or variance estimated via the exponential window recursions. However, since the mean calculation requires a value of N for the rectangular window case, we may consider $E(\bar{p_i}-\bar{p})^2$ for the two algorithms producing $\bar{p_i}$, and postulate a suitable value for N thus allowing F-test based detection of σ^2 changes.

Consider the case for the rectangular window.

$$E(\bar{p_i}-\bar{p})^2 = E(\frac{1}{N}\sum_{i=1}^{N}(p_i-\bar{p}))^2$$

$$= E(\frac{1}{N}\sum_{i=1}^{N}(p_i-\bar{p}).\frac{1}{N}\sum_{j=1}^{N}(p_j-\bar{p}))$$

$$= \frac{1}{N^2}\sum_{i=1}^{N}\sigma^2 \text{ since } E(p_i.p_i)=\sigma^2+\bar{p}^2$$

$$= \frac{\sigma^2}{N}$$

For the exponential window case,

$$E(\bar{p_i}-\bar{p})^2 = E(\bar{p_i})^2 - 2.E(\bar{p_i}).\bar{p} + \bar{p}^2$$

Noting equation (3.11c) gives

$$= \sigma^2.\alpha^2.\frac{1-(1-\alpha)^{2i}}{1-(1-\alpha)^2} + \bar{p}^2.(1-(1-\alpha)^i)^2 - \bar{p}^2$$

As $i \to \infty$, $(1-\alpha)^i \to 0$, therefore

$$\lim_{i \to \infty} E(\bar{p}_i - \bar{p}) = \frac{\sigma^2 . \alpha^2}{1-(1-\alpha)^2} = \sigma^2 . \frac{\alpha}{2-\alpha}$$

In summary, the variance of the rectangular window mean estimate is σ^2/N while for the exponential window mean, the equivalent variance is $\sigma^2.(\alpha/(2-\alpha))$. This leads one to propose that

$$N_{equiv} = (2-\alpha)/\alpha$$

and the resulting degrees of freedom (d.f.) is

$$d.f. = 2/\alpha - 2 \quad \ldots(3.15)$$

Equation 3.14 may be used to obtain an estimate of σ given V_k. In combination with equation 3.15 to estimate the d.f., and with F tables stored in ROM, a variance change detector may be implemented in a real-time microprocessor system yielding possible confidence limit specification.

3.2 Exponential Estimator Tests

Tests with cane harvester pressure data have been performed on the JCUNQ DECsystem-10 mainframe computer. Data segments obtained from field tests conducted at constant ground speeds and at controlled base cutter heights have been concatenated to form a data sequence corresponding to base cutting at low, medium, high, medium, and low heights. Figure 14 shows that the exponential estimator's

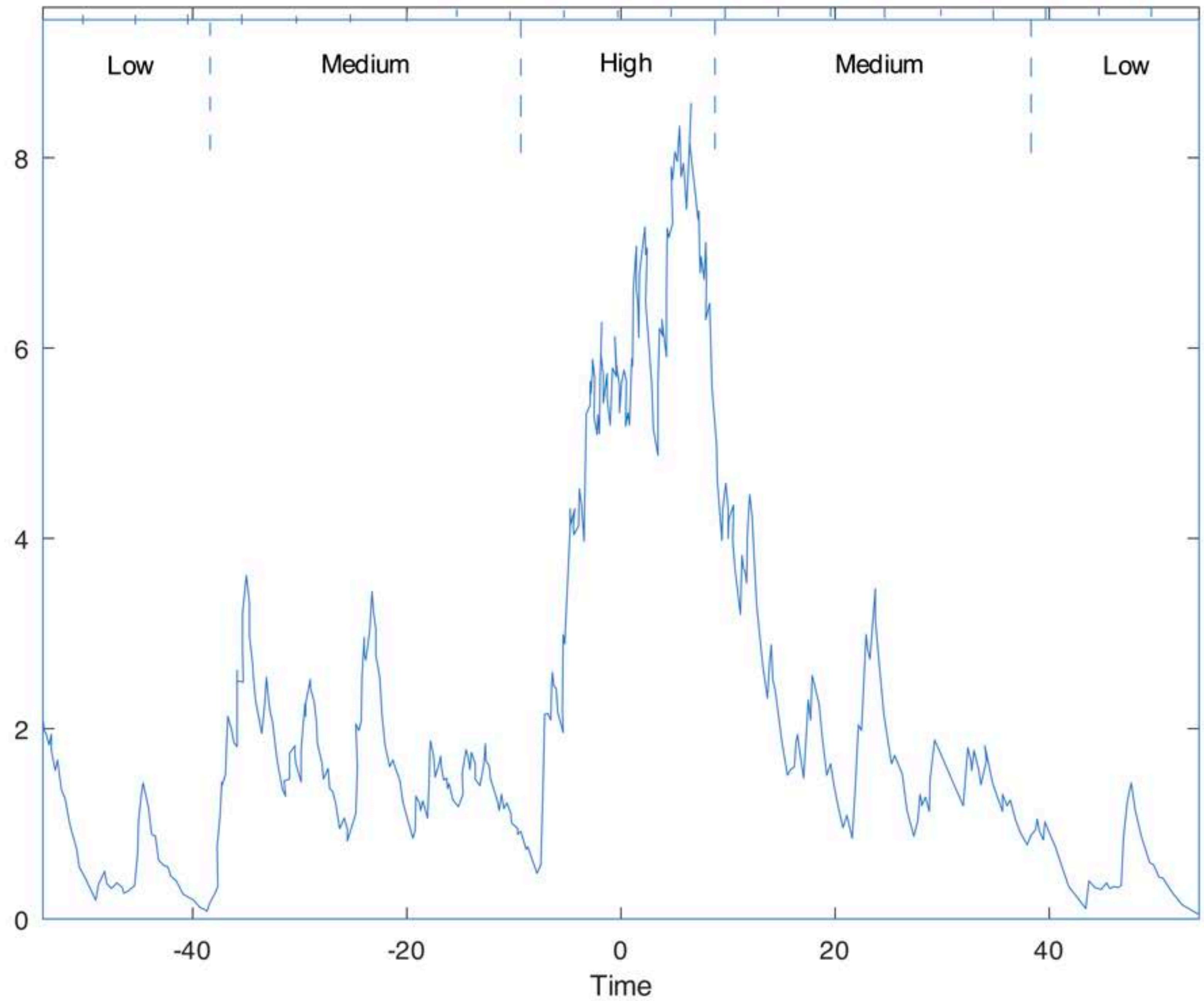


FIGURE 14

response to a change of variance is rapid when the underlying variance is increasing (low→medium and medium→high) and decays exponentially when the underlying variance is decreasing (high→medium and medium→low). These response rates are controlled by the αs and βs, and examination of figure 14 shows that their choice is critical to gain effective noise smoothing and rate of response.

3.3 Summary

The pressure signal $\{p_i\}$ has been described, and two variance estimators outlined. The variance estimator using an exponential window has been chosen, and its statistical properties have been investigated, showing that the mean estimator and variance estimator produce asymptotically unbiased values (the variance is scaled). A height detection algorithm is outlined via F-tests, and the exponential estimators are tested. The hardware and software tools of this study will now be described.

