An Online Opto-electronic Sensor for Abrasive Waterjet Nozzle Internal Diameter Monitoring

by

Mehmet Gülşen
B.S., Middle East Technical University, 1986

Abstract of Thesis

Submitted in partial fullfilment of the requirements for the degree of Master of Science in Manufacturing Engineering in the Graduate School of Syracuse University
December 1990

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On-line tool monitoring plays a crucial role in all automatic manufacturing units. As in all machining processes, correctly monitoring Abrasive Waterjet nozzle wear, change of internal diameter ID, is a key aspect not only in producing high quality parts, but also in using Abrasive Waterjet (AWJ) as a part of an integrated manufacturing system. Currently the measurement of AWJ nozzle ID is done either inspecting the tip of the nozzle or relating some AWJ parameters to the nozzle wear. In this study a nozzle ID monitoring system with an optoelectronic sensor is proposed for abrasive waterjet cutting applications.

The nozzle ID monitoring system consists of a camera, a monitor, a digitization unit for the incoming video signal, and the host computer for storage and analysis of the images. The nozzle ID is monitored by detecting waterjet diameter at the tip of the nozzle. The first step of the developed algorithm is image acquisition. The analog signals from the camera are digitized by the MV-1 frame grabber board, and the digital data of the image is sent to the host computer in the form a numerical data. The second step is the calculation of the actual waterjet diameter. In this step, the edges of the waterjet is determined by performing quantitative analysis on numeric data. First the distance between two edges is obtained by the number of pixels, then the actual waterjet diameter is determined by using the camera calibration function.

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Chapter 1

INTRODUCTION

In today's rapidly developing manufacturing environment, speed and the reliability of manufacturing units have become the most critical issues that determine the competitiveness of a company. As the integration of different kinds of manufacturing units and systems increases, more companies are starting to replace their conventional manufacturing units with newer ones capable of changing machining parameters automatically – producing several parts on the same line. To achieve these purposes highly reliable manufacturing systems that can operate without any outside interference of man are needed. In such systems, various functions of the manufacturing process are monitored by automatic control devices and sensors. Although automatic monitoring is used in various aspects of manufacturing, the most significant field of monitoring is used for cutting tools. Most of the wear and failure in a cutting tool is actually a function of many parameters which makes the exact evaluation of tool life very complex.

In Abrasive Waterjet cutting, the nozzle is the cutting tool of the system, and is a vital influence on the overall performance of the system. The nozzle diameter, which is initially 1 mm, increases almost linearly as the cutting time increases. The detoriation of the nozzle internal diameter in the form of increasing average nozzle diameter and changing cross-sectional shape of the nozzle, makes the tool substitution necessary. Today's standard procedure for the direct tool wear control involves tool removal, wear measurement, and finally repositioning of the tool holder. All these steps take a significant amount of time and cause expensive down time.

Automatic monitoring systems can measure either the wear directly or other parameters of the process which can be related to the wear. The principal advantage of using monitoring systems instead of conventional methods is the on-line measurement of tool wear, without shutting down the system. In the past, several monitoring systems using direct or indirect methods were implemented for AWJ. A brief summary of these systems is given at [1].

At this point a detailed comparison between automatic tool wear sensing and the manual tool wear sensing should be done. First, the advantages of the simple manual sensing should be discussed in order to get a better understanding of differential points of machine vision monitoring. People are very flexible and can be trained for various jobs, and can make reasonable adjustments to compensate for certain conditions. People, like machines, are also quite capable of interpreting the true nature of a condition, and when trained, can take routine actions to correct pending process failure.

The primary reason for using machine vision in place of labor, however, should not be regarded as a saving in the labor. The advantages of machine vision are grouped in two pairs in most of the studies[2]. The first advantage is the cost of quality, which may be thought as financial gain due to increased quality, or lost opportunity cost due to low quality. The second is the cost of failure which may be thought as savings stemming from the cost of failure. Although it is possible to quantify the gains due to improved quality of cost at the time, it is much more difficult to get a numerical estimate for the failure cost. This cost involves the unexpected failure of the nozzle, which will cause the breakdown of the system, and will lead to materials scrap and rework of the workpiece.

The automated control system has another important advantage. Human inspectors can only make decisions about whether or not the nozzle wear is large enough to be replaced or kept in operation. This is a yes or no type decision. On the other hand, in a machine vision system it is possible to spot the progress of the wear and observe the trend. This statistical data can be analyzed, and can be used for corrective purposes. Moreover, we can also estimate the expected tool life, and estimating the tool life minimizes the down time of the entire system.

Chapter 2

ABRASIVE WATERJET SYSTEM

Abrasive waterjet machining is a new type of non-traditional metal cutting process, which uses pressurized water with or without abrasive material for cutting various types of metals. Although Abrasive Waterjet cutting is different from other conventional machining processes, its ability to cut extremely hard material such as ceramics and carbides has increased its use in the metal cutting industry.

A standard AWJ equipment basically includes a high-pressure water pump, a cutting head, and an abrasive handing system. To control the process, a controller unit should be used. The experimental set up of the Syracuse University Abrasive Waterjet Lab has a CNC controller for the x-y positioning of the cutter head.

The pressurization of the water is attained by an intensifier pump (Mode 9xH) that can be used for both waterjet and abrasive waterjet cutting applications. The first intensifier pump of 55000 psi is used for waterjet cutting. The second one of 36000 psi is used for abrasive waterjet cutting applications. The cutting head, which generates the narrow waterjet, has two basic components. The first component is the sapphire jewel with an orifice diameter of 0.45 mm, and the second component is a tungsten carbide nozzle. The pressurized water is first forced through sapphire jewel orifice and then through tungsten carbide nozzle. The water is mixed with the abrasive particles in the mixing chamber between the nozzle and the orifice before it

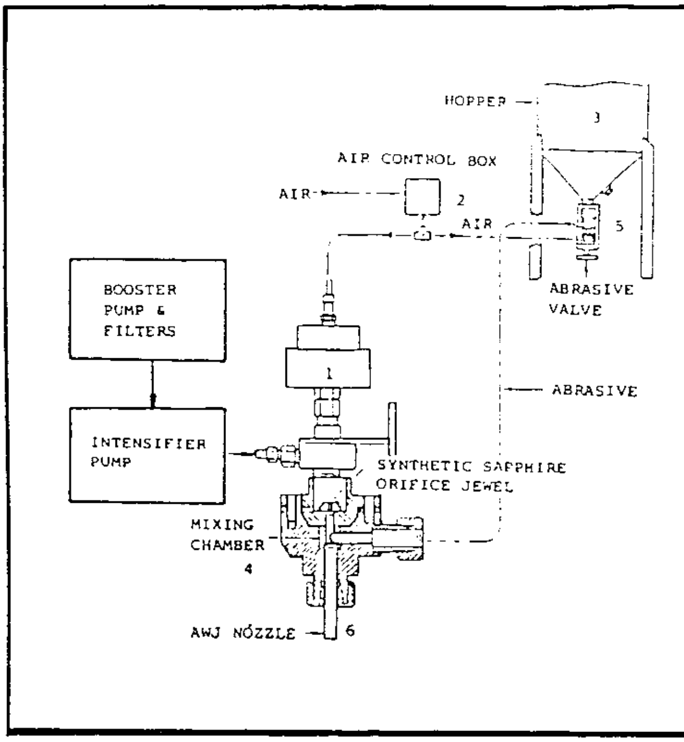

Figure 2.1: A general concept of an abrasive waterjet system (From Abrasive Waterjet Manual by Flow Systems)

is directed to the workpiece through the nozzle.

The tungsten carbide nozzle where the waterjet mixes with abrasive particles, is the most critical component of AWJ system. It determines not only the surface quality of the cut workpiece, but also the overall performance of the system. Because of heavy metal erosion, currently available nozzles have an average life of four hours.

The basic functions of an AWJ system is shown in Figure 2.1. High-pressure water from the intensifier pump is supplied to the pneumatic valve(1), which provides a carrier medium for the abrasive material. The air valves, which are controlled by 3-way air control valve(2), provide rapid ON/OFF control of the waterjet at the sapphire nozzle. The abrasive material is stored in a hopper(3), and fed to the mixing chamber phenomatically. The abrasive material rate is controlled by the adjustable valve under the hopper(5). After abrasive material and pressurized water are mixed at the chamber, the newly formed jet is directed to the workpiece by tungsten carbide nozzle.

In the Abrasive Waterjet cutting process, there are several operational parameters that have significant effect on the performance of cutting. These abrasive waterjet parameters are generally grouped into four: The first group is hydraulic parameters; such as waterjet orifice diameter and water pressure. The second group of parameters are related to the abrasive materials. The type of the material and its grain size are two important physical parameters of the abrasive material. Moreover, the rate of material fed into the system is another parameter that can be put into group two. The third group includes the nozzle parameters such as nozzle length and diameter. The fourth group of parameters are related to cutting operation, which includes waterjet speed, transverse speed of the cutting head, standoff distance, vertical distance between the nozzle and the workpiece, and angle of attack. It is apparent that the output of the process such as surface texture, geometrical accuracy, metal removal rate, and actual depth of cut will depend on the inter-relationship of the above mentioned variables.

Chapter 3

CONCEPT OF NOZZLE WEAR

The cutting operation in Abrasive Waterjet is achieved by the impact of the abrasive particles onto the surface of the material being cut. The abrasive particles, which are primarily used to increase the cutting performance, also cause the nozzle wear. According to Hasish[3], who first studied the nozzle wear in AWJ, the nozzle is subjected to abrasive and the erosive modes of wear. When the jet stream first enters the nozzle, the abrasives hit the conic section of the nozzle tip at random angles. This form of wear is called erosion wear. Once the jet stream advances through the inner tube of the nozzle, abrasive particles travel parallel to the inner surface of the tube. During this movement the particles cause abrasion or shallow impact erosion of the wall(Fig3.1).

Today it is generally accepted that the concept of erosion is first developed by Finnie[10]. The theory is based on the assumption that metal removal from a surface due to erosion can be considered a metal cutting operation by small particles attacking the surface. Finnie introduced a formula for the calculation of worn out volume in terms of total abrasive used; particle velocity; ratio of the chip height and depth of cut; horizontal contact pressure; ratio of horizontal and vertical contact forces; angle of attack; and the incidence separating two types of erasive cutting.

Abrasive waterjet cutting is basically an erosion process that depends on several basic parameters of the process. Although various attempts have been made to

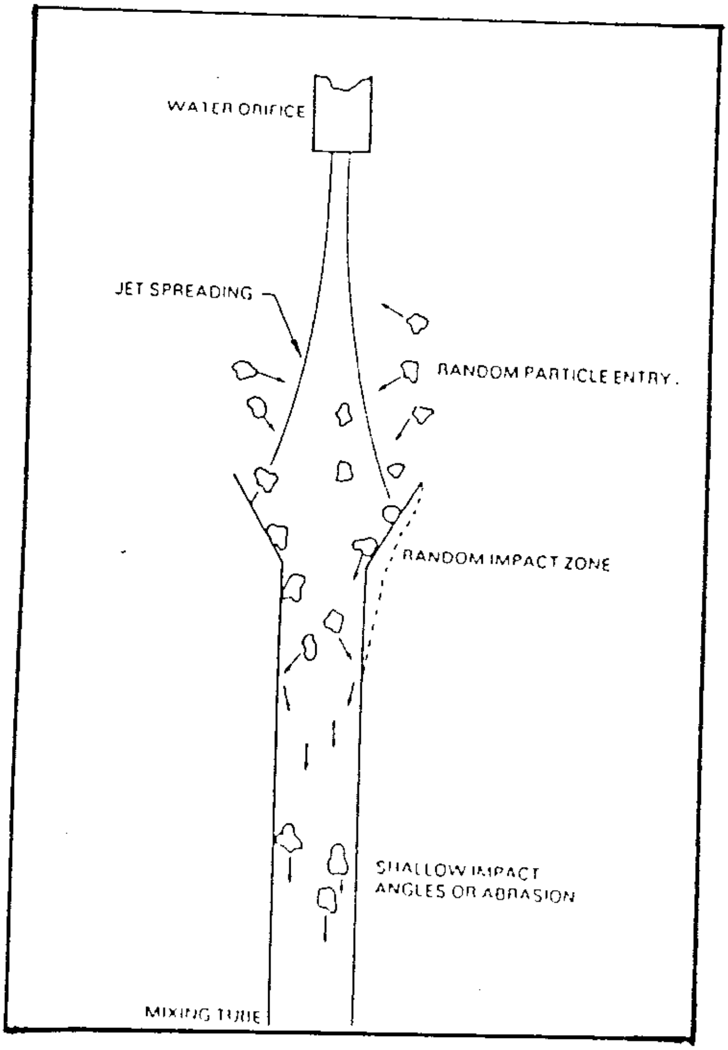

Figure 3.1: Wear modes in abrasive waterjet

relate these parameters, namely water pressure, water flow rate, abrasive material, the eroded material, and jet stream velocity, the developed formulas are largely application specific, and are valid only for a small domain of jet cutting operations. However, the previous research in this area has also shown that the amount of wear in the nozzle is mostly influenced by abrasive material, as well as eroded material type and the velocity of the jet stream velocity. These two parameters are completely independent of each other.

