A SPECIAL PURPOSE PROCESSOR FOR LOCOMOTION DATA EXTRACTION

A Thesis
Presented to
The Faculty of Graduate Studies
The University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Michael J. Slonosky
September 1979

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TO MY PARENTS

ABSTRACT

This thesis describes the LODE (Locomotion Data Extraction) System, which was designed as a real-time data acquisition system for use in locomotion studies. It employs a special purpose, bit-sliced microprogrammed processor for the reduction of sampled coordinate pairs to coordinate centres. The system is designed such that the collection of data is totally independent of the computer to be used for a detailed analysis. This fact combined with the capabilities of the system, makes it attractive for possible uses in a clinical environment.

ACKNOWLEDGEMENTS

The preparation of a dissertation, among other things, is a learning process. One of the most salient features of any learning process, like most aspects of applied engineering, is that the results are not usually spontaneous in nature. Rather, it is a combined result of many factors, of which probably one of the most important is that it's creation must be guided and directed. In this respect, I would like to express my most sincere appreciation and gratitude to my thesis advisor, Dr. E. Shwedyk, who provided me with, not only his valuable time, but also his technical guidance, support and encouragement.

I would like to thank Signetics for their grateful contribution of a microassembler, which simplified and shortened the job of microrogramming.

My appreciation is expressed to the National Research Council of Canada for their financial support.

I would like to thank the technicians of the Department of Electrical Engineering for their support and technical advice.

Last but not least, I am grateful to my Mother, for the careful and special care she took in the typing of this thesis. Her patience and support during that phase contributed greatly to it's completion.

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LIST OF SCHEMATICS

GLOSSARY OF MNEMONICS

ALU	- Arithmetic Logic Unit.
ALUCNTL	- ALU Control.
ALUD	- ALU Destination.
ALUF	- ALU Function (sub-field).
ALUFCN	- ALU Function (field).
CC	- Condition Code.
CCEN	- Condition Code Enable.
CCLUSTER	- Calculate Cluster.
CCMC	- Condition Code Multiplexer Control.
CMPOUTDEL	- Comparator Out Delayed.
CN	- Carry In (from microinstruction).
COUT	- Carry Out.
CPU	- Central Processing Unit.
DIV	- Divide.
D/A	- Digital to Analog.
EA	- Enable A.
EAC	- Effective Address Contol.
EFA	- Effective ABUS Address.
EFB	- Effective BBUS Address.
EVERFR	- Every Field.
FLDEN	- Field Enable.
HORIZSYNC	- Horizontal Sync.
IEN	- Instruction Enable.
INT/EXT	- Internal/External.
LBYTE	- Lower Byte Enable.
LEDS	- Light Emitting Diodes.

LINCOMP	- Line Complete.
LINST	- Line Start.
LSFC	- Least Significant Bit Field Counter.
MAXLINDET	- Maximum Line Detect.
MCU	- Microprogram Control Unit.
MK	- Marker Register.
MKEN	- Marker Register Enable.
MSTEN	- Master Enable.
MUSA	- Multiplexer Select ABUS.
MUSB	- Multiplexer Select BBUS.
NEG	- Negative.
NEWCLUS	- New Cluster.
OEY	- Output Enable Y.
OVR	- Overflow.
PCK	- Processor Clock.
POL	- Polarity Control Bit.
PRDYFLG	- Processor Ready Flag.
PRENT	- PRT Entries.
PROM	- Programmable Read Only Memory.
PRT	- Previously Encountered Object Table.
PRTFULL	- PRT Full.
PRTPT	- PRT Pointer.
PRTPTA	- PRT Pointer A.
PRTPTB	- PRT Pointer B.
PRTPTEN	- PRT Pointer Enable.
PSMADCL	- Processor Sample Memory Address Clear.
PSMADEN	- Processor Sample Memory Address Enable.

PSMREN - Processor Sample Memory Enable.

QREG - Q Register.

RALU - Register/Arithmetic Logic Unit.

RAM - Random Access Memory.

REFMRK - Reference Marker.

RESETBUF - Reset Buffered.

RMAEN - Result Memory Address Enable.

RMEN - Result Memory Enable.

RMENDEL - Result Memory Enable Delayed.

RMOV - Result Memory Overflow.

ROLLTBL - Roll Table.