Chapter 4

4.0 Hardware and Software Tools

Information processing for this project has been performed on two computers - a dedicated microprocessor (μP) system and a mainframe machine. Descriptions will be given of; the dedicated μP system hardware and its associated data acquisition subsystems, the μP system software development tools and applications software that have been developed for this project, and the mainframe signal processing software. Major programs are included in the Software Addendum.

4.1 μP Hardware

Figure 15a shows a schematic of the various components in the dedicated μP system, with a table of the common abbreviations used in this description. The choice of μP used in this project was made independently of the author when the Electrical and Electronic Engineering Department acquired the resources necessary to develop Motorola M6800 systems in the 1970's. Thus, an MC6800 based system has been used, based on the Motorola Evaluation Module II (EM-II) board.

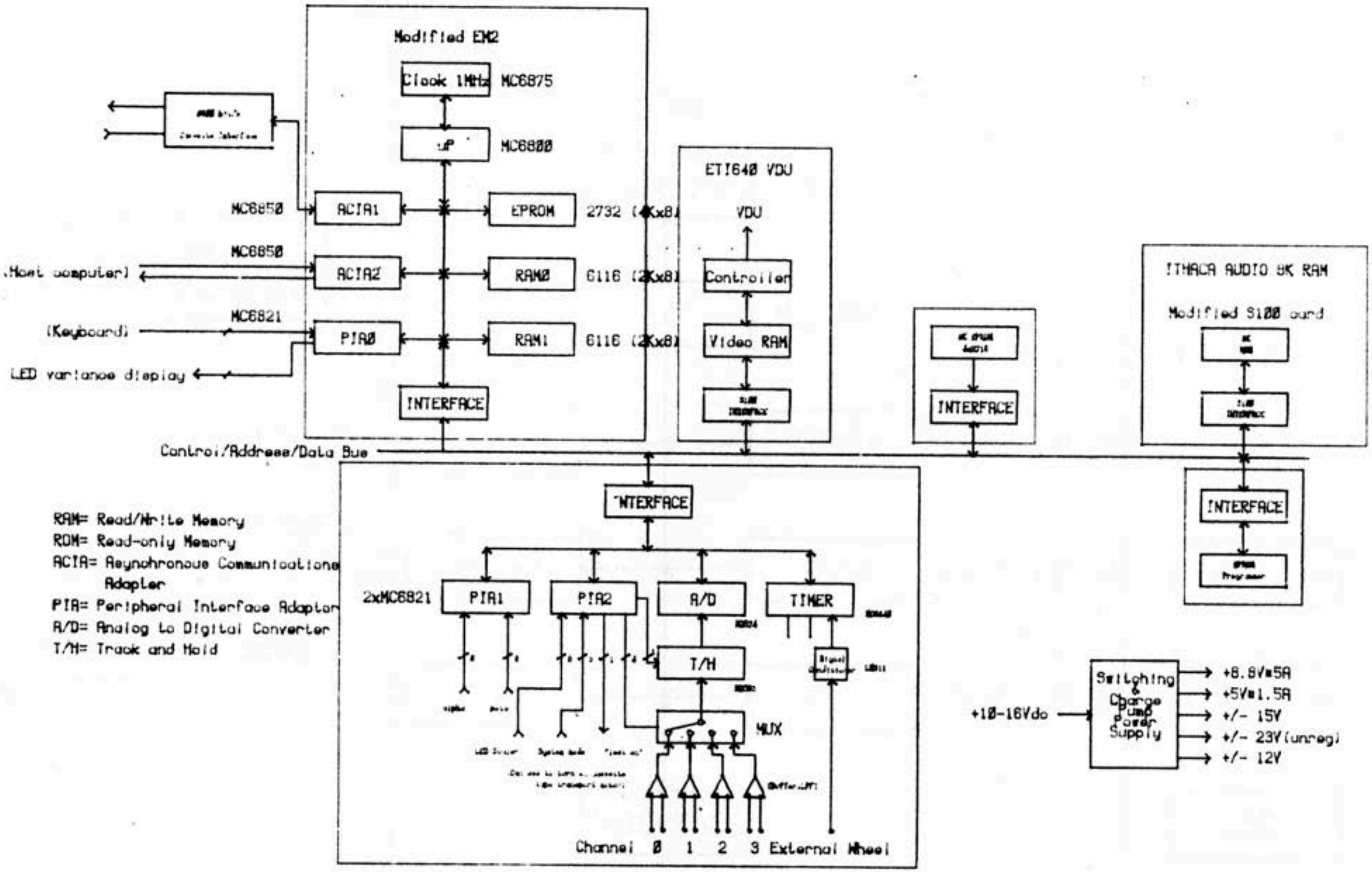


Figure 15a Schematic of the uP System

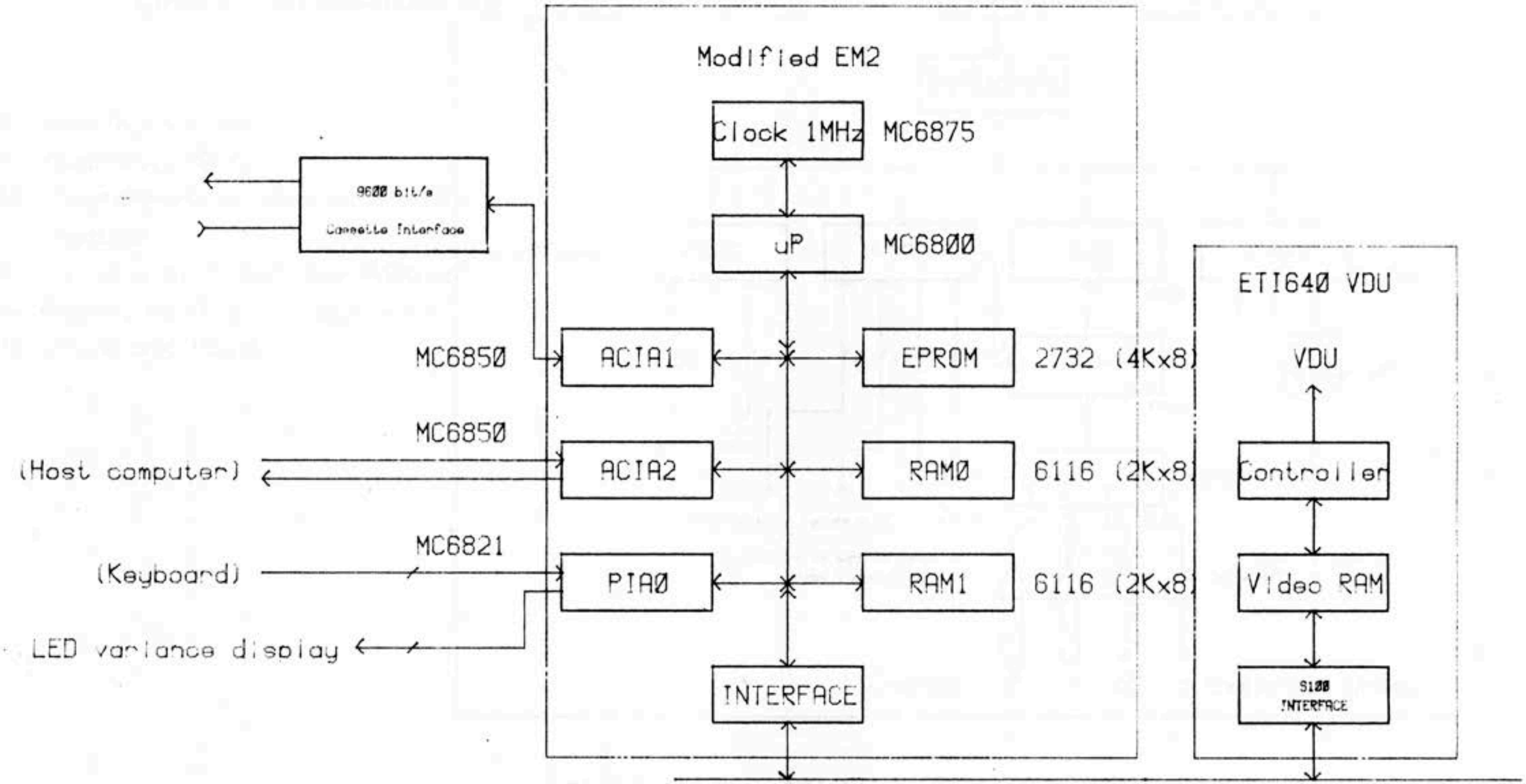


Figure 15b Modified EM-II board

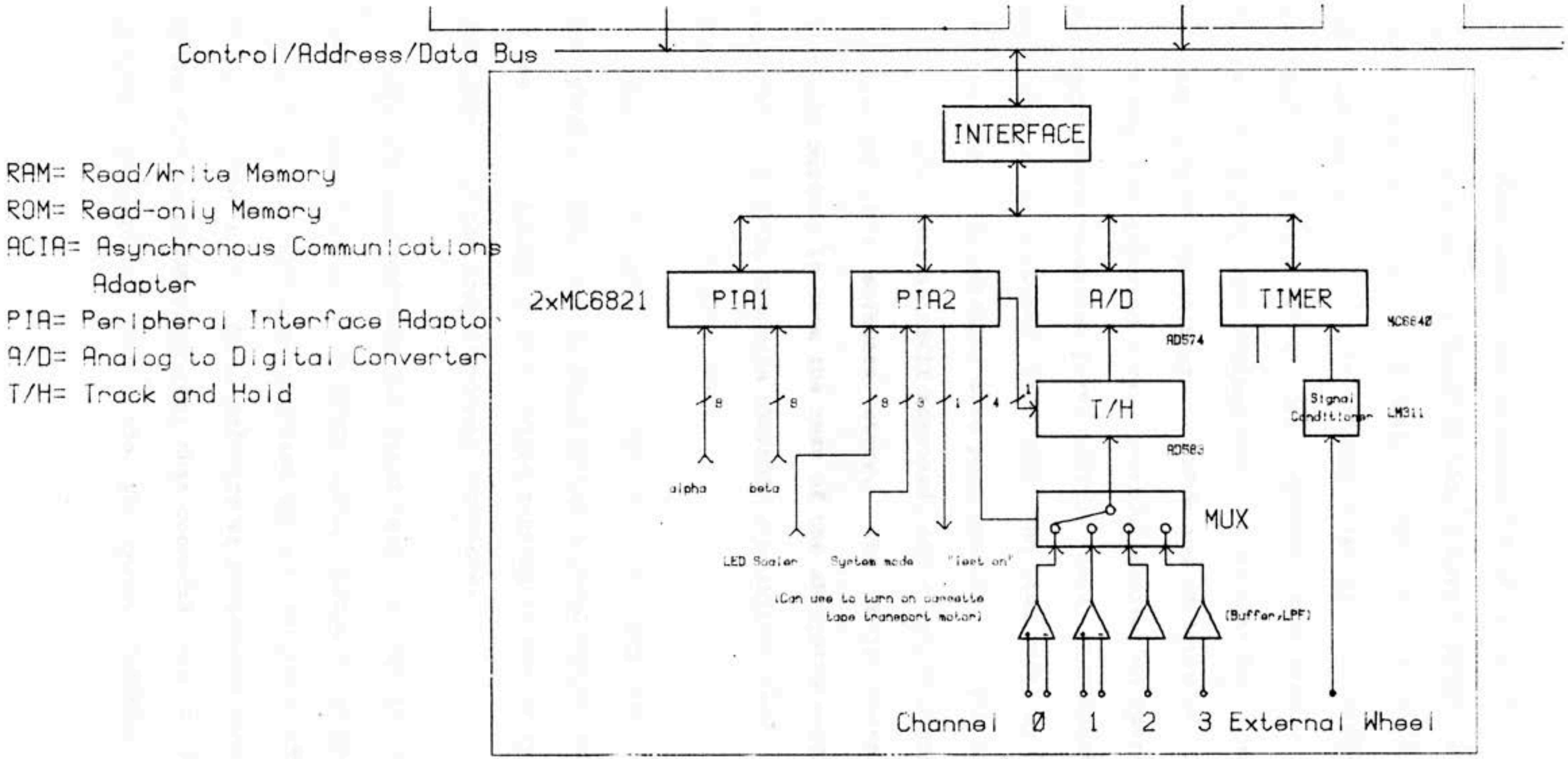


Figure 15c Data Acquisition Subsystem

The standard EM-II board possesses a 1K Bytes EPROM or ROM monitor program, 384 Bytes of RAM, 2 asynchronous serial data communications ports (ACIAs), 1 dual 8 bit parallel data communications port (PIA), and a set of fully buffered Control/Address/Data lines for system expansion. As figure 15b shows, the storage capacity of this EM-II board has been expanded to 4K Bytes of EPROM and 4K Bytes of CMOS static RAM thus allowing a very powerful monitor to operate. The serial communications ports provide data communication with the host computer and with the high capacity tape storage unit. The parallel data port provides 7 input lines to read the user's ASCII keyboard, and 4 output lines to indicate the µP's software state. The EM-II interface circuitry buffers it from the rest of the µP system which is expanded around the Motorola EXORBUS, a modified S100 bus, and at an individual line level.