3.1 Abrasive Waterjet Nozzle Wear Sensing Systems

As it was mentioned earlier, nozzle wear in an abrasive waterjet system has two big disadvantages. The first one is the deterioration of the surface quality and dimensional accuracy caused by the waterjet, and the second one is the problem of detecting the point when the nozzle is worn out completely. In order to overcome these problems and to detect the progress of AWJ nozzle wear, various sensing systems have been developed. These systems are categorized into two groups according to the type of measurement involved [1]. The first is the direct measurement in which either the inside diameter of the nozzle at its tip or the material loss of the nozzle is measured. Although this method gives excellent results, the entire process should be shut down completely for each measurement. Shutting down the system is not practical, or at least not economical, because of the excessive down time of the entire system. The measurement of wear by determining the material lost is also not practical because it involves radiometric techniques, which may cause safety problems due to radioactivity.

The second method, an indirect measurement technique, basically involves measuring some parameters that can be related to nozzle wear. Although these measurements are not as accurate as the direct measurement technique, they provide

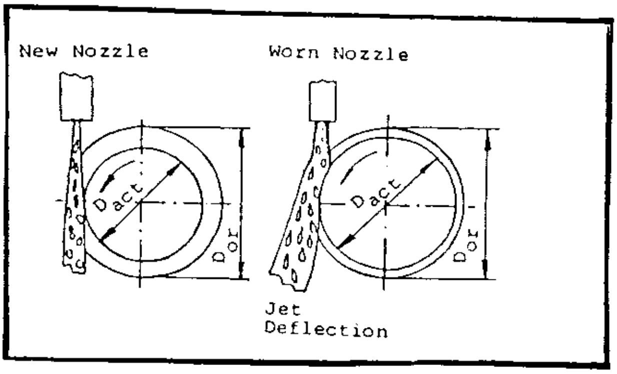

Figure 3.2: The position of the jet with respect to the cylindrical workpiece in the turning operation

the on-line monitoring of the nozzle wear. The indirect measurement system can be optical, electrical, or acoustic. Some of the indirect methods, which are already used or coming into operation, are discussed below.

3.1.1 Sensing AWJ Nozzle Wear by Monitoring Normal Force on the Workpiece

In this method, the reactive normal experienced by the workpiece is monitored and related to the nozzle wear. Figure 3.2 shows the orientation of the jet with respect to a cylindrical workpiece. In the first position the nozzle is new, and therefore it has a high cutting efficiency. In this position the normal force is minimum. Position II represents a worn-out nozzle, where there is a significant variation in the jet orientation. Here, the waterjet is deflected radially and has a very low cutting efficiency. As a result of this, the normal force on the workpiece is increased. Based on the change of reactive force, the wear in the nozzle is monitored by the system.

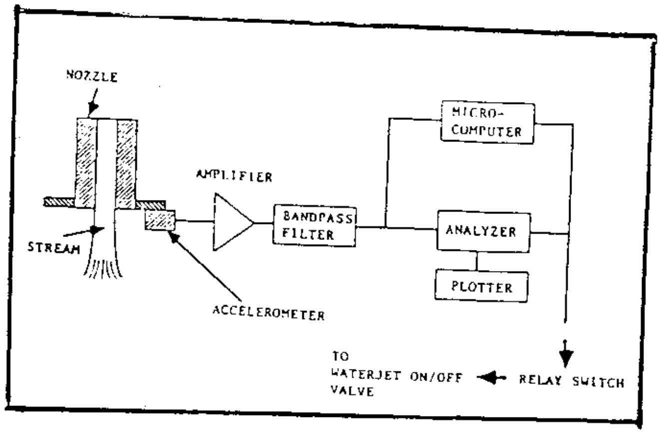

Figure 3.3: A setup for vibration monitoring

3.1.2 Sensing AWJ Nozzle Wear by Vibration Monitoring

As the nozzle wear increases, the vibration frequency of the abrasive waterjet is expected to increase. A sensory system, which relates the frequency of the AWJ to nozzle wear, ensures wear monitoring. The vibrations generated by the AWJ are detected by an accelerometer and converted into a digital signal. Later on, this signal is passed through an ampilifier and a band-pass filter. Statistical analysis can be performed on the data by an analyzer and a microcomputer. Based on the result of data analysis, some corrective steps can be initiated. When the amplitude of the vibration is longer than a predetermined value the system can be shut down by a relay.

3.1.3 Sensing AWJ Nozzle Wear by Noise Monitoring

This is basically an acoustic sensing system used to detect the worn out AWJ nozzle. This system relates the wear in the nozzle to the change in the sound generated by jet flow.

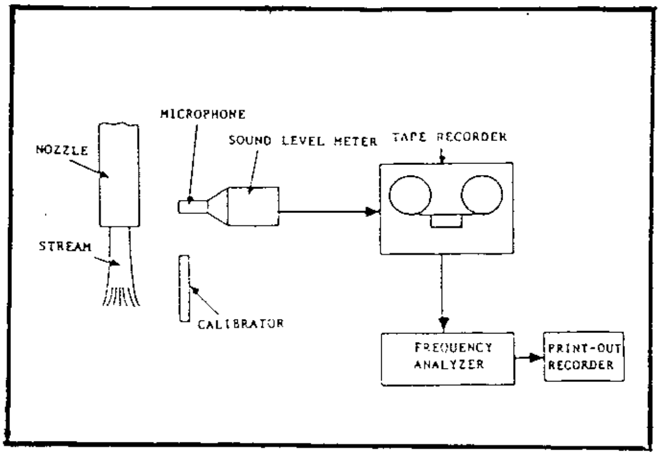

Figure 3.4: A setup for noise monitoring

3.1.4 Ultrasonic Gaging of AWJ Nozzle Wear Thickness

Ultrasonic gaging method is a new application that is used in measuring wall thickness. This method is very convenient, especially when access to both sides of a workpiece is difficult or impossible. This system operates by using an ultrasonic pulse-echo technique similar to sonar. A short duration electrical pulse is sent to a piezoelectric transducer, which converts the pulse into short bursts of high frequency sound energy. The sound energy is later transmitted into the test material via a coupling material such as water.

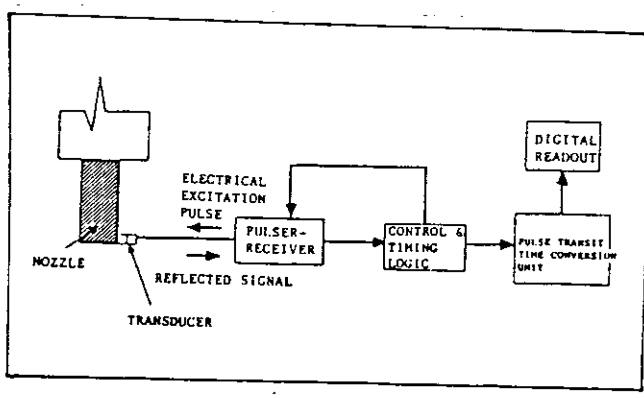

Figure 3.5: A setup for ultrasonic gaging of AWJ nozzle wear thickness

Chapter 4

OPTO-ELECTRONIC WEAR MONITORING SYSTEM

The ultimate purpose of developing an opto-electronic wear monitoring system is to detect the nozzle wear more effectively than current systems. The most significant benefit of an opto-electronic wear sensing system is its simplicity. As it is discussed in the previous chapter, in conventional tool monitoring systems some parameters of the AWJ are related either directly or indirectly to the tool wear. Since there is no closed form equation that directly relates all the necessary parameters of AWJ to the nozzle wear, the user should be very well informed about the nature of the process. However in the opto-electronic tool wear monitoring, the jet diameter on the screen is automatically related to the actual waterjet diameter by the developed program. Thus, the information required for the operation of the monitoring system is kept at a minimum. The second important advantage of opto-electronic sensor is its flexibility. It is a non-contact type of sensor, and it doesn't require any installation, or maintenance. Furthermore, opto-electronic wear sensing system can detect the complete worn-out point of the nozzle very effectively. Unlike a human inspector, who can only detect a failure condition, the opto-electronic wear monitoring system can spot trends, and forecast the approximate nozzle life.

4.1 Definition of Wear Monitoring System

The developed wear monitoring system first acquires an image of the waterjet, and then analyzes and interprets the image for the purpose of control. In engineering terminology we do not have any particular name given to the such systems. However three different names - image analysis, image processing, and machine vision - are frequently used by people. Image analysis refers to equipment that makes the quantitative assessments on patterns associated with the biological and meteorological phenomenon. On the other hand, image processing generally refers to equipment designed to process and enhance images for ultimate user interpretation. Machine vision has been defined by the Machine Vision Association of Manufacturing Engineers and the Automated Vision Association/Robotics Industry Association as the use of devices for optical non-contact sensing to automatically receive and interpret an image of a real source to obtain information and /or to control machine or process.[5]

Within the framework of the above definitions the wear sensing set up used in our research is more likely to be classified as machine vision system. The abrasive waterjet wear sensing system takes pictures of the jet by using an optical non-contact device(camera), and then digitizes the acquired image before sending it to the computer as data input. This data is used for information (to assess to correct internal diameter of the nozzle), and may be used to control compansation movements of the tool in order to maintain dimensional cutting quality of the workpiece.

4.2 Components of the Wear Monitoring System

The block diagram of wear monitoring system is given in figure 4.1. The standard components of such a system are also explained below.