ROM - Read Only Memory.

SCK - Sampler Clock Rate.

SELQ - Select Q Register.

SEQFCN - Sequence Function.

SMCK - Sample Memory Clock.

$\mathrm{SM}\overline{\mathrm{CL}}$ - Sample Memory Clear.

$\mathrm{SM}\overline{\mathrm{CS}}$ - Sample Memory Chip Select.

SMEN - Sample Memory Enable.

SMI - Sample Memory Input.

SMO - Sample Memory Output.

SMOV - Sample Memory Overflow.

SMOVFLG - Sample Memory Overflow Flag.

SMPCMP - Sample Complete.

SMPCMPFLG - Sample Complete Flag.

SMPEN - Sample Enable.

SMPRDY - Sample Ready.

SMPRDYFLG - Sample Ready Flag.

SMPST - Sample Start.

SM$\overline{\text{WE}}$ - Sample Memory Write Enable.

TBLCK - Table Clock.

TOPWIN - Top Window.

UBEN - Upper Byte Enable.

VERTSYNC - Vertical Sync.

WALU - Write ALU.

WINDCMP - Window Complete.

WINDCMPBUF - Window Complete Buffered.

WINDCMPDEL - Window Complete Delayed.

WINDCOMPD2 - Window Complete Delayed Twice.

WRAM - Write RAM.

XCOOR - X Coordinate.

XCOOREN - X Coordinate Enable.

YCDCK - Y Coordinate Clock.

YCOOR - Y Coordinate.

YCOOREN - Y Coordinate Enable.

Z - Zero.

CHAPTER 1

INTRODUCTION

Interest in human movement has fascinated people for centuries. In fact, investigations into human locomotion have been done dating back to the Greeks. It is only until recently, within the last 150 years or so, that actual recording, measurement and study of locomotion has taken place. This has been due largely to the fact that body movements, even those associated with just simple walking, are quite complex and the analysis requires examination of a large number of parameters. Accurate measurement and processing of this data has really only been possible with the advent of the digital computer.

The study and analysis of human locomotion is of great importance to rehabilitation engineers and clinicians. The potential applications of these studies has been stated by Brügger and Milner [1] and are:

1. The design and evaluation of prosthetic and orthotic devices;
2. The follow-up of the dynamic performance of patients undergoing therapeutic or surgical treatment (e.g. major joint replacement);
3. Biofeedback (online displays);
4. General use in the study of human motion and gait.

1.1 The Problem - Collection of Locomotion Data

A major problem that has plagued those interested in locomotion investigation, has been that of efficiently collecting and processing data. Many methods and systems have been developed to achieve this end.

A list of criteria that may be used in the development and evaluation of a data acquisition system suitable for use in locomotion studies are:

1. The patient or subject should be influenced as little as possible by the instrumentation. The marking of the body landmarks should be simple, light and non-obstructive to body movement.
2. The system should be simple to use. The set-up and calibration should be almost nonexistent, and the operation be done by nontechnical personnel (e.g. nurses or therapists).
3. The collection of data should be done in real-time.
4. Real-time (or virtually so) visual display of data collected should be possible.
5. Spatial information should be accurate and ideally available in 3-dimensions.
6. Data storage and processing should be possible with inexpensive minicomputers or microprocessors. The actual collection of data should not be dependent on the host computer used for detailed analysis.
7. To be usable in a clinical environment, the system should be relatively inexpensive.

This thesis describes the LODE (Locomotion Data Extraction) system. It was designed with the above criteria in mind to be used in the analysis of body motion. Using present day technology, it allows the collection of locomotion data to be independent of the computer to be used for detailed analysis. In Chapter 2, a review of some existing systems is done, the LODE system is discussed, and its capabilities and differences described. In Chapter 3, the system hardware is discussed in detail, while in Chapter 4, the clustering/reduction algorithm is described. In Chapter 5, conclusions and recommendations for future expansion are drawn.

CHAPTER 2

COMPARISON OF LODE WITH EXISTING SYSTEMS

2.1 Introduction

It is not the intent of this chapter to review the history of the study of human locomotion and the methods developed to capture and store this information. Instead, it will briefly review systems that have made use of recent technological advances permitting the exploitation of optical remote sensing systems which use television or other optoelectric measurement techniques. If one is interested, an excellent historical look at locomotion studies and systems that have been developed, has been done by Jarrett in [2].