The user's output is sent to an ETI-640 S100 memory-mapped VDU. Memory mapping has allowed direct access to the user's screen by any routine running in the µP system thus improving the computer-human interface.

Applications software for field tests is stored in a non-volatile form in an 8K EPROM card. During development, the applications software is stored in an optional ITHACA AUDIO 8K RAM card. Final software is programmed into the EPROMs with an EPROM programmer that connects via a spare EXORBUS connector. Thus, the µP system contains the hardware necessary for major system development.

The data acquisition subsystem uses two PIAs, one TIMER/COUNTER peripheral device and a memory mapped A/D convertor with T/H circuitry. Remote analogue signals such as the base cutter pressure signal and the roughness signal are transmitted around the cane harvester in a balanced form to reduce noise interference. These signals enter the data acquisition system via channels 0 or 1 as shown on figure 15c (two other unbalanced signals may also be read). The receiver preamplifiers perform simple low pass filtering to prevent aliasing, and the analogue signals then enter the multiplexor. 4 PIA(2) lines select the desired analogue signal and this signal enters the AD583 based T/H circuit. A data read consists of; setting the T/H circuit to hold, initiating and pausing ‡ while the A/D conversion occurs, reading back 12 bits of data (2 8bit reads) and then resetting the T/H circuit to track. A control line from PIA(2) controls the T/H. PIA(2) also has 8 data lines reading the cane harvester operater's LED variance display scaling factor, coded as two 4 bit BCD character's, and the user's applications software mode control. PIA(1) is devoted to reading the operator's choice of α and β which are each two 4bit BCD characters. The TIMER/COUNTER device provides regular interrupts for internal timing and counts pulses from the fifth wheel placed behind the harvester as a displacement measure (and hence ground speed measure).