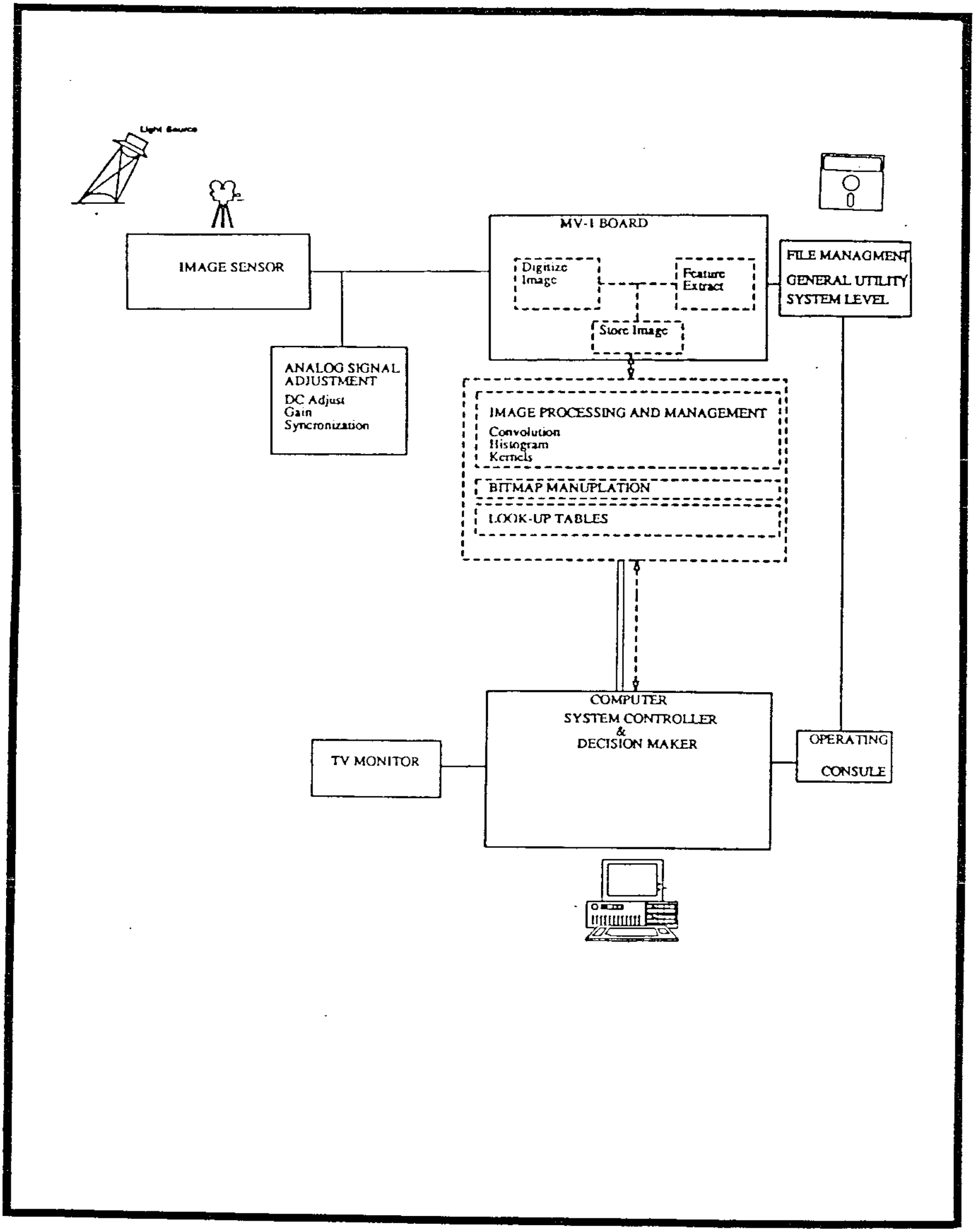

Figure 4.1: Block diagram for the machine vision system

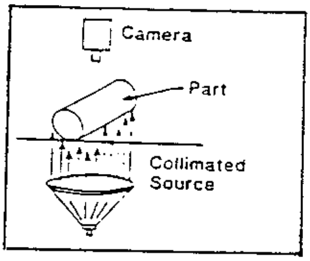

Figure 4.2: Backlighting

4.2.1 Illumination (Lightning)

Although it is possible to perform image analysis without using any kind of illumination, or just using the lightning of the environment, in most of the applications poorr illumination may result in low contrast, specular reflections, and shades. Furthermore, illumination minimizes the complexity of the resulting image, while the information required for inspection or manipulation is enhanced.

A well-designed lightning system illuminates the scenes so that the complexity of the resulting images is minimized, while the information required for inspection and the manipulation is enhanced. Four basic schemes are used for illuminating objects manipulated. The detailed information about illumination techniques is given in reference [11]. In Abrasive Waterjet applications the basic aim is to obtain the exact thickness(diameter) of the jet stream. To detect waterjet air interface accurately, backlighting in which silhouettes of the object(waterjet) is sufficient for recognition should be used(Figure4.2).

4.2.2 Image Sensor (Camera Model)

The basic function of the image sensor is to match the object and the sensor. Once the matching is achieved the optical image is converted into digital electrical signals. The camera should be adjusted before image acquisition. The purpose of the camera calibration is to establish the relationship between three dimensional world coordinates and their corresponding two-dimensional image coordinates on the screen. Once this relation is established the geometric dimensions, which are obtained from the screen image, are related back to the actual real geometric dimensions so that the actual waterjet diameter can be detected.

A camera has six degrees of freedom; three rotation and three translation parameters. The three rotation parameters give the orientation of the camera, and the three translation parameters give the location of it. Since these parameters must be calibrated every time the camera is fixed, it is necessary to establish a convenient method of camera calibration.

Definition of Parameters

The six unknown variables of the camera model can be determined by choosing the camera parameters. These parameters are classified into either fixed(device dependent) or changeable(location and orientation dependent)[9].

The fixed parameters are determined by the physical specifications of the camera, the lens, and the digitization unit of the image processing software

These fixed parameters are defined as follows:

- Length/Width ratio of the monitor(image screen).
- Focus(image center of the lenses)

The changeable parameters are depend on the location and the orientation of the camera, and they should be calibrated every time the camera is set up.

The changeable parameters are defined as follows:

- Direction of the camera (optical axis normal to the lenses)
  (Three rotation parameters)
- Location of the center of lenses.
  (Three translation parameters)
- The imaging distance from the lens to the image plane.
  (Focus length of camera)

The first group of parameters defines the orientation of the camera. These are called rotational parameters, and they are described as functions of Euler angles; θ, φ and ψ. The second group of parameters defines the location of the camera in cartesian coordinate system, and they are called translational parameters. The third parameter is the imaging distance(focus length), which is adjusted so that the lens is exactly focused on the image plane.

Figure 4.3 shows a world coordinate system (X,Y,Z) used to locate both the camera and the 3D points. The figure also shows the camera coordinate system (x,y,z) and the image screen coordinate system (x_i, y_i, z_i)(see also Figure 4.4) . The origin of the lens center is the origin of the camera coordinate system, and z axis corresponds to the optical axis of the lenses. The relation between coordinate systems is described by using a rotation matrix (**R**), and a translation matrix (**T**)[9].

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \mathbf{R} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \mathbf{T} \tag{4.1}$$

where;

X,Y,Z are real world coordinate axes.

x, y, z are camera coordinate axes.

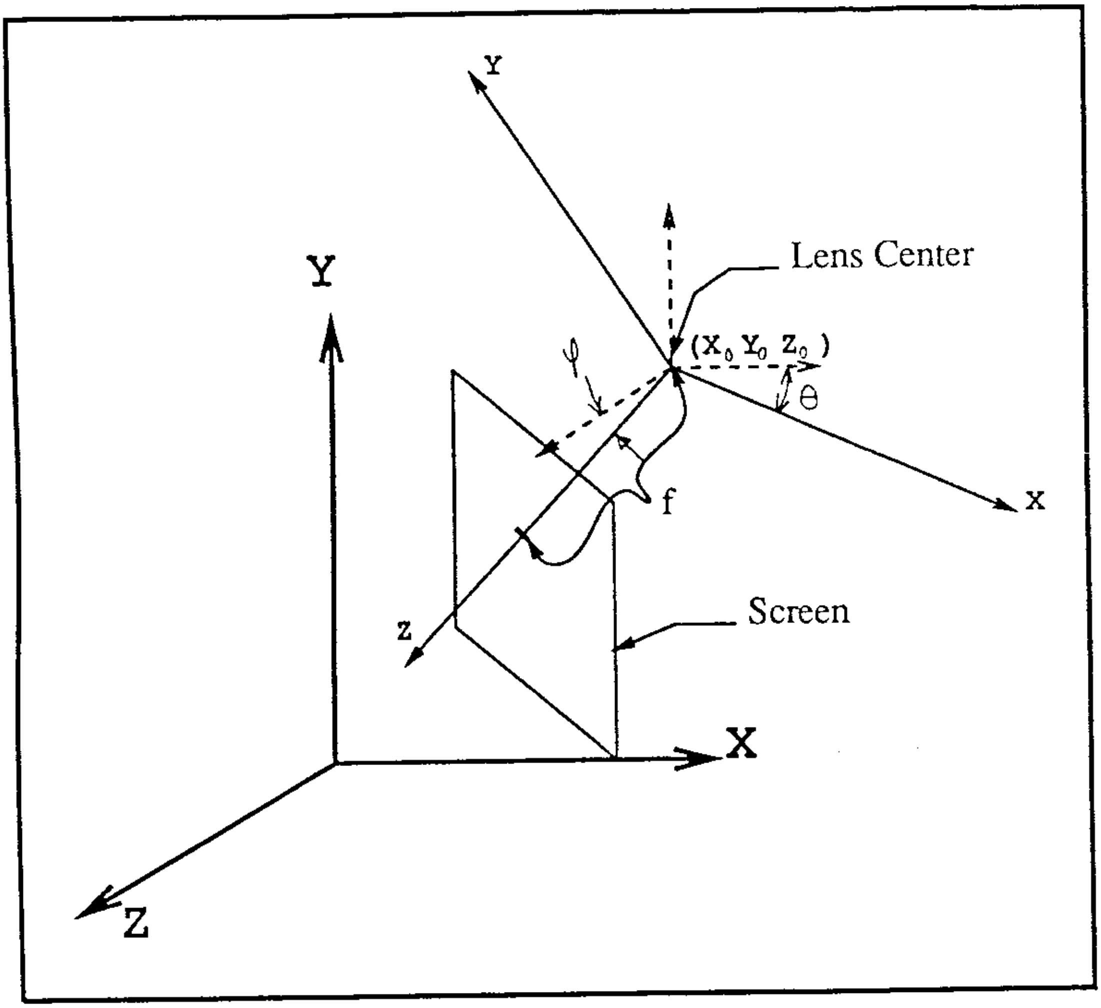

Figure 4.3: World coordinates (O - XYZ) and camera coordinates (o - xyz)

Since the orientation of the camera matrix is expressed in terms of three rotation parameters, the rotation matrix **R** can be described as a function of Euler angles yaw θ, pitch φ, and tilt ψ as follows.

$$\mathbf{R} = \begin{pmatrix} E_{xx} & E_{xy} & E_{xz} \\ E_{xy} & E_{yy} & E_{zy} \\ E_{xz} & E_{zy} & E_{zz} \end{pmatrix} \tag{4.2}$$

When the rotation parameters are inserted into the above equation, it takes the following form:

$$\mathbf{R} = \begin{pmatrix} \cos\theta\cos\varphi\cos\psi - \sin\varphi\sin\psi & -\cos\theta\cos\varphi\sin\psi - \sin\varphi\cos\psi & \sin\theta\cos\varphi \\ \cos\theta\cos\varphi\cos\psi + \cos\varphi\sin\psi & -\cos\theta\sin\varphi\sin\psi + \cos\varphi\cos\psi & \sin\theta\sin\psi \\ -\sin\theta cos\psi & \sin\theta\sin\psi & \cos\theta \end{pmatrix} \tag{4.3}$$

where;

θ:yaw, angle between X and x axis

φ:pitch, angle between Y and y axis

ψ:tilt, angle between Z and z axis

The transformation matrix **T** is equivalent to the position vector of the lens center which is denoted as:

$$\mathbf{T} = \begin{pmatrix} -X_0 \\ -Y_0 \\ -Z_0 \end{pmatrix} \tag{4.4}$$

Recalling back the equation 4.1

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \mathbf{R} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \mathbf{T} \tag{4.5}$$