2.2 Review of Existing Systems

Many methods have been used to collect locomotion data over the last century and a half. The types of data collected varies depending on the interests of the researchers. The data collected generally falls into one of the following:

1. Body motion which includes duration of walk cycle; length and width of steps and strides; foot angles; saggital rotation of pelvis, hip, knee and ankle; vertical, forward and lateral excursions of head and neck; transverse rotation of pelvis and thorax; limb displacement, velocity and acceleration.
2. Foot pressure as well as muscle force; internal joint force; muscle tension vs length; segment energy levels; joint power; muscle power.
3. Periods of muscular activity.

The LODE system was designed to be used for the study of body motion.

In the past, the most popular method of capturing body motion had been the use of photography. Body landmarks were marked in some fashion, and the motion captured on film. The film was then developed and the information extracted from it. The manual effort and time to prepare and enter the data into the computer was the greatest disadvantage of this method. Kasvand and Milner [3], developed a flying spot scanner which was used to acquire data directly from cinefilm and transfer it to a digital computer. Even with this improvement, it still required a great deal of off line processing time.

A television system developed by Winter et al. [4] using an interface developed by Dinn [5] was probably a milestone in television/computer locomotion analysis. Many subsequent systems have used the ideas developed by Winter, and it is therefore appropriate to dwell and review the system in a little more detail. Also, the LODE system is based on the features found in Winter's system.

The body is marked with circular markers covered with retro-reflective tape. Winter and Reimer [6] have shown that the larger the marker size, the less the resolution error is in determining the marker's centre coordinate. Figure 2.1 shows the error in centre coordinates vs marker diameter. Jarrett [7] also comments on the response of the retro-reflective tape, in that, when illuminated by high intensity lights, the video level of the marker is 90% higher than the level of skin tones. The advantage of this type of 'passive' marker is that it is easily attached to the skin and no power supply or connecting leads are required.

The marker coordinates are determined by using a regular video TV camera which is sampled by Dinn's interface using a 96x96 sample matrix. The sampling occurs on every second line at a rate of 60 fields/sec. The data is stored in a computer and subsequently

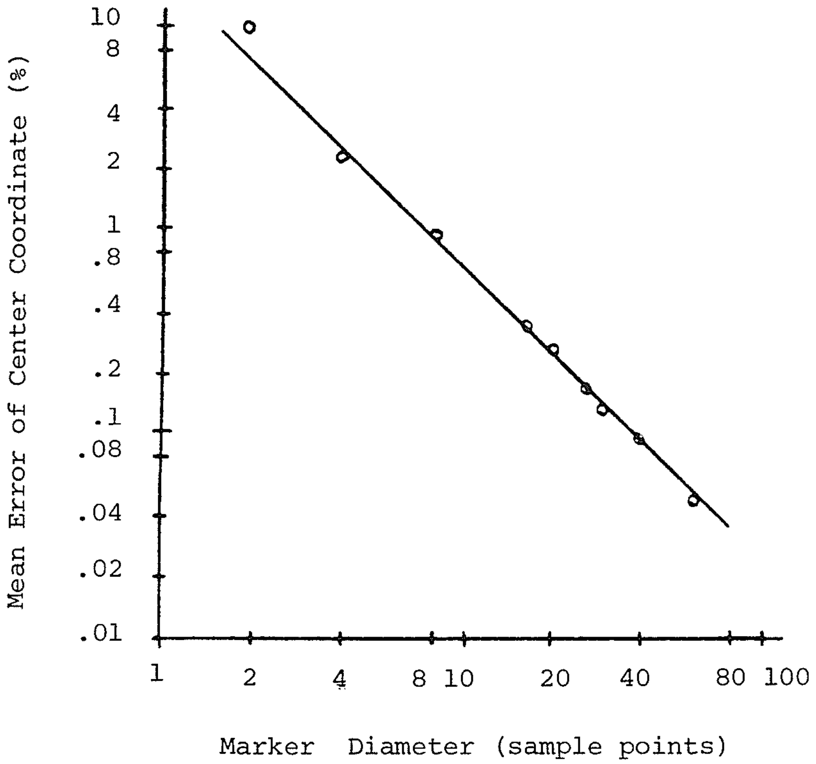

Figure 2.1 Error in centre coordinate vs. marker diameter. (sample points within the marker)

(from Winter and Reimer (1972))

processed to obtain trajectory information. The sparseness of the sample matrix leads to limited resolution, which is overcome by moving the camera parallel to the subject in the walkway.