‡ Interrupt servicing overhead takes longer than the A/D conversion.

The hydraulic oil pressure drop across the base cutter motor is monitored with temperature compensated National Semiconductor LX series pressure transducers. The two analogue voltage signals corresponding to the input and the output pressure are subtracted with a temperature insensitive single chip amplifier arrangement and a balanced voltage signal is transmitted to the data acquisition system. The oil pressure transducers shown in figure 16 are connected into the cane harvester's oil pressure test points so that no plumbing modifications are necessary. Mounting the pressure transducers and installing the μP system typically takes less than 45 minutes.

The cane throughput signal is obtained from one LX series transducer connected to the chopper mechanism's hydraulic motor. The roughness signal is obtained from two strain gauges which are mounted on each side of the bending spring-steel member of the trailing scratcher as shown in figure 6. This signal is amplified and inverted to produce a balanced voltage signal.

The cassette tape storage unit contains a serial data bit/audio signal encoder and decoder. The encoder features user selectable baud rates and number of audio signal cycles (or half cycles) per serial bit time. One of the slow formats available is the Kansas City Standard since the tape interface always uses two audio tones that are related in frequency by a factor of 2.

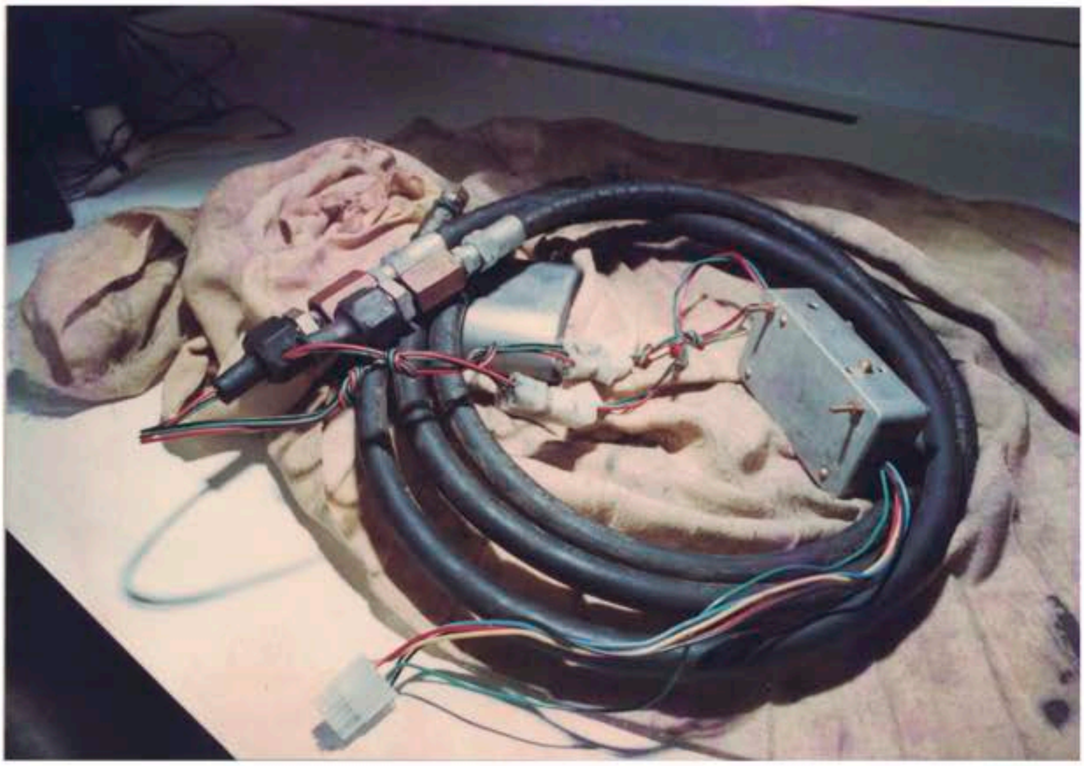


Figure 16 Oil Pressure Transducers

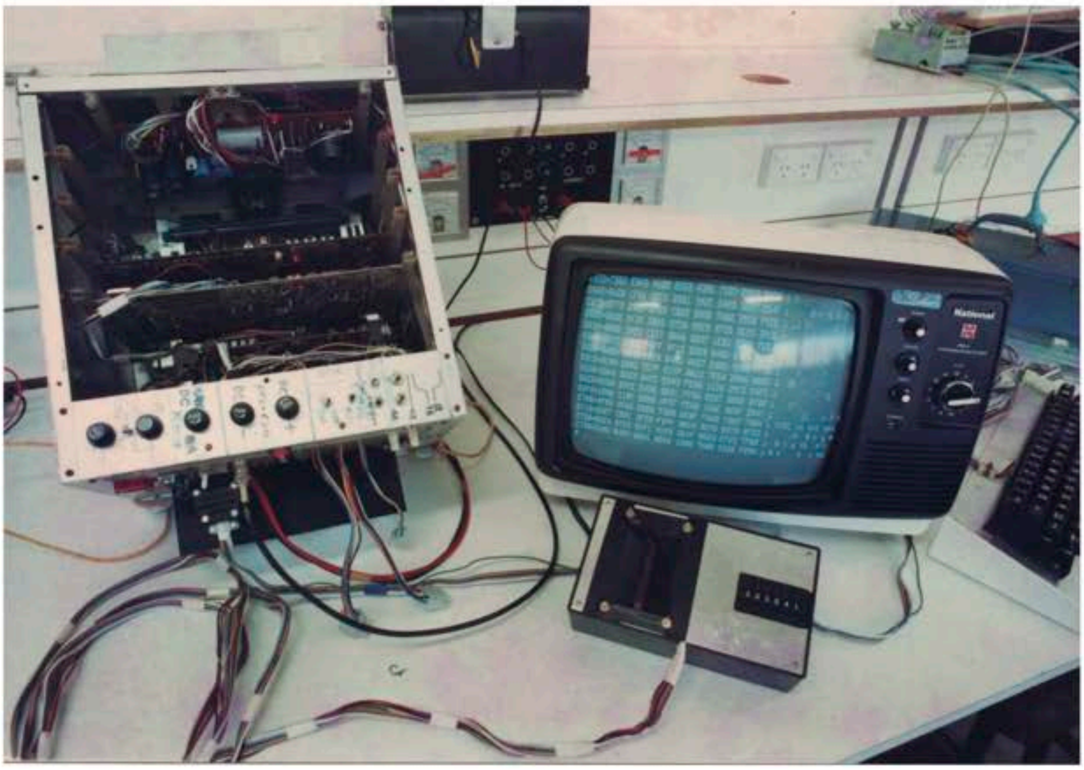


Figure 17a View inside the uP system
with the LED bar display on the right

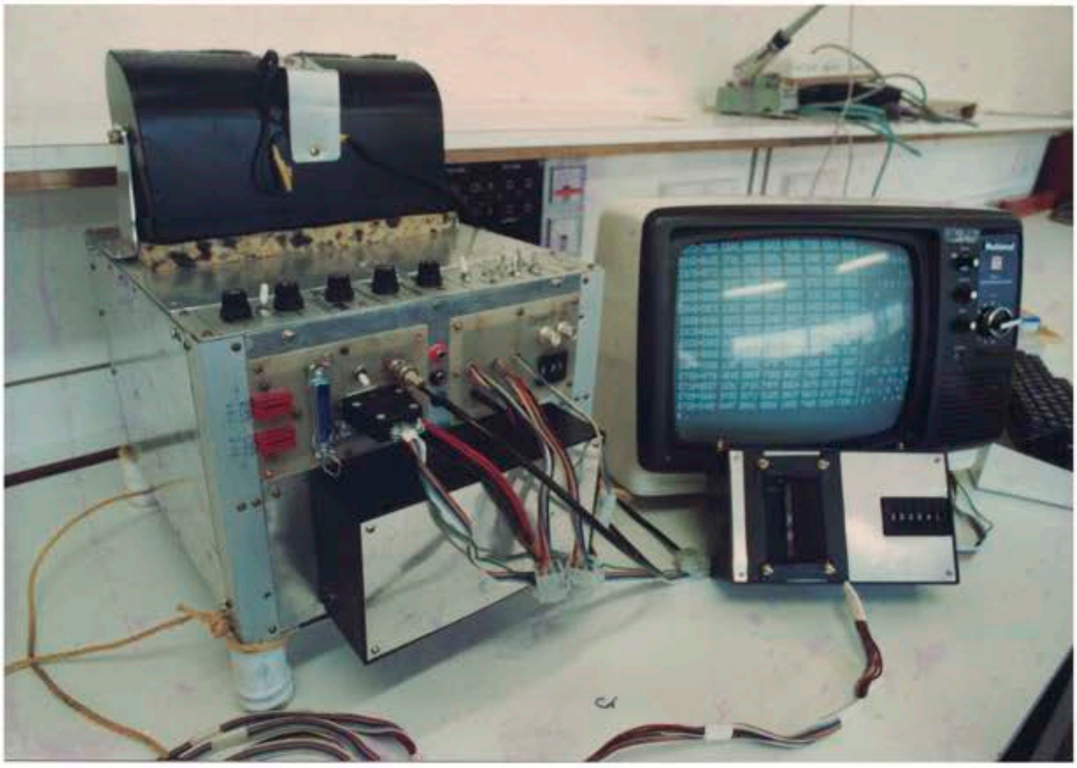


Figure 17b uP system with fan mounted

Figure 18 Cassette Tape Deck in foam lined tool box with Interface Electronics at right

The serial data port of the μP system communicating with the tape interface is an MC6850 which has separate data transmit (Tx) and data receive (Rx) clocks which, for this application, are both set to 16 times the baud rate. When operating at maximum data transmission speeds, the tape interface uses this 16X data clock as its digital sinewave generator clock. Suitable gating allows the input serial data from the MC6850 to change the audio output's sinewave frequency at its zero crossings so that the output audio waveform is locked to the bit rate. Such a technique greatly simplifies the decoder design which measures the time period between zero crossings of the audio tone and, by continually updating a hardware queue of length 1 bit, outputs a serial data 1 whenever 2 consecutive short time periods are detected, and a serial data 0 otherwise.

In the high speed mode of operation used in this project, a half cycle of the lower frequency tone corresponds to a serial data 0 and a full cycle of the higher frequency tone corresponds to a serial data 1. At 9600 baud, a 90 minute METAL cassette tape costing less than $15 can store approximately 6.4 Megabytes. (A maximum data transfer rate of 9600 baud exists because $f_{high\ tone} = 19k2Hz$ which corresponds to the bandwidth of the cassette deck's audio channel).