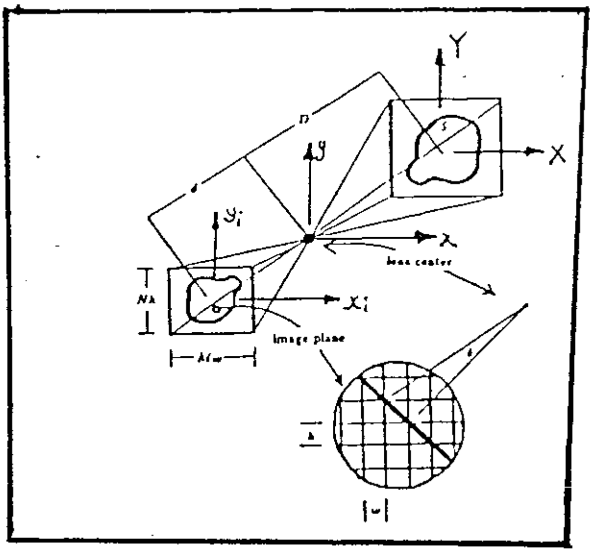

Figure 4.4: Camera and the resolution for orthogonal projection view of surface

The equation 4.5 brings the world and the camera coordinates systems into coincidence. The image plane coordinates of the screen are finally obtained by using the perspective projection transformation with respect to camera coordinates.

$$\begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix} = \mathbf{P}[\mathbf{R}\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \mathbf{T}] \tag{4.6}$$

where;

x_i, y_i, z_i: are the screen coordinates

P: perspective transformation matrix

Figure 4.4 illustrates an orthogonal projection view of surface S lying at distance D from the lens center. The image plane consists of an array of pixels arranged in N rows and M colums. Each pixel has width w and height h. The image plane, d, from the lens center, where d is related to D and to the lens focal length , f, by the

Gaussian lens equation.

$$\frac{1}{f} = \frac{1}{d} + \frac{1}{D} \tag{4.7}$$

The exact mathematical solution of the equation 4.6 for $\psi = 0$ is given in reference [12].

$$x_i = f\frac{(X - X_0)\cos\theta + (Y - Y_0)\sin\theta}{-(X - X_0)\sin\theta\sin\varphi + (Y - Y_0)\cos\theta\sin\varphi - (Z - Z_0)\cos\varphi + f} \tag{4.8}$$

$$y_i = f\frac{(X - X_0)\sin\theta\cos\varphi + (Y - Y_0)\sin\theta + (Z - Z_0)\sin\varphi}{-(X - X_0)\sin\theta\sin\varphi + (Y - Y_0)\cos\theta\sin\varphi - (Z - Z_0)\cos\varphi + f} \tag{4.9}$$

where;

$X_0, Y_0, and Z_0$: camera location in real world coordinate system.

$X, Y, Z,$: represent the location of the object in real world coordinate axis.

The above equations are simplified for the setup used in our experiment. The evaluation procedure is discussed in Chapter 6.

4.2.3 Image Processor

The image processor's basic function is to digitize the analog electrical signals coming from the camera. After the digitization the processes, such as reducing noise and enhancing and processing the image are carried out. Most of the time these are done by the software. Some hardware may also be used for image processing.

4.2.4 Computer and Display

After the image processing the image is sent to the computer as a data array. At this stage the user can manipulate various computational processes on data in order to extract information. In the developed algorithm for AWJ we send the pixel values of a specified window, and we try to figure out where the edges start and what is the width between two edges in terms of number of pixels. This width is later converted to some numerical value by using camera parameters. TV monitor is used in the system to make visual display.

Chapter 5

FRAME GRABBER SOFTWARE AND DEVELOPED ALGORITHMS

The software used in this research, MetraByte's MV-1, is a 512x512x8 bit frame grabber for real-time digital image processing on IBM personal computer. The board installed into the computer digitizes analog video inputs and stores them in one of the video memory banks. It is also possible to add text and graphics to the stored image. Following the digitization, the stored images are displayed on a monitor. The software, which can be used either interactively or within a high level programming language, has capability to display up to 30 images per second.

The MV-1 features 512 kB of dual ported video memory and an 8-bit digitizer that can perform 512x512 resolution in 1/30 of a second. The software has a programmable video adjustment including; source gain, synchronization offset, dc restorations, and any of 8 inline Look-Up Tables (ILUTs). Additionally, acquisition window size is software programmable [6]. The MV-1 is also accompanied by a subroutine library, MVLIB-1, which allows the user to create flexible custom designed video data acquisition.

5.1 Basic Functions of the Frame Grabber Software

The basic of function MV-1 software is to transform the frame acquired by the image-sensing devices into a digital data, and then display the digitized frame on a monitor. This unique process of the software is actually performed by several components each having its own specific function. These components can be separated into five different groups according to their specific function. These are video input; in-line Look-Up tables (ILUTs); video memory; the display Look-Up tables; and video output. Figure 5.1 provides a block diagram of the MV-1 board.

The frame acquired by the cameras is first sent to the MV-1 board in the form of analog signals. The MV-1 board has the capability to process analog signals coming from different image sensors (up to 4). The board then converts analog signals into the digital signals. At this stage the digitized image can directly be stored as a separate file. This option gives the user the flexibility to use digitized image as a source of data whenever it is required. The signal is then sent through the in-line Look-Up tables (ILUT's). After this stage the data can be transferred into two different processing units. If the image data is to be stored in a database or passed to another board for storage, then the data is sent out to the PC Bus. If the data is to be redisplayed, then it is sent through the display Look-Up tables(DLUT's). As a final step the signals are converted back to analog signals through D/A converters.

When MV-1 stores the frame data it stores it pixel by pixel. The digitized value of each pixel within the frame is stored in two banks of the frame storage memory. Each pixel within the frame is identified by line and pixel coordinates. This also identifies the pixel's memory address. Lines are numbered 0 to 511 top to bottom, and pixels are numbered 0 to 511 left to right as shown in Figure 5.2. The MV-1 stores an image up to 512 lines by 512 pixels. However, because of the video-format

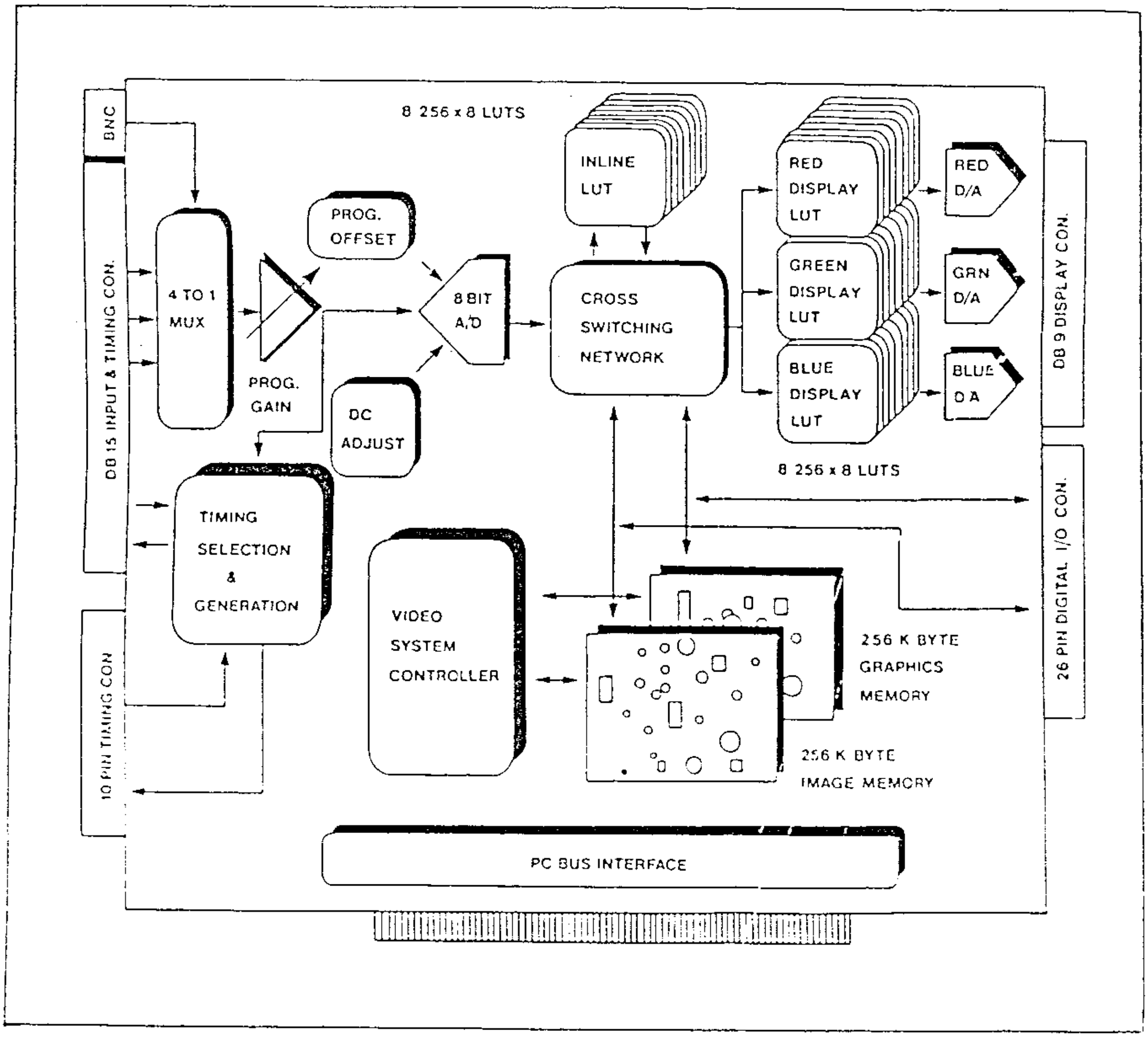

Figure 5.1: Functional block diagram (From MV-1 Software User Manual)

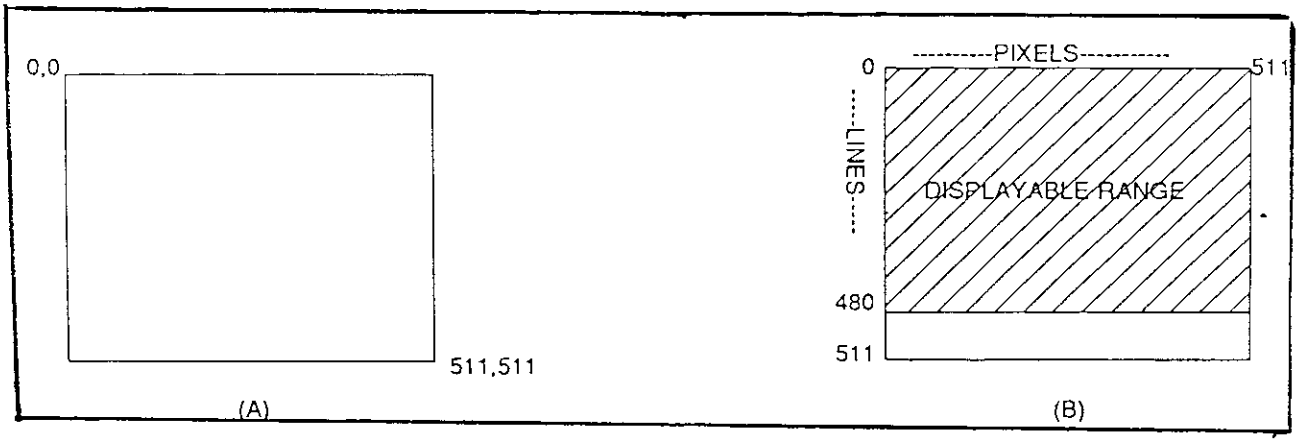

Figure 5.2: Screen Coordinates

standards only first 480 of 512 lines can be displayed.

During the digitization process the A/D converter samples the brightness of the image at a particular location, and also stores the brightness value on the address assigned to that location. Thus, the entire image represented by a rectangular array of integers can be processed for further analysis or kept as is by MV-1.

The basic functions of the previously mentioned components are briefly explained below.

- *Video Input:* After the video signal enters the MV-1 board, it goes directly through a four to one multiplexer. The multiplexer establishes a source signal, and sends it through an 8 bit analog to digital(A/D) converter after the gain. The offset adjustment of the signal is carried out, and it is converted to a digital signal.