The major disadvantage of Winter's system is that the information is video taped before processing and that large amounts of storage space is required on the computer with no online representation of data.

Jarrett [2] developed a two camera system which is interfaced to a PDP-12 computer. The interface stores horizontal and vertical information in a buffer memory and then transfers it to a computer core memory during line spacing. The data is subsequently reduced, and further processed. The system uses a 50 fields/sec, 625 line interlaced video camera. Body markers are identical to Winter's, but in this system, the video cameras are stationary.

Brügger and Milner [1,8] have developed a similar system using charge coupled device image sensor cameras. These are interfaced to a PDP 11-10 computer. The cameras are used with both a 100x100, and 190x244 array image sensors and are capable of field rates from 10 to 300 fields/sec. The number of markers that can be detected is limited by the software detection algorithm and is as high as 20. The markers are identical to Winter's and the cameras are also stationary.

A commercially available system, SELSPOT [9], uses a silicon photo sensor capable of transducing the coordinates of light emitting diods (LEDS). The cameras must be sampled by a computer, and the computer must also process and store the data. The LEDS are individually connected to the switching circuits and power supply, and may require current pulses as high as 10 amps. This system has scan rates higher than 300 Hz and can handle many markers. The primary disadvantages are the fact that the cameras must be sampled by a computer, the placement of LEDS and their power supply is difficult and obstructive to a normal gait. The cost of a system with two cameras is approximately $17,000.00 (this is without the computer).

The major disadvantage of all the above systems is the fact that each system is dependent on the host computer. That is, the sampling of the scanned TV images and the subsequent marker's coordinate reduction is dependent on the computer they are connected to. In most cases it has been a minicomputer, and in Winter's case at the time of reporting, a CDC 1700.

2.3 The LODE System

The LODE system has been designed so that the collection and reduction of the sampled data to marker's coordinates is independent of the computer to be used for the detailed locomotion analysis. In fact, as will be seen later, it may be possible to have the LODE system perform these tasks as well.

LODE is a real-time data acquisition system designed for locomotion studies. It basically consists of two subsystems, and is shown in block diagram form in Figure 2.2. The first subsystem, called the sampler, is a random logic, TTL design. Its function is to form the sampled coordinate pairs of the markers within a sample matrix, and store these points into one of two intermediate sample memories.

The second subsystem, called the processor, is a microprogrammed, bit-sliced, special purpose computer. The computer's architecture is designed to optimize the marker coordinate's clustering/reduction algorithm which is microprogrammed in control store PROMs (Programmable Read Only Memories). The reduction algorithm has only one function, that of reducing the sampled data collected in a TV field to the centre coordinate of each marker. The resulting coordinates are stored in the result memory. The result memory can then be accessed by a host computer for detailed analysis

2.3.1 LODE System Capabilities

LODE was designed to be used with a system similar to Winter's. Video cameras have been used in many locomotion data acquisition systems, and it is sufficient to state that the spatial resolution obtained provides excellent results. A normal SONY video camera, with a standard

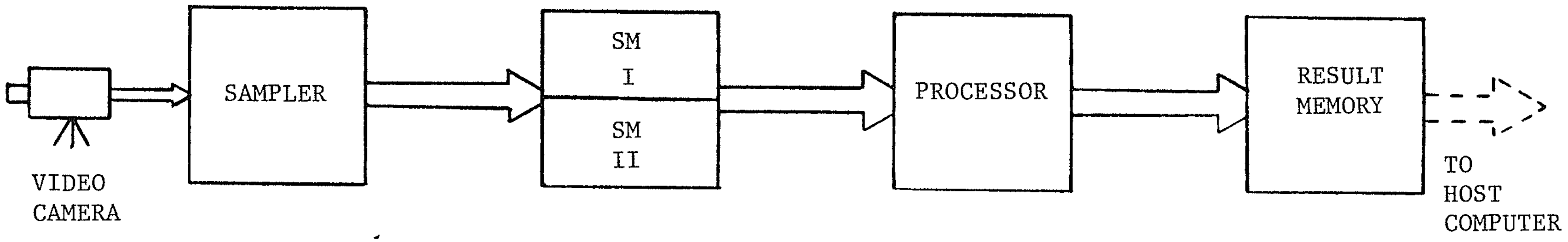

Figure 2.2 The LODE System.