The height estimate produced by the variance estimator is displayed to the operator on an analogue display consisting of a bar of rectangular light emitting diodes (LEDs) shown in figure 17a. This display is mounted on the cane harvestor operator's overhead instrument panel. The LEDs are driven by a circuit consisting of shift registers and discrete driver transistors. The serial-in serial/parallel-out shift register's are cascaded and are controlled by 3 output lines of PIA(0). The present system uses 24 LEDs with display size modification simply requiring the addition (or deletion) of shift registers and one assembly language constant definition change. The display uses common components, is low cost and provides the height information in a form that the human operator can assimilate with a quick glance.

The remote signal conditioning units are mounted in strong die cast aluminium boxes. Figure 17b shows the main µP system mounted in an aluminium box with a fan forced air flow. The data storage unit is a METAL tape Hitachi Hi-Fi cassette deck which has been modified to operate from DC only. This unit features a tape transport mechanism with a vertically mounted flywheel that helps resist wow and flutter. By enclosing the tape deck in foam and mounting it in a tool box as shown in figure 18, a high degree of mechanical vibration resistance has been achieved with the resultant constant tape speed and interface electronics achieving high data transfer rates. The µP system and the data storage unit boxes also have soft rubber feet to reduce mechanical vibration and associated system deterioration.

As figure 15a shows, the power supply generates +5V, ±12V, ±15V, ±23V, and +8.8V dc. The ±23V unregulated supply is generated with a charge pump circuit, with the lower positive and negative voltages obtained with standard regulators. The +8.8V supply is generated via an LM317 based switching regulator. This regulated supply is fed to all the +5V regulators so that their individual heat dissipation is minimised. The +8.8V regulator uses an externally mounted heat sink and the other regulators use the µP system case as a heat sink. If the +8.8Vdc regulator fails with Vout = +12V, the various +5V dc regulators would continue to operate until thermal shutdown occurred. When in the field, the unit operates from a combination of cane harvester dc and an auxiliary battery dc supply with lower and upper voltage limits of +10V and +16V (the auxiliary battery is necessary during cane harvester starting).

4.2 µP System Software Development Tools

The EM-II's resident program (MOPS50) contains two separate sections providing the local monitor mode and the host computer virtual terminal mode. (MOPS50 is located in upper memory, as shown in the memory map of figure 19.) The features of these two modes will now be briefly described.