- *Inline Look-Up Tables;* The second step of the processing after digitization is storing the in Look-Up tables. The MV-1 board has eight 256 by 8 bit in-line

Look-Up tables, any of which can be used in the processing of the digitized signal. The signal is stored in either of the video memory banks. The most important advantage of storing data into the ILUT's is to have the capability to perform various logical and mathematical operations such as; multiplication and division by a constant; offsetting; AND, OR, NOR logical operations; contrast and brightness adjustment on the single 8-bit pixel.

- *Video Memory:* The MV-1 has two different types of memory with the same capacity of 512 kB. The first one is called image memory and the second one is called graphics memory. The basic function of the image memory is to store the acquired and retrieved images. On the other hand, the graphics memory bank functions as a main storage area for graphics over-lay data. However each memory can substitute the functions for the other. Either graphics or image memory can be accessed during acquisition and display operations by using read and write instructions.

- *Display Look-Up Tables (DLUT's):* The display Look-Up tables are used to select the colors and intensity of the signal when it goes to the display

- *Video Output:* Once the signal has gone through the DLUT's, it is then translated back into an analog signal by the red, green and blue digital to analog (D/A) converters.

5.2 Algorithms Developed

The algorithms developed for the sensing of the waterjet stream are formed from several subprograms where each one has a specific feature. These sub-programs are combined in a root file. The algorithm of the procedure is given in functional block diagram of Figure 5.1. The left side shows the steps of the decisional real time algorithm. The right side shows the options such as printing, storing, and plotting routines; these utilities can be stated up to report. The developed algorithm has two main sections. The first one is image acquisition and digitization, and the second one is mathematical and statistical analysis of the digitized image to detect the edges of the waterjet stream. The basic steps of the first section of the algorithm, which defines how to transform a live image into numerical data is presented in the form of flow chart(Fig 5.3). A brief explanation for each step is given below. In the second part of the algorithm the numerical image data that is already obtained from the first step, is used for extracting relevant information regarding the diameter of the waterjet stream. The second part of the algorithm is discussed in Section 5.3.

Once the program is executed, it initializes system level functions that consist of board control and basic initializing tasks. Board control tasks consist of activating and reactivating the board(s) in the system. Also included in this category is the routine that shows which active boards, if any, are currently available on the system. The basic initializing tasks are those the program user needs to perform upon initial start-up of the system. They can also be performed throughout the program. These tasks are reading the base address file, initializing the Look-Up tables, setting and saving the configuration file, and loading the logic cell array.

The default values are assigned to the above mentioned initialization parameters, and the program user is not supposed to change these parameters unless he/she wants to make a substantial change in the program, such as using two or more cameras instead of one, or rearranging the VSC registers.

As soon as the system is initialized, the program automatically switch to the camera mode so that the live image of the object within the camera's scope can be seen on the screen. At this stage, the user should check the monitor to be assured that the image is sufficiently clear. Furthermore, if any zooming is required it should also be done at this stage. The initial picture of the nozzle and the jet on the screen should not be too small or too large, so that any problem in the accuracy of the

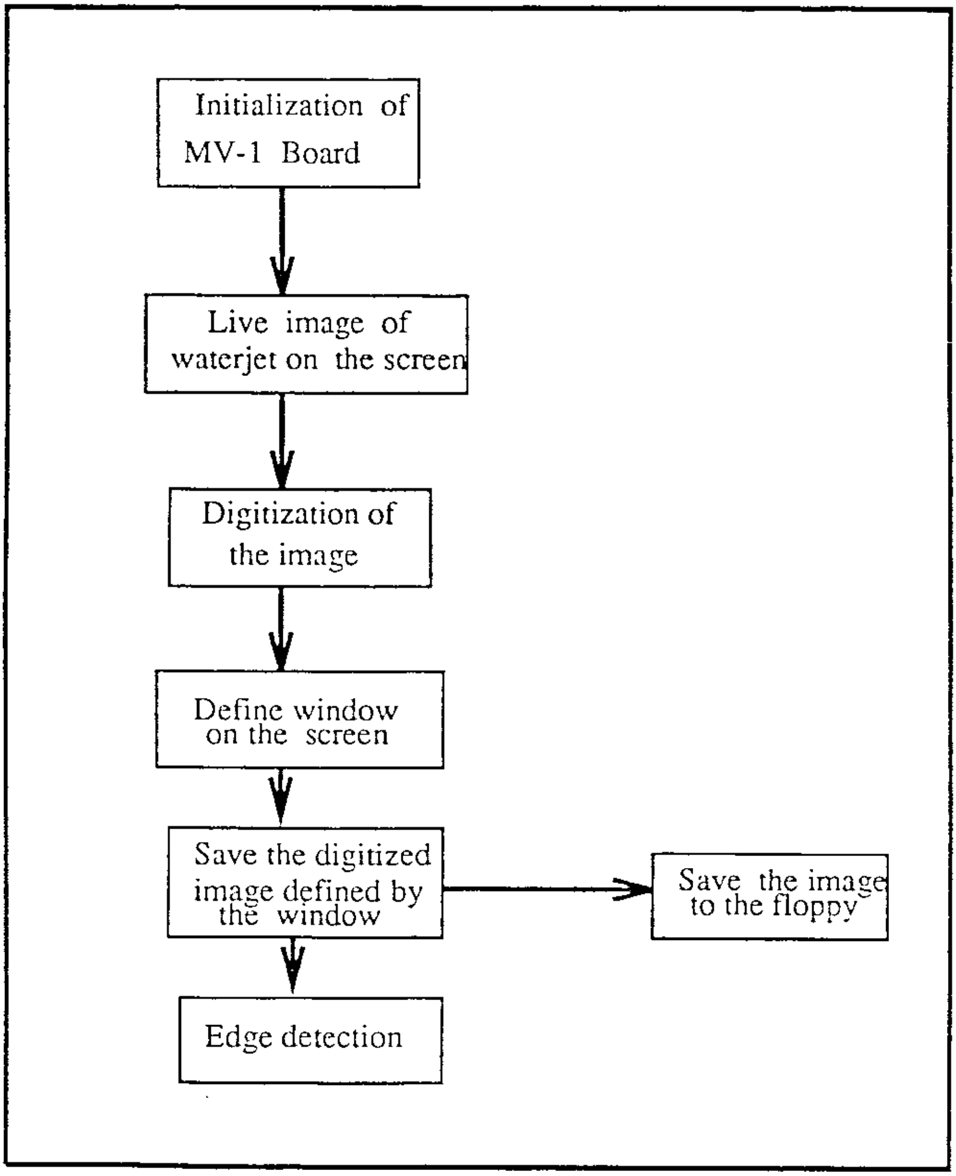

Figure 5.3: Image acquisition and digitization flow chart

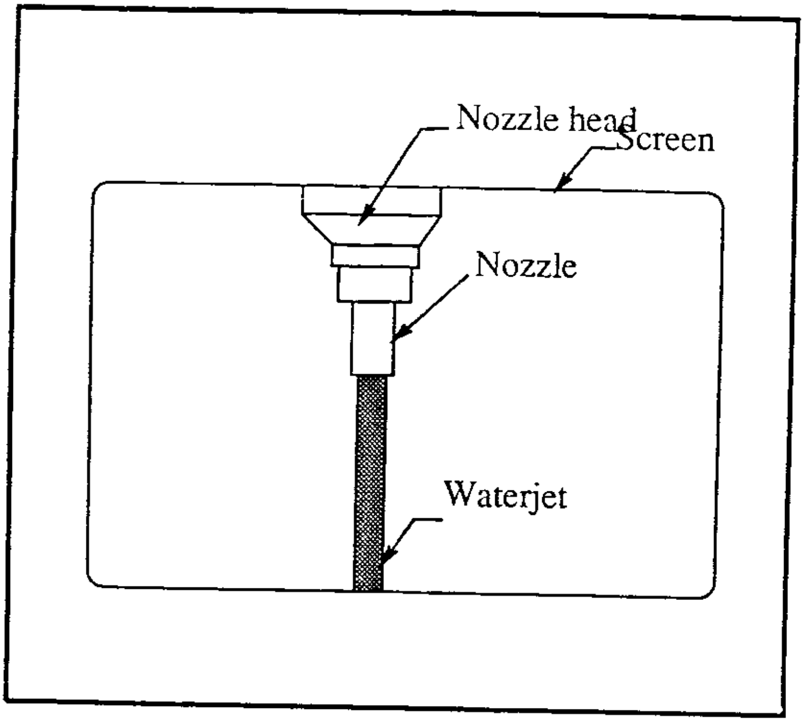

Figure 5.4: Digitized image

image after digitization can be avoided.

After the image on the monitor is made clear the image acquisition process can be carried out. Image acquisition freezes the live image on the screen (5.4). There are a total of 245,280 points on the screen ($480 lines * 511 pixels = 245,280$). A numerical value is assigned to each point. The assigned values range from 0 to 255, where 0 represents a completely black point and 255 represents a completely white point. The program automatically switches into the image mode from the camera mode, and the digitized image is stored. It is also possible to store an acquired image on the graphics mode. However, in our program the graphics memory is completely reserved and used for the graphical representation of waterjet diameter.

The next step following the image acquisition and image digitization is the window definition on the screen (Fig. 5.5). The basic purpose of defining a window is to minimize the area on the screen so that the execution time can be reduced. Furthermore, there is another advantage of defining a small window, especially in the form of a narrow strip due to geometrical deterioration of the water jet stream.

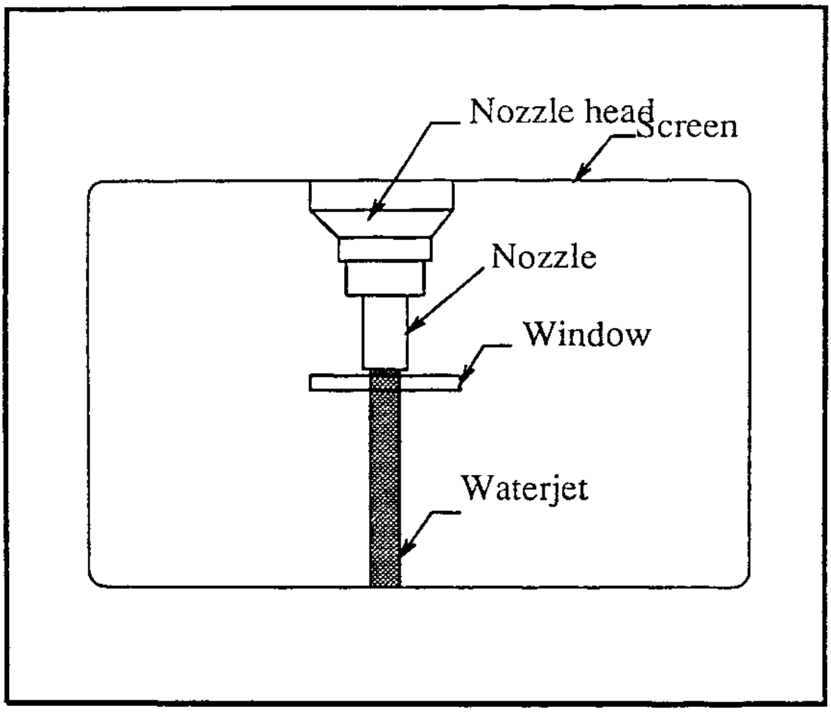

Figure 5.5: Defining a window on the screen

When the water jet leaves the nozzle, it starts to expand and the jet diameter does not remain as a representative parameter for the internal nozzle diameter. Because of these reasons the window on the screen should be as small as possible.