30 frames/sec, 525 line interlaced raster scan is used as the optical sensor. The camera tracks with the subject, which reduces the problems of parallex and creates greater resolution.

The body markers are also the same as those used in many of the previously mentioned systems. That is, they are circular and covered with retro-reflective tape. Since the camera follows the subject, larger background markers also covered with retro-reflective tape are used to provide a reference for subsequent calculations. The relative size of the markers can be set by thumb wheel switches. The relative size is a default condition used to determine if a marker is a body or reference marker. The reference markers detected are flagged to prevent confusing them with the body markers. The number of markers that can be used is a function of their size. The sample memories are designed to store 1024 sampled coordinate pairs. The reduction algorithm is able to reduce and calculate 5 markers at a time.

The system has two available window (sample matrix) sizes, 128x128 and 234x256. Sampling can be done at 60 fields/sec, and at a slower rate of 30 fields/sec. Any other sampling rates were deemed unfeasible, since not enough data could be extracted to be of any use. The length of a run can be chosen to be either 255, 399 or 510 fields (approximately 4.3, 6.7 or 8.5 seconds respectively). Presently the result memory size is sufficient to store 32k bytes of information, which would be equal to 399 fields with 20 markers/field.

The LODE system capabilities can be summarized as follows:

1. Uses a normal SONY video camera for 2-dimensional data acquisition;
2. Body markers are light and unobstructive to body motion;

3. Marker default sizes can be set by external switches;

4. The result memory is sufficient to store 20 markers for 399 fields;

5. It is a real-time data acquisition system independent of the host computer used for detailed analysis;

6. Two sample window sizes are available (128x128, 234x256). Sampling can be done at 60 fields/sec or 30 fields/sec;

7. The reduction algorithm is totally microprogrammed, with the processor's architecture optimized to suit the algorithm. The field of data is reduced within 1/60 of a second;

8. It is relatively inexpensive.

2.4 System Differences

The LODE system has two differences over existing systems which are advantageous. They are as follows:

1. The collection of data is completely independent of the host computer. All reduction of data to marker coordinates is done by the LODE system. The result memory holds the final marker coordinates and no control of sampling is required. The LODE system can be interfaced to almost any computer by the simple design of an interface to read the result memory.

2. It has the capability to handle many markers, (more than 20) with a maximum of 5 markers per scanning line.

CHAPTER 3

THE LODE SYSTEM

3.1 Introduction

The LODE system as described in Chapter 2 consists of two sub-systems, sample memories and a result memory, which together form a real-time data acquisition system. The two sub-systems are designed to operate independently of each other. The sampler passes the sampled coordinate pairs to the processor via the sample memories, while the processor uses this data to calculate the marker's centre coordinates. The sub-systems set status flags to inform each other of the fact that they have finished their respective jobs within the time constraint of a field, or 1/60 of a second.

The system's functions are controlled via a control box which contains switches to select various system functions. Two thumb wheel switches are used to set the default values for the body marker and reference marker sizes. The run length (i.e. the number of fields to be sampled) is selected by a three position double pole switch generating the signals $\overline{F256}$ and $\overline{F512}$. The window size is selected by a single pole double throw switch and generates the signal 128/235. The sample rate, either 30 or 60 fields/sec, is selected by a single pole double throw switch and generates the signal EVERFR. Three momentary push button switches are used to generate the signals STOP, START and RESET. A separate switch (not part of the control box) is used for the result memory selection and generates the signal INT/EXT.

In this chapter, the hardware design will be discussed along with prototype construction and suggestions on system usage. All schematics unless otherwise stated are found in Appendix A and are referred to, for example, as schematic A21, which is the schematic dealing with the control box switch connections.

3.2 The Sampler

The function of the sampler subsystem as mentioned earlier is to collect and store a field of sample data. Figure 3.1 shows a block diagram of the sampler. It is a completely random logic design using TTL circuitry throughout.