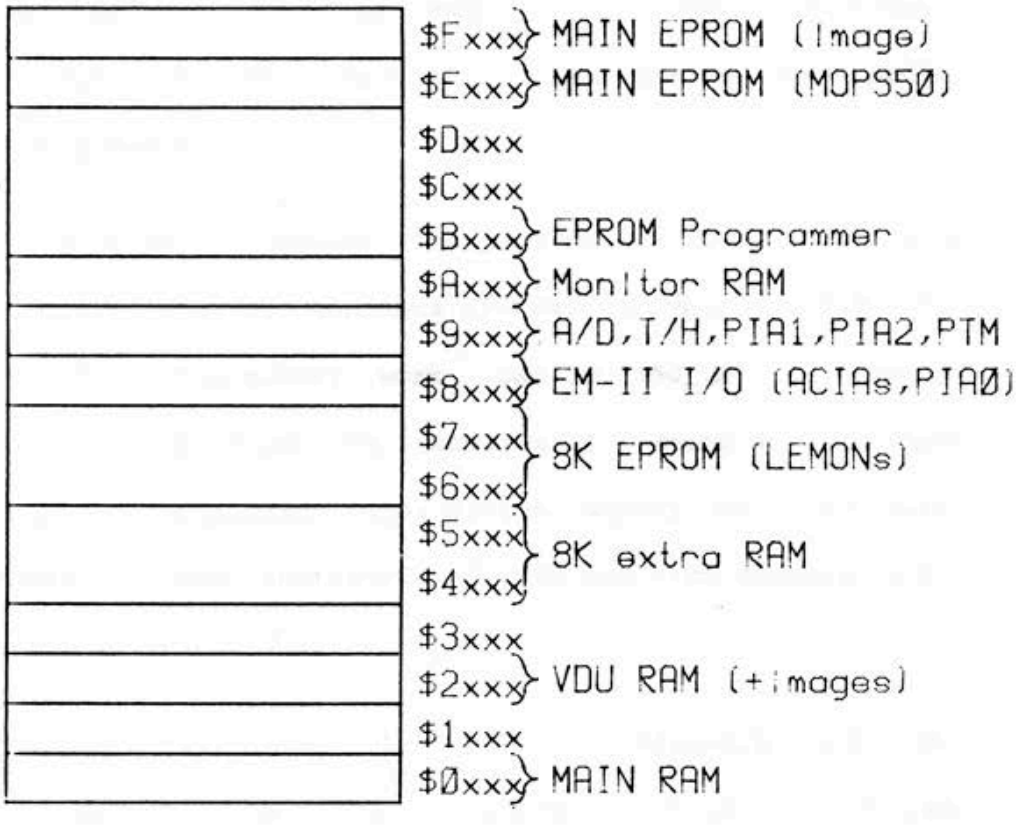

$Fxxx MAIN EPROM (Image)
$Exxx MAIN EPROM (MOPS50)
$Dxxx
$Cxxx
$Bxxx EPROM Programmer
$Axxx Monitor RAM
$9xxx A/D,T/H,PIA1,PIA2,PTM
$8xxx EM-II I/O (ACIAs,PIA0)
$7xxx
8K EPROM (LEMONs)
$6xxx
$5xxx
8K extra RAM
$4xxx
$3xxx
$2xxx VDU RAM (+images)
$1xxx
$0xxx MAIN RAM

Figure 19

4.2.1 Outline of the Local Monitor - MOPS50_LM

The MOPS50_LM commands available to the user are shown in figure 20. The usual memory register read_modify commands are available. In addition, a memory contents display command produces a combined HEX and ASCII dump of user specified 16byte records. An auto-repeat feature allows the user to very easily and quickly scan through consecutive records, immediately recognising any ASCII strings present.

When testing software, the user often finds that the same local monitor commands are repetitively entered. To remove this unnecessary work load MOPS50_LM includes a facility which allows the execution of command strings that have been downloaded into system memory by the host computer, stored and retrieved with the tape storage unit, or typed in by the user.

A choice of concurrent execution of MOPS50_LM and the user's applications software results in software controlled swapping between the applications software and MOPS50_LM. The MC6800 software interrupt instruction (SWI) is used to change µP execution from the application software to MOPS50_LM. The SWI instruction saves a complete copy of the µP's registers on its stack, and MOPS50_LM's SWI handler then stores the position of this stack and redefines a new stack in the system RAM area (as shown in figure 19). This copy of the µP's registers may be modified by MOPS50_LM

```
  { Let CH contain the user's input command character }
      { Assume that HEX numbers have a "$" prefix }

INPUT_CH;

CASE CH OF

  <space> : REPEAT; { repeat last OPEN or DISPLAY command }

  'd' : DISPLAY;   { display 16bytes of data in HEX,ASCII }

  'O' : OPEN;       { open user specified memory location }

  'E' : EXECUTE;       { execute a user specified command
                                 string stored in memory }
  'P' : PUT_ASCII;       { store a string in memory (may
                               be used by the E command) }
  'G' : SWAP_BACK;         { reenter execution of user's
                                   applications software }
  'C' : SWAP_NEW;            { execute a new user program }

  'R' : REGISTER_INSPECT/CHANGE;       { open a specified
                register in the application's software }
  'S' : SUBROUTINE_EXEC;           { execute a subroutine }

  'T' : ENTER_MOPS50_VT;    { enter virtual terminal mode }

  'A' : ALLOCATE_VDU_RAM;              { allocate VDU RAM }

  <control Y> : SOFT_RESET;

  <control A> : GOTO $6000;         { go to jump vector 1 }

  <control B> : GOTO $6003;         { go to jump vector 2 }

  <control C> : GOTO $6006;         { go to jump vector 3 }

  OTHERS : IGNORE_OTHER_CHARACTERS;

END;
```

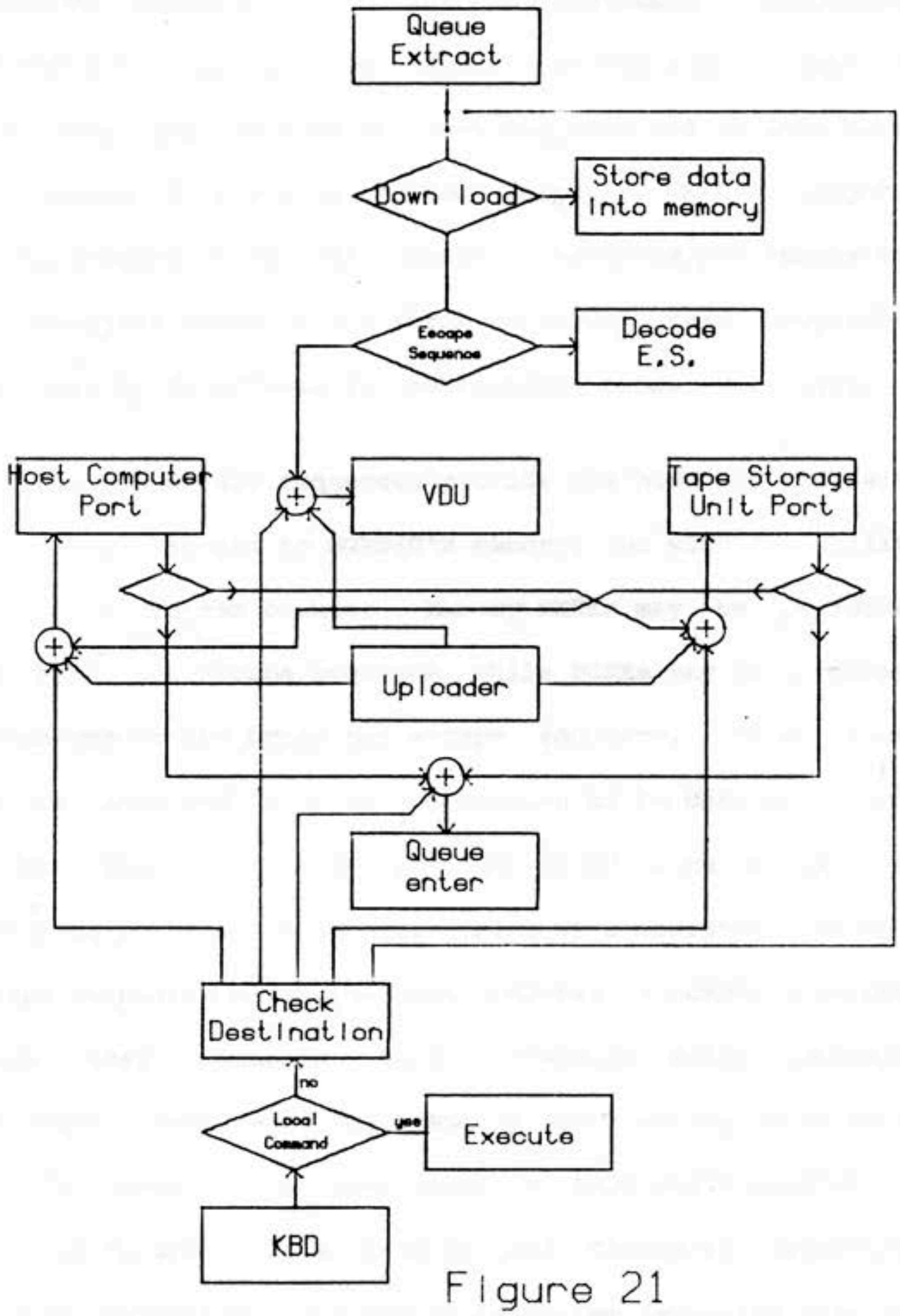
Figure 20 MOPS50_LM user commands

commands so that the user may specify all register contents at commencement of application software execution. Re-entry to the user's applications software is achieved by resetting the stack pointer and executing a return from interrupt instruction (RTI).