After the window is defined, the image can be saved as screen image file (SIF) either on the hard disk or on a floppy disk (Fig. 5.6). The SIF is pictorial data that can be displayed on the screen whenever it is required. Although it is not necessary to save the SIF file, the image can be safely retrieved for further analysis if it is saved after each operation. In the software, there is another type of file that should be stored after each step. This file is named as an object file, which is kept throughout the entire process. If the user does not define any specific to the object files, the system automatically assigns a default object file name and an object file type. Since the expressions object, object type, object name, object file, and screen image file will be used throughout the thesis, it is better to make a brief explanation about these terms.

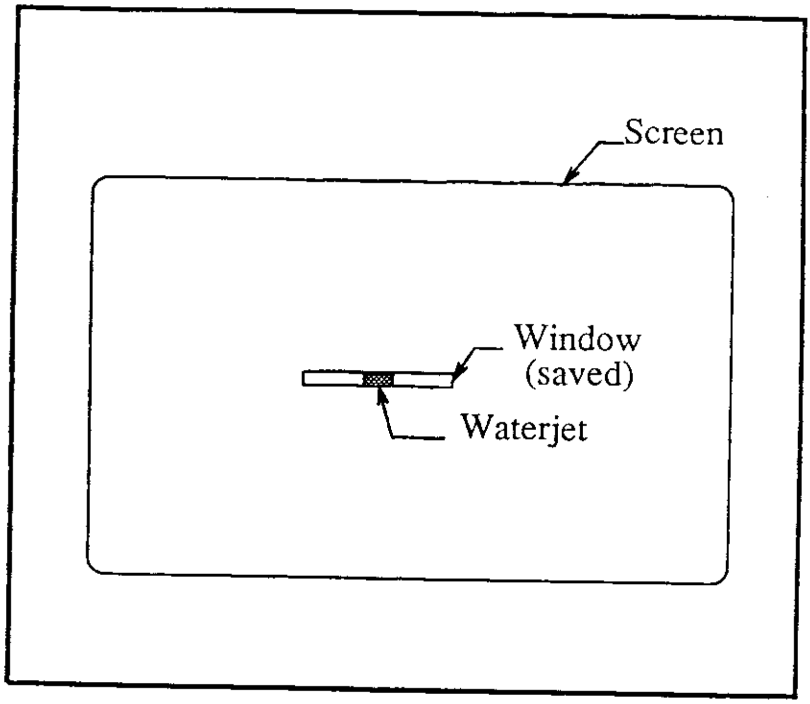

Figure 5.6: Window saved for statistical analysis

Object: An object is any unique item on the screen. Object specified by a name and an object type.

Object type: the object type is the general class to which the objects belongs. Several distinctly different objects may be all of the same type.

Object Name: An object name uniquely identifies each object within its type. The program automatically assigns "Fig. 1", "Fig. 2", ..., "Fig. n" names by default.

Object file: An object file consists of instructions for creating various objects. The number of objects in an object file is unlimited and the new objects are added to the end of the existing file. The program, by default, only opens a single object file, and stores the all objects into this single file. When the volume of stored objects exceeds one megabyte, the program gives a warning to the user. Furthermore, all the object's file may be killed after the execution of the program.

Screen image files (SIF): A screen image file contains the instructions for recreating an entire frame (screen) of data. When data is saved onto the SIF, only the pictorial data is saved. Any editing by histograms and Look-Up tables will not be saved.

To put the image into the best form for a specific application, standard functions were developed in MV-1. These functions manipulate the image data to obtain the type of image required by that particular application. MV-1 software supports several built-in functions, which can perform the task such as kernel management, bitmap, convolution, and histogram management. Only histogram and filtering manipulations are used in our program.

Filtering function enhances contrast of the image and histogram function calculates the distribution of points on the window according to their darkness value.

5.3 Edge Detection

After getting binary image of the screen, the next step is the detection of waterjet stream's edges. The digitization process gives the binary image matrix of the frame. Once we have the darkness value of all ponts of the image within the defined window. We can determine points where the edges start by performing mathematical analysis on the data. The edge detecting algorithm in the program[1] is based on figuring out patterns of increasing and decreasing intensities or gradients generally founded at the edge of the object. The first step of this algorithm is to read each column of the binary image matrix and obtain average pixel value for each column. This process replaces the binary image matrix with binary image array as it is illustrated in Figure 5.3. The other significant benefit of getting the average pixel value for each column is to eliminate possible problems due to spontaneous small, dark spots that may appear in the screen after the digitization.

[1]The full list of program is given in Appendix

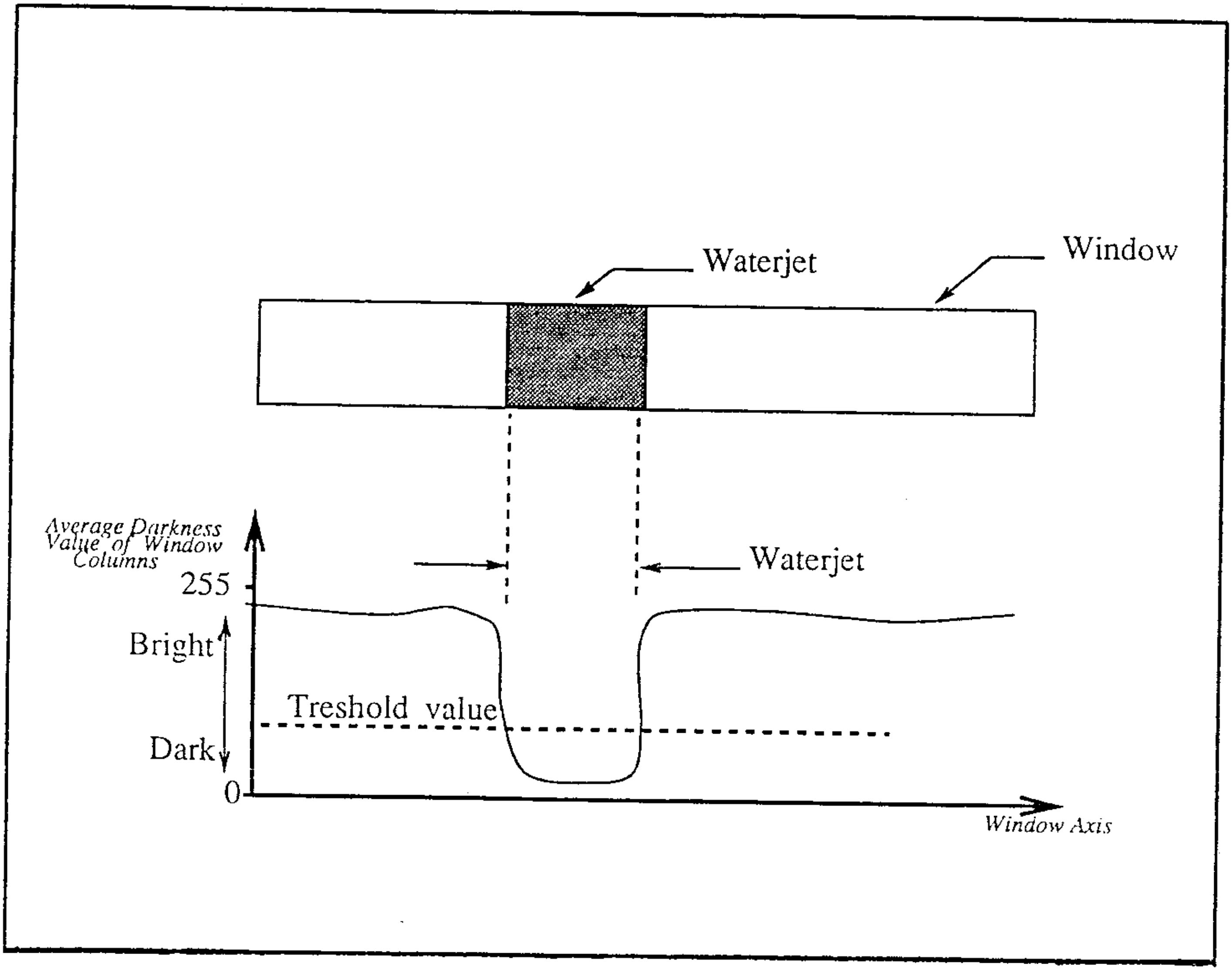

Figure 5.7: Jet stream detection

At this point the average darkness level of each column of the window is plotted, with respect to horizontal axis of the window. As it can be seen in Figure 5.3, the section where the waterjet is positioned can be detected immediately. The width of the jet stream is obtained in terms of pixels by counting the number of pixels, which have lower darkness level than a specific threshold value. Normally the best threshold value can only be obtained by trying different numbers. In our exprerimental set up where backlighting [2] is applied to the jet stream threshold values around 40 (0:completely dark and 255:completely bright) is used throughout the experiments.

[2]Backlighting is explained in chaper 4

Chapter 6

RESULTS AND DISCUSSION

The results obtained from the research are evaluated and discussed in this chapter. Since the basic objective in developing an opto-electronic sensor is to monitor the changes in nozzle internal diameter more accurately than the currently used systems, we primarily concentrated on evaluation of a new system's monitoring accuracy. In the first section, the results of the camera calibration process and how to relate the camera calibration parameters to the actual results are presented. In the second section, the performance of the wear monitoring system under different operating conditions is discussed. In the last section the time requirement for the execution of the developed nozzle internal diameter monitoring program[1] is presented.

6.1 Camera Calibration

The camera used in the monitoring system should be calibrated before taking picture of the waterjet. The basic purpose of this calibration is to get the relation between the real world coordinate axis and the image screen coordinate axis. Once this relation is known, the jet diameter, which is determined from the screen in terms of number pixels can be directly converted into the real world dimensions(in terms of mm) by using the relation.

The equation, which gives the relation between actual dimensions, is derived in

[1]The listing of the program is given in the appendix

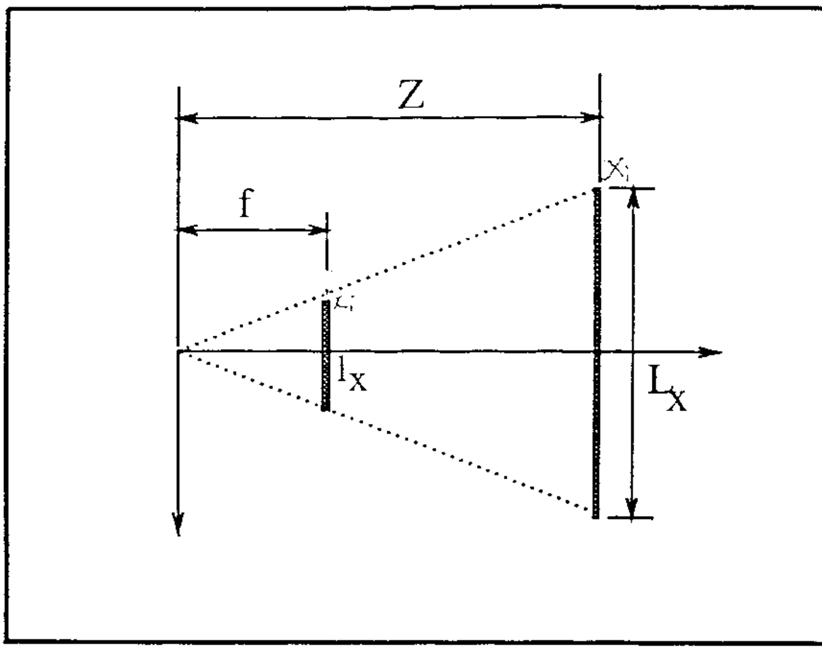

Figure 6.1: Orthogonal projection

chapter 4.2.2. The equation reduces to the orthogonal projection equation for the camera setup used in our monitoring system.

$$X_i = x_i \frac{Z}{f} \tag{6.1}$$

$$L_x = l_x \frac{Z}{f} \tag{6.2}$$

where;

L_x: actual length of the object

l_x: screen length of the image

f: focus length of the camera

Z: distance between camera and object

The camera used in the research is initially adjusted for Z=290mm. The distance between camera and waterjet(Z) can be adjusted to any reasonable value. However, if the camera is placed far away from the waterjet the accuracy of the system will decrease.