The sampler takes the active picture information within a video field and forms a sample window. The window is then further divided into a grid called the sample matrix. It uses the horizontal scanning lines to form the rows of the matrix, and samples along the line to form the columns. Two window sizes can be chosen, either 128x128 or 234x256.

A sample coordinate pair is formed and stored in the sample memory for every point in the matrix that a marker covers. For example, Figure 3.2 shows a marker within part of the matrix. The sample coordinate pairs that would be formed and stored in the memory are (8,8), (8,9), (9,8) and (9,9).

The sampler is composed of two counters, the Y Coordinate (YCOOR) and X Coordinate (XCOOR) counters along with their respective detection logic which are used to form the matrix coordinates. The sampler control logic contains the video interface circuitry and other logic to generate the appropriate control signals for the counters and the sample memories.

The coordinate pairs generated by the sampler are sent to the sample memories on the 16 bit wide Sample Memory Input (SMI) bus. The x coordinates form the lower byte of the SMI bus, while the y coordinates form the upper byte. The sampler when active stores coordinate pairs detected within the sample window. When the bottom of the

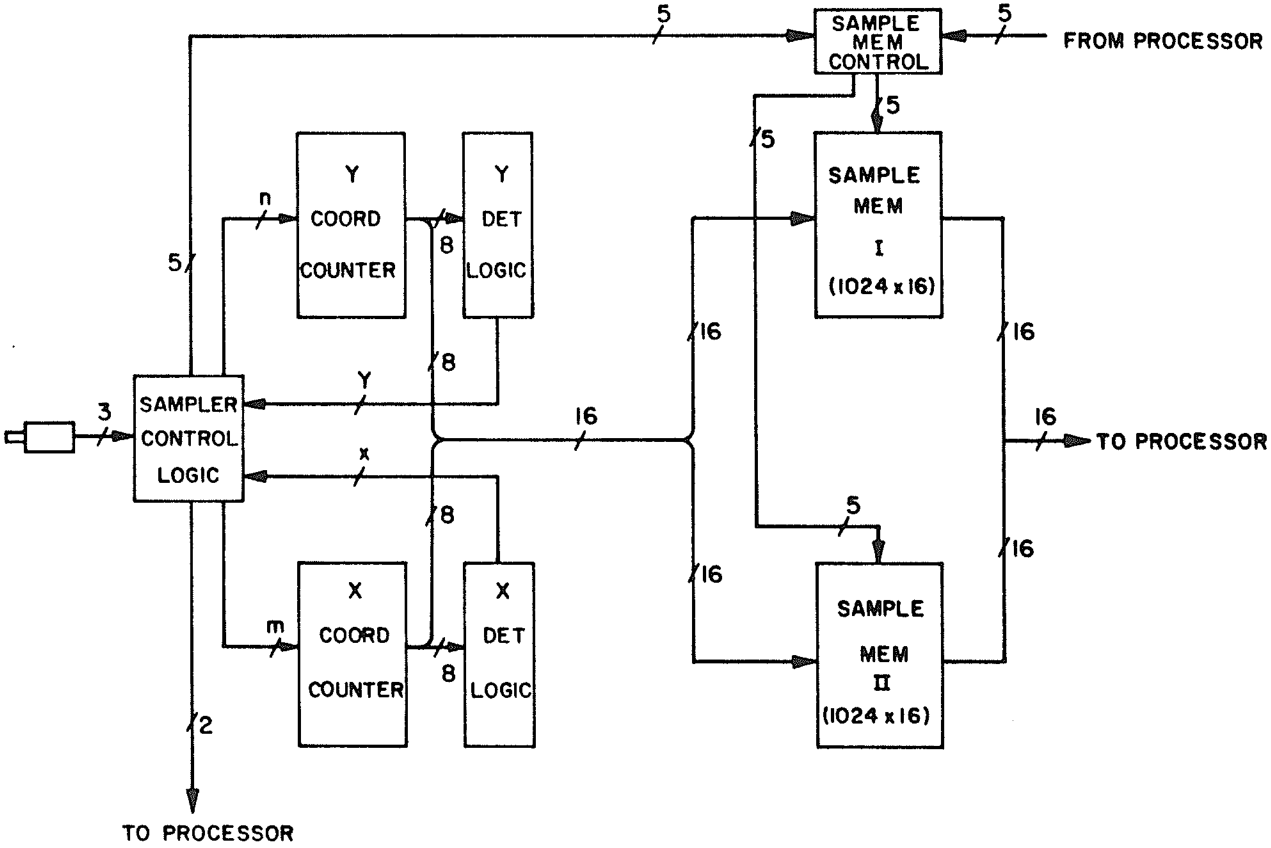

Figure 3.1 The Sampler.