Since MOPS50_LM allows the user to modify any register of the µP's application software, multiple application software programs may be individually executed by pointing the application software stack pointer to the desired copy of the µP's registers which includes the new program counter.

4.2.2 Outline of the Virtual Terminal - MOPS50_VT

Virtual Terminal mode is implemented using the interrupt system as shown in figure 21. Since the µP system is simulating a terminal, the background task is primarily concerned with extracting characters from the system queue, displaying these characters on the VDU and managing the memory mapped VDU - a significant load because of the software scrolling. At power up the user allocates extra RAM to provide up to 4 extra pages of VDU memory. By storing these extra lines-of-text in a circular buffer, no significant scrolling overhead is suffered. The background task is also responsible for performing downloads of TEKTRONIX formatted object code into the µP's memory, and



Queue Extract
Down load
Store data into memory
Escape Sequence
Decode E.S.
Host Computer Port
VDU
Tape Storage Unit Port
Uploader
Queue enter
Check Destination
no
Local Command
yes
Execute
KBD

Figure 21

for decoding and executing escape sequence commands with handshaking.

Group 1 escape sequences provide 4 EPROM programmer primitive functions which set the programming time period, set the programmer's EPROM address, perform a block read of data from the EPROM to the host computer and perform block programming of data from the host computer. A host computer PASCAL program (CLONE.PAS) controls the EPROM programmer via the primitive commands and forms an easily used programmer that readily interfaces to the existing cross assemblers.

Group 7 escape sequences provide the host computer with byte level access to MOPS50's memory, and with the ability to set the program counter. Memory PEEKs may be performed one byte per escape sequence, while POKEs may be performed either one or two bytes per escape sequence. This allows vectors involved with I/O processing to be changed. Since all the user's commands are concerned with setting or resetting flags which control MOPS50_VT's operation, group 7 escape sequences allow the host computer to remotely perform these user commands thus providing fully automatic operation. Because of the symmetry shown in figure 21 it is equally possible to play back a tape which enables the downloader, downloads a program and commences execution. Another important application is system debugging when the normal user I/O is inoperative and the host computer is able to access all of the MOPS50 system.

The foreground tasks handle all incomming data from the user, the host computer and the tape data storage unit. As figure 21 shows, serial port data from the host computer or tape data storage unit usually enters the queue or is transferred to the other serial port. A port to port data transfer allows cane harvester binary test data to be sent to the host computer for postprocessing (this data transfer is affected by downloading an MC6800 program UPLOAD to 'sit' on top of MOPS50_VT and provide another queue between each serial port).

User commands and memory uploads are performed as alternative background tasks. The most useful feature has been the download capability which has allowed rapid software development with cross assemblers.

4.3 Outline of real-time base cutter pressure data processing software - LEMON4.

LEMON4 uses the MC6800's non-maskable interrupt facility to switch between five modes of operation:

Mode 0 - to exit LEMON4 and to reenter MOPS50_LM,

Mode 1 - to process user commands (this is the usual LEMON4 entry point),

Mode 2 - to perform variance calculations with all results displayed on the VDU,

Mode 3 - as for mode 2 but with all output data directed to the cassette tape data storage unit,

Mode 4 - as for mode 3 but with a minimum set of data stored on tape to increase throughput.

Mode swapping is initiated when the user forces the µP to execute a non-maskable interrupt and the system mode switch is then read. The µP usually commences operation in the new mode immediately, apart from the exception described shortly.

Figure 22 shows the two foreground tasks which perform timer initiated processing (task 1) and data initiated processing (task 2). Part A of task 1 maintains a real-time clock and, once every 50ms to 100ms (user's choice), initiates part B which estimates the height. The height estimation calculation and the associated A/D and T/H control operations must always be completed before part B is again entered so that height estimates are produced

```
TIMER_INTERRUPT: UPDATE_SAMPLE_TIMER;           { part a }

                 IF DATA_SAMPLE_DUE THEN  { start part b }

                   BEGIN        { part b processes data }

                     IF PROCESSING_ON THEN GOTO ERROR;

                     PROCESSING_ON := TRUE;{set semaphore}
                     ENABLE_INTERRUPTS;      { allow time }
                     INPUT_DATA;            { keeping etc }
                     UPDATE_OPERATOR'S_DISPLAY;
                     PROCESS_IT;

                     CASE MODE OF{process data three ways}
                               {modes 2,3 send data=>tape}
                       2: UPDATE_VDU_DISPLAY;

                       3: BEGIN
                            ENQUEUE_ALL_DATA;
                            ENQUEUE_ALL_DATA;
                            CHECK/ADJUST_TASK2_STATUS;
                          END;

                       4: BEGIN
                            ENQUEUE_INPUT_DATA;
                            ENQUEUE_INPUT_DATA;
                            CHECK/ADJUST_TASK2_STATUS;
                          END;

                     DISABLE_INTERRUPTS;
                     PROCESSING_ON := FALSE;

                   END;

                 RETURN_FROM_INTERRUPT;

         ERROR: REPORT_ERROR_TO_USER;   { handle high }
                STOP_TIMER;       { sample rate error }
```

Figure 22 (Task 1)

```
ACIA1_TX_INTERRUPT:

                 IF DATA_IN_QUEUE THEN

                   BEGIN         { part b processes data }

                     EXTRACT_BYTE;
                     TRANSMIT_BYTE;

                   END
                   ELSE
                   BEGIN

                     CLEAR_DATA_TX_FLAG;
                     DISENABLE_THE_ACIA'S_TX_INTERRUPT;

                     IF NEW_MODE THEN GOTO MODE_CHANGE;

                   END;

                 RETURN_FROM_INTERRUPT;
```

Figure 22 (Task 2)

regularly and in correct order. This is achieved by having part B test and set a semaphore at its start, and clear it on completion. Interrupt processing is allowed during this interval so that time keeping and data transfer functions are maintained, but any attempt to commence processing the next set of pressure data results in a system halt at the semaphore test stage with an appropriate user message. The final data is sent to the VDU when operating in mode 2, or to the cassette tape data interface via a queue when operating in modes 3 or 4. Mode 2 allows complete system tests to occur with the μP system mounted on the harvester before a field trial commences. Modes 3 and 4 perform all calculations and enqueue the output data for task 2 to send to the tape unit. Task 2 and task 1 (part B) are naturally separate since the first runs continuously and the second is periodic.