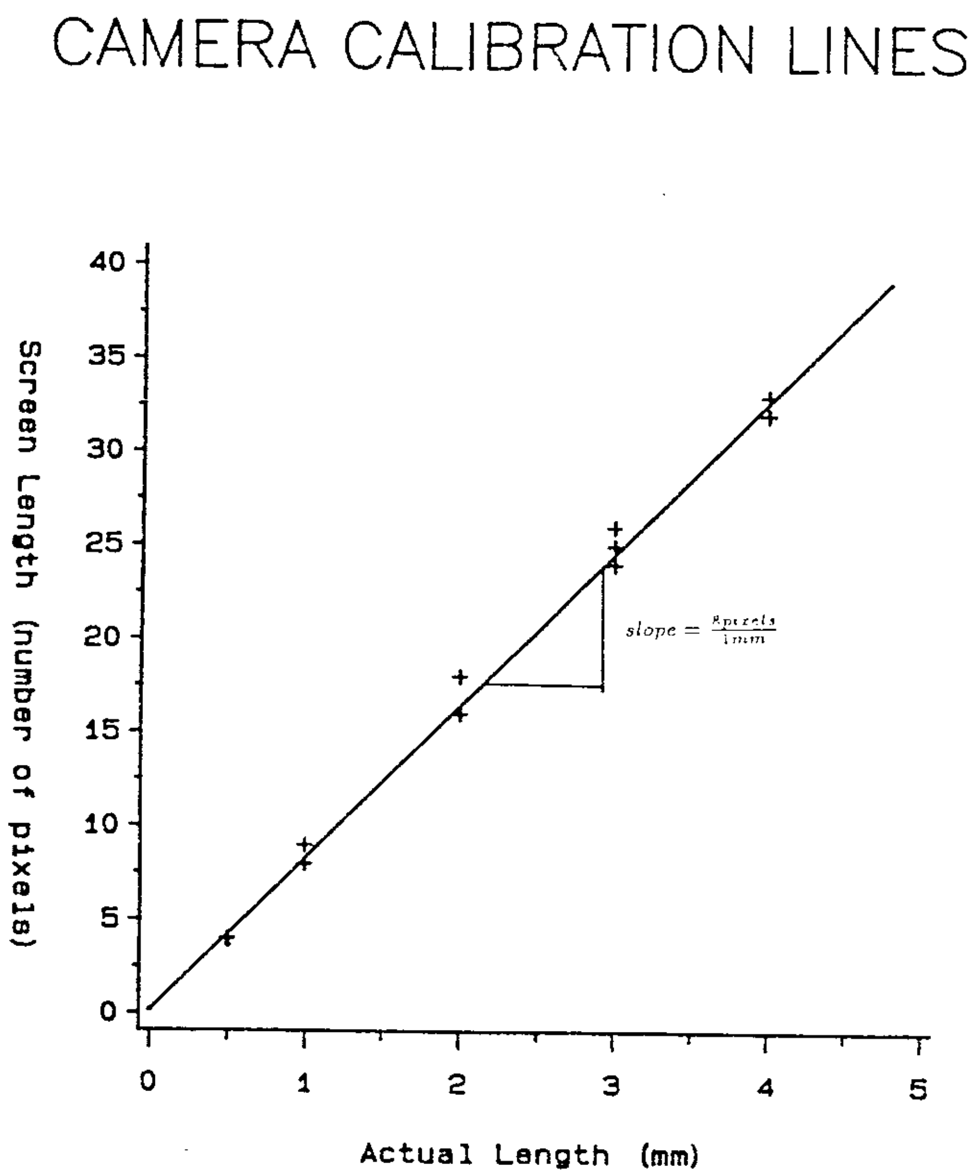

Figure 6.2: Camera calibration lines

Figure 6.2 illustrates the relation between the camera and real world dimensions. For this adjustment process, paper strips with diameter ranging from 0.5mm to 4.0mm are placed on a board which is exactly 290 mm away from the camera. The width of the each strip on the monitor is measured in terms of number of pixels. It can be seen from the figure that there is exactly a linear relation with zero intercept between the real world dimensions and the camera dimensions. This actually conforms with the equation 6.2.

The slope of Figure 6.2 is constant, and it gives the number of pixels on image screen per mm of real world length. The actual waterjet diameter is obtained by dividing the pixel width of the image with this constant value. However, the user should kept in mind that this value will change with the changing focus length of camera and changing distance between waterjet and camera.

6.2 Accuracy of the Wear Monitoring System

To evaluate the performance of the system the waterjet diameter is monitored under different operating conditions. Three different water pressures and abrasive flow rates are selected, and the system's performance is determined for four different nozzle ID ranging from brand new(ID=1.15mm) to completely worn out(ID= 2.30mm). The results of these measurements are given in Table6.1, Table6.2, and Table6.3.

The Figure 6.3 illustrates the accuracy of the monitoring system under different water pressures. In this figure, the monitored waterjet diameter is plotted with respect to the actual nozzle internal diameter. The regression functions, which give the linear relation between the actual nozzle ID and monitored waterjet diameter, is determined for each pressure value. As it can be seen from the figure the difference between the monitored and actual diameter increases as the waterjet pressure increases. This is basically due to deterioration of the waterjet geometry at higher pressures.

	Monitored Diameters								
Monitored D.	P=207MPA			P=241MPA			P=275MPA		
1.15	1.13	1.13	1.13	1.38	1.13	1.25	1.13	1.38	1.38
1.50	1.25	1.50	1.50	1.25	1.38	1.63	1.63	1.63	1.63
1.90	1.63	1.88	1.75	2.00	1.88	2.00	2.00	2.13	2.00
2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.38	2.25	2.13
All dimensions are in mm									

Table 6.1: Monitored jet diameter for abrasive flow rate of 0.45kg/min.

	Monitored Diameters								
Monitored D.	P=207MPA			P=241MPA			P=275MPA		
1.15	1.13	1.38	1.00	1.38	1.25	1.25	1.25	1.25	1.25
1.50	1.50	1.38	1.50	1.25	1.63	1.50	1.50	1.63	1.75
1.90	1.63	1.88	1.88	1.75	2.00	1.88	2.00	2.00	2.25
2.30	1.88	2.50	2.38	2.50	2.50	2.13	2.38	2.25	2.13
All dimensions are in mm									

Table 6.2: Monitored jet diameter for abrasive flow rate of 0.68kg/min.

	Monitored Diameters								
Monitored D.	P=207MPA			P=241MPA			P=275MPA		
1.15	1.00	1.25	1.00	1.00	1.25	1.00	1.25	1.13	1.38
1.50	1.38	1.38	1.38	1.63	1.63	1.63	1.75	1.75	1.50
1.90	2.00	1.63	1.88	1.88	1.75	1.63	2.13	2.13	2.00
2.30	2.59	2.25	2.13	2.50	2.38	2.50	2.38	2.25	2.38
All dimensions are in mm									

Table 6.3: Monitored jet diameter for abrasive flow rate of 0.91kg/min.