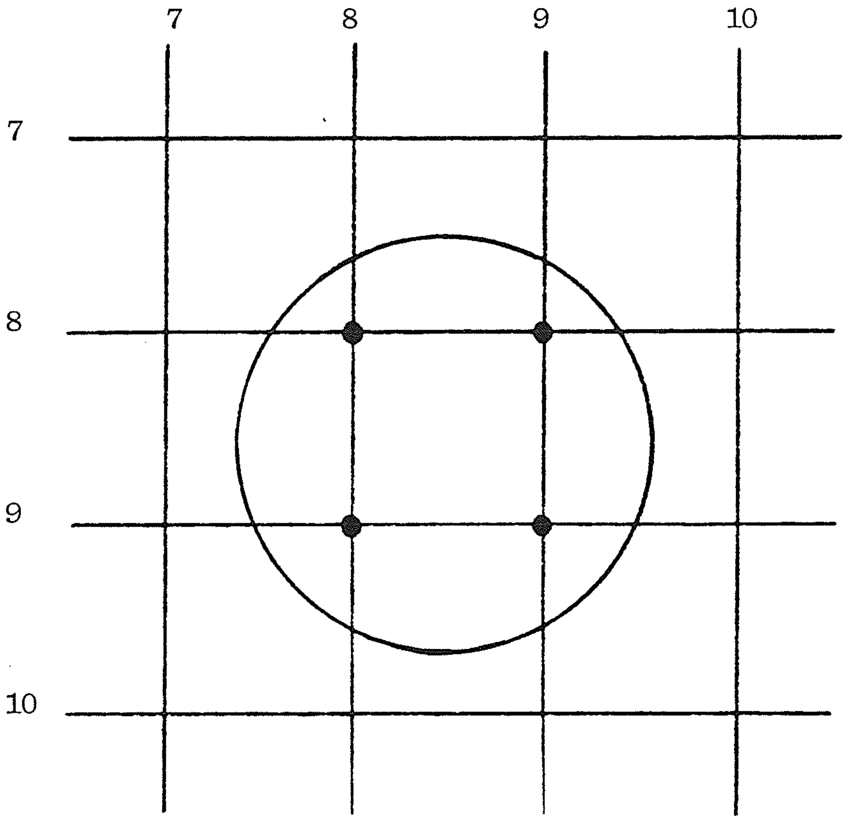

Figure 3.2 An Example of the formation of coordinate pairs.

window is detected, the sampler stores an all ones pattern in the sample memory to flag the end of data for a particular field. This is used to inform the processor that the end of the data for this field has been reached and that no more coordinate pairs exist.

3.2.1 Video Interface

The video camera is used as the optical sensor for data collection. The one used in the LODE system is a standard SONY black and white, 30 frames/sec, 525 line interlaced raster scan camera. The camera was modified so that the vertical and horizontal sync pulses, as well as the composite video are all available from the VIDEO/SYNC connector on the rear of the camera. All are positive signals, with the horizontal and vertical sync pulses being +7 volts maximum.

Each frame of the interlaced picture is composed of 2 fields, each field containing 262.5 of the 525 interlaced raster scanned lines. The sampler (and the LODE system) considers each field to be a complete picture, which results in a sampling rate of 60 Hz. Thus each field is 1/60 of a second in duration, or 16.67 msec. Since there are 262.5 lines per field, each line is 62.49 usec in duration.

In the SONY camera, 93.5% of the horizontal lines actually contain picture information, or 245 of the 262.5 lines are useful. Each horizontal scanning line is made up of the horizontal sync pulse and useful picture information. A horizontal sync pulse is equal to 11.11 usec, which leaves 52.38 usec of each line for picture information.

As mentioned earlier, the sampler uses the horizontal lines to form the rows of the matrix and samples along the line to form the columns. It is desired that the matrix be square, that is, the