Task 2 is enabled when an enqueue operation of task 1 detects that this process has been suspended. If task 2 empties the queue, it suspends itself after ensuring that no mode change is imminent. As was briefly stated, if a mode change is to occur out of modes 3 or 4, a flag is set and further data sampling disabled so that task 2 may send a complete data record and then tidily effect the mode change.

The data entered into the tape queue is duplicated so that time diversity on the tape will assist in avoiding data loss resulting from a severe disruption of the tape speed.

All the important functions of LEMON4 and its predecessor (LEMON1) are performed by subroutines, thus providing the core code for an in-field data postprocessor (LEMON2). LEMON2 allowed the user to rerun field tests in real-time with new αs and βs, and to compare the results on the VDU in the form of bar graphs. Experience has shown that this type of data postprocessing is impractical because of constraints on the harvester contractors who must equate lost harvesting time with lost money. In-field data postprocessing software has therefore been discontinued and is not discussed here.

All arithmetic is performed with a 32 bit integer 2's complement maths package called PMATHS. Since all division operations required in the calculation of the mean and vaiance estimates involve known divisors, PMATHS does not include a division subroutine because it is faster (and easier) to multiply by binary fractions that have been calculated by the MC6800 cross assembler.

Two assembly options provide extra features in LEMON4. Setting the CALLIB option results in an application program (LEMONC) which is designed to assist in the calibration of the analogue signal processing circuitry. Setting the UPSIDE option allows the user to easily compensate for the mounting orientation of the LED bar display (right side up or up side down).

4.4 Outline of Mainframe Signal Processing Software

The cane harvester data is in the form of 8 bit binary bytes. The MC6800 program UPLOAD is assembled and downloaded into MOPS50_VT so that fully buffered communication is established with the host computer (DEC-10). The data tapes may be played back via UPLOAD to a DEC-10 MACRO-10 program UPTAPI.MAC ‡ which compacts 4 bytes into each word of DEC-10 disk storage.

Pascal program MAGIC.PAS reads these binary data files and decodes them taking into account the various formats. By RESETing the input file as a FILE OF 0..255, the Pascal system splits up the data into a sequence of 8 bit bytes. Pascal program PRESTO.PAS then processes the ASCII data removing redundancy (LEMON4 enqueues data to tape twice) and errors by analysing checksum data. A data retrieval report is given.

A modified version of MAGIC (MAGIC_PLUS) is being tested and developed. It is a finite state machine simulation of a phase lock loop that locks onto the byte data stream during decoding. Data losses should be minimised since it analyses the data stream in both a forward and reverse direction.

‡ written by Mr. A. Shipman

Fortran program WIZARD.FOR, run with subroutines in WITCH1.FOR and WISP.FOR, provides a graphics display simulating the operation of the LEMON software. Pressure, pressure mean, pressure velocity, and harvester velocity recorded during tests are plotted in the 4 quadrants of the graphics display.

Running WIZARD.FOR with Fortran subroutines WITCH2.FOR provides plots of means and variances recorded in field tests, and plots of similar quantities calculated locally. This allows LEMON system verification.

Interactive design of the variance estimator's αs and βs is performed by running Fortran program GENIE.FOR with WITCH2.FOR compiled so that lines commented out with D are now included. After observing a data display obtained using the field values of α and β the user can adjust α and β until a satisfactory result is displayed. Since the graphics display routines (HP.FOR) developed during this project also allow pixel clearing, GENIE erases old information so that only two sets of results are displayed at any one time.

4.5 Summary

The hardware and software tools description shows that considerable original design was required ranging from practical aspects such as vibration proofing, operator display construction, and analogue/digital electronics to the software design of the μP's monitor and real-time variance estimation programs, and the DEC-10's signal processing/graphics programs. Chapter 5 concludes with a description of the achievements gained with these tools, and a discussion of future work.

Chapter 5

5.0 Conclusion

The base cutter height control problem for sugar cane harvesters has been described and justified. Various methods have been proposed and examined, and the one focused on here as the most promising was the base cutter hydraulic motor's pressure difference method. An experimental and physical analysis of this system led to the proposition that the base cutter hydraulic motor's pressure difference variance could be used as a quantifier of cutting height. This is a novel approach to processing the pressure difference signal as other pressure difference methods relied on mean estimation - a notably insensitive measure. The estimation of variance provides a particularly robust procedure for height determination since it is tolerant of sensor offsets and inter-machine pressure variations. Since the thesis of this work is that the distribution of the random pressure signal is a function of base cutter height the use of variance as a height measure requires the application of an adaptive variance estimator to detect and determine height changes.

Two techniques were considered for variance estimation; the rectangular window estimator and the exponential window estimator. The former of these is familiar from statistical theory and would initially appear to have statistical advantages as an estimator - being well documented and unbiased. However, for real-time applications, it may be storage bound. The latter technique was presented and examined to demonstrate its capabilities for the task. In particular, it was used to derive an asymptotically unbiased computationally simple estimation algorithm suitable for microprocessor implementations. In addition, a novel proposition was advanced to associate a degrees of freedom measure to the estimator to allow the application of an F-test to detect variance changes.

Hardware was structured to implement the estimation procedures on board an operating sugar cane harvester taking into account the hostility of the environment and the need for effective computer-human communication of the height estimates to the operator.

There were several novel aspects of the hardware and software such as; a cheap cassette tape data storage system operating at variable baud rates up to 9600 baud, a local monitor that swaps between self execution and user application program execution in a concurrent manner, host computer communication software that provides remote peek and poke and other higher level functions allowing remote system testing, pressure interface data logging, and the human's analogue display.

The status of the system is that preliminary tests have been conducted to verify the operation of the exponential window height estimator. These results would indicate that there is necessarily a compromise between noise smoothing in the estimate and tracking speed. The adaptation speed demonstrated in figure 14 indicates that a significant time delay may need to be introduced so that reliable height discrimination is possible.

5.1 Future Directions

At present, the selection of suitable αs and βs depends on knowledge of the soil's characteristics. A knowledge of how to select α and β for various soil types and conditions will greatly simplify operator operation. It is considered that automatic selection of α and β is not possible since this would require total knowledge of varying field conditions.

The addition of the F-test based variance estimate change detector proposed in Chapter 3 will greatly simplify operator use since this will enable the height sensing system only to gain the attention of the cane harvester operator when a change in base cutting height has occurred. This feature would also allow a semi-automatic control loop to be developed. Successful implementation of a semi-automatic control system would reduce the operator's task to a level chiefly concerned with the intelligent selection of α and β.

As the hardware costs of more powerful μPs continue to decrease, the decision to disregard an acoustical sonar system because of the computational complexity of the necessary digital signal processing algorithms will eventually be negated. Further, the increasing availability of high level language support will allow reasonable development times for the signal processing software. Higher μP throughput will also allow more complicated mean and variance estimation algorithms to be considered for use with non-stationary signals. For example, Timofeyev and Nikitenko [14] have proposed a modification to a stochastic stationary signal mean estimation algorthm which features fast convergence and adaptive smoothing/tracking but which cannot be implemented presently because of computation constraints.

In summary, further work is envisaged on the selection of the exponential estimator's αs and βs, and on the implementation of an F-test based height estimate change detection algorithm. Further consideration is also justified on signal processing intensive techniques such as the acoustical sonar system since it features notable control implementation advantages and the necessary μP power is becoming readily available.

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