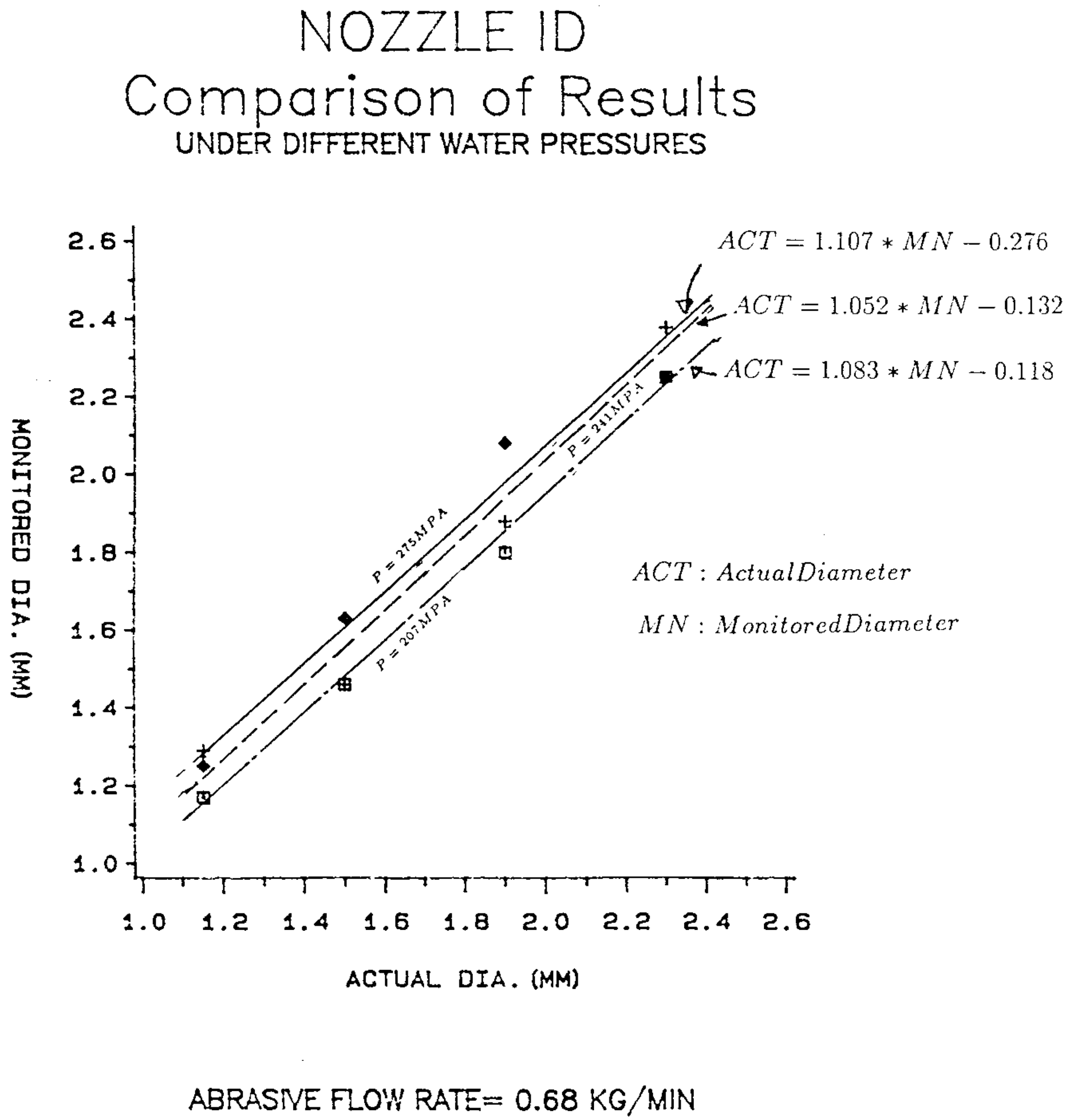

Figure 6.3: Monitored diameter vs actual diameter under changing pressure

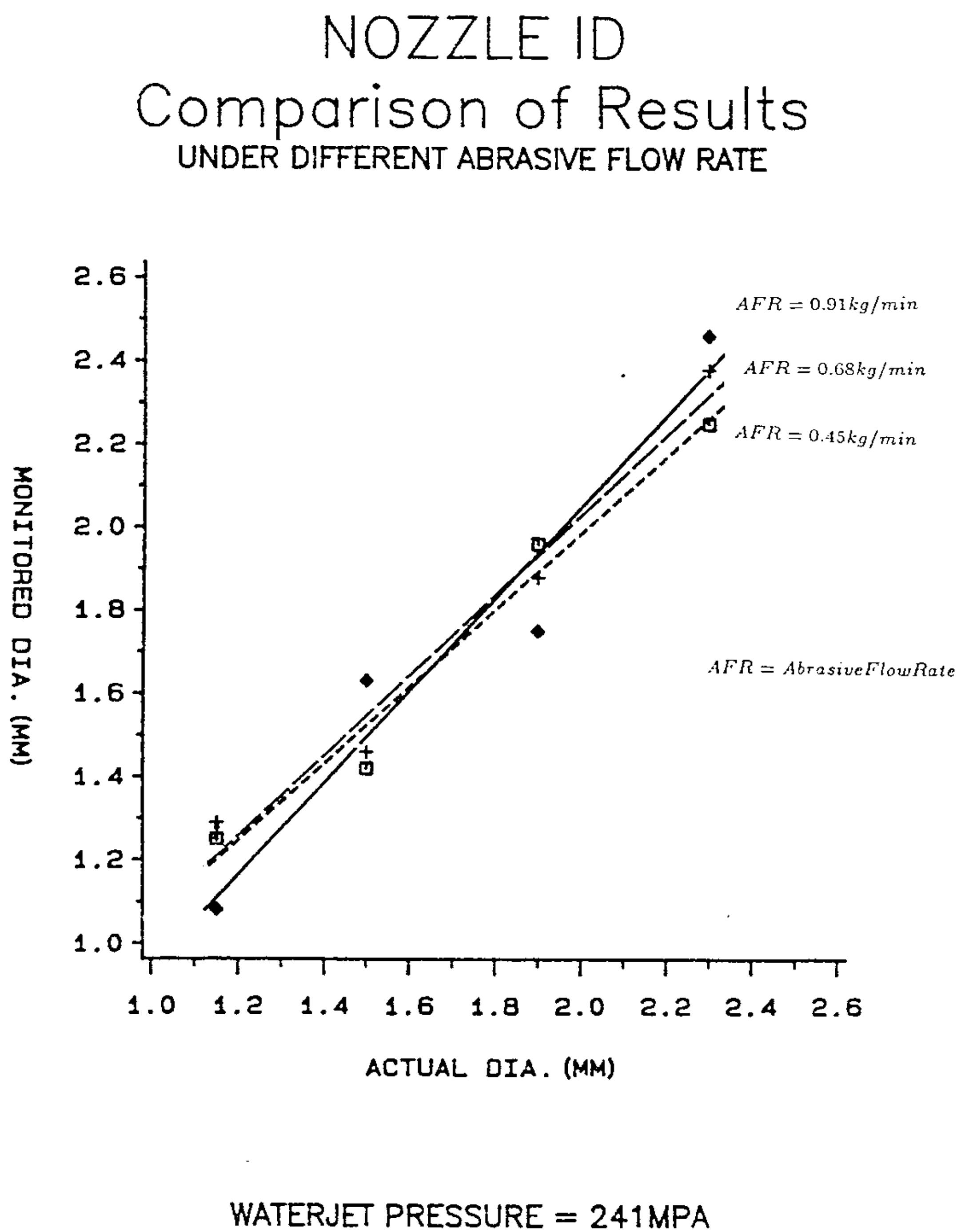

Figure 6.4: Monitored diameter vs actual diameter under changing abrasive flow rate

The linear regression functions calculated for each pressure show that all the relation lines have slope values larger than 1. As the pressure increases, the slope also increases. This can be explained by the fact that the waterjet experiences a sudden expansion when it leaves the nozzle which causes the overestimation of the waterjet diameter. The effect of the expansion becomes more apperant when the nozzle is new or the pressure is high. When we look at the monitored diameters for 1.15 mm actual nozzle ID, we can see that the monitored diameters under different pressures are all significantly higher than actual nozzle ID of 1.15 mm.

The effect of the abrasive flow rate, which is another significant parameter on the accuracy of the wear monitoring system, is illustrated in figure 6.4. As it can be seen from the figure, although the changes in abrasive flow rate affect the accuracy of monitored ID, it is not possible to establish a relation that can be generalized for the entire range of monitored diameters. The effect of the sudden expansion of the waterjet can also be detected from this figure. All the monitored diameters for the nozzles with smaller internal diameters are overestimated as in previous situation.

6.3 Time Requirement for the Execution of the Program

The nozzle wear sensing program developed in this research is prepared step by step, and the performance of the system is evaluated after each step. The whole program can be separated into two modules; frame acquisition and mathematical analysis. This separation is based on the tasks performed by each module being independently executable.

First, the frame acquisition can be run, and the result, which is a pixel value matrix of the specified window, can be stored in a file. Later on, the second section of the program that uses the output of the first program can be run for the statistical analysis of the data. This part of the program includes algorithms for detecting the edges of the waterjet and estimating the waterjet diameter. The processing time requirements for the various functions of the program is given below.

Frame Acquisition Section

Initiation of the MV-1 Frame Grabber	18 sec
Frame Acquisition	5 sec
Window Definition and Clearing of the Screen	16 sec
Second Frame Acquisition	5 sec
(If the quality of the fist one is not satisfactory)	
Second Window Definition and the Clearing of the Screen (If the quality of the fist one is not satisfactory)	16 sec
Saving the Object Files	4 sec
Saving the Screen Image File (Optional)	9 sec
Total Time for Frame Acquisition	48 sec (min)
	78 sec (max)

Mathematical Analysis Section

Taking the Histogram of the Image (Including storing in ILUTs)	8 sec
Passing the Image Through the Filter	12 sec
Clearing the Screen and Displaying the Histogram	40 sec
Retrieving the Object File (Optional)	20 sec
Edge Detection Algorithm	25 sec
Total Time for Mathematical Section	105 sec
Total Time for the Entire Program	183 sec

As it can be seen above, a complete run takes around three minutes in maximum. This time interval between two successive measurements is sufficient to get at least five or six data of the nozzle wear, even under worst operating conditions. (maximum pressure and maximum abrasive flow rate).

Chapter 7

FUTURE IMPROVEMENTS

In this research the performance of an optical sensing system developed for abrasive waterjet is proposed, and the various aspects of this system are discussed. The developed system gives fairly good results for the on-line estimation of the nozzle wear over the full range of nozzle internal diameters. However, there is still room for further improvement and enhancement of monitoring system. In this section these possible improvement areas are discussed.

7.1 Two Camera System

In our study, we used a single camera for the monitoring of the waterjet. During the cutting process, the cross-sectional profile of the nozzle wear remains almost circular or ellipsoidal, sometimes it is possible to have an irregular shape especially when the wear progresses heavily in one direction.

Therefore using another camera, which is perpendicularly oriented with respect to the first one, will give a better geometrical representation of the waterjet.

However, the improvement in the accuracy due to the two-camera technique will still be marginal because of the immediate change in the geometry of the jet when it leaves the nozzle. As it is explained in the previous part, the jet expands and takes a uniform shape as soon as it leaves the nozzle. This is the reason why the waterjet thickness is more related to the maximum diameter of the worn out nozzle than the

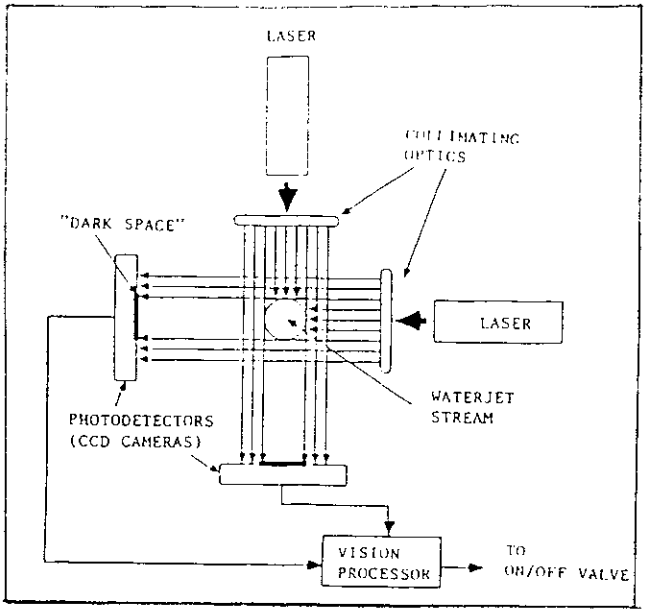

Figure 7.1: A laser camera assembly

average diameter.

7.2 Using Laser for Illumination

Illumination is the most important feature that determines the accuracy of an image processing system. The system developed in this project can function without any illumination in which the image is passed from various filters. However, it is always desirable to use some kind of illumination, since it improves the accuracy of the overall system. On the other hand, when dealing with illumination, the user should be very careful in choosing the proper technique. Improper illumination may create shades and reflections which may cause a loss in accuracy. To eliminate this problem, laser can be used as an illumination medium.

Laser light can especially be useful under the following situations :

- When ambient or room lighting is difficult to control

- When the changing reflection of the part makes conventional light sources difficult to use

- When selective high-intensity illumination, that is, illumination of only a portion of the part is required, where flooding of light over the entire scene is found to have disadvantages.

Chapter 8

CONCLUSIONS

- The nozzle wear (internal diameter of the nozzle) in abrasive waterjet can be determined effectively by using an opto-electronic sensor, which takes the picture of the image, digitizes it, and performs quantitative operations to figure out the thickness of the waterjet.

- The execution of the program takes three minutes in maximum. This amount of time interval between two successive measurements is sufficient to get at least five or six data of the nozzle wear even under worst operating conditions. The trend of the wear progress can easily be spotted, and the tool replacement can be carried out safely before the complete failure of the nozzle.

- The monitored diameter is principally independent from any AWJ parameters. However, it is observed that the monitored diameter slightly increases as the water pressure increases.

- The system developed uses a non-contact type of sensor (camera) that doesn't require any installation or maintenance. Thus, it can be used effectively in all kinds of abrasive waterjet cutting operations.

- The developed monitoring system can be further improved by implementing new algorithms that can determine the edges more effectively, especially for commercial applications.

Appendix A

APPENDIX

USER'S MANUAL

The wear monitoring program consists of two separate programs written in C language. The first program is the main program(WEAR.C), which initializes the MV-1 board, and then performs the steps of image acquisition and digitization. The digitized image is stored in a data file(DATA.DAT) in the form of two dimensional array whose elements are the darkness values of the pixels within the defined window. The second program(EDGEDET.C) includes an algorithm that detects the edges of the image and determines the waterjet thickness in terms of number of pixels.

A.1 How to Use the Wear Monitoring Program

A.1.1 Hardware Requirements

The necessary equipment for implementation of the program is listed as follows.

- IBM Personal Computer(preferably AT)
- MV-1 Frame Grabber plug-in board.
- Video camera and monitor.

Furthermore, the jumpers on MV-1 Frame Grabber board should be set to the values given in the manual [6].

A.1.2 External Parameters of the Program

The external parameters are the inputs of the program, and they should be entered by the user.

- *Window Coordinates:*

  The user should define a window so that only a portion of the screen where the object of interest positioned is saved and processed. The window is defined by the terminal points of the window's diagonal line; (r0, c0) and (r1, c1).

  - r0: is the row number identifying the beginning of the diagonal line. Valid row numbers are 0 to 479.
  - c0: is the column number identifying the beginning of the diagonal line. Valid column numbers are 0 to 511.
  - r1: is the row number identifying the end of the diagonal line. Valid row numbers are 0 to 479.
  - c1: is the column number identifying the end of the diagonal line. Valid column numbers are 0 to 511.

- *Gain and Offset Values*

  Greater image contrast can be achieved by adjusting the gain. This consists of increasing or decreasing the amplitude of the analog wave form. The user can adjust the amplitudes by the following amount.

  1.0 The signal essentially remains the same.

  1.5 This amplifies the signal by a factor of one and half.

  2.0 This de-amplifies the signal by a factor two.

  0.5 This halves the value of the signal.

The offset value is a constant value which is added to or subtracted from each pixel value in the frame. This will uniformly brighten or darken the image so that the image's features are sharpened. Some values of significance are:

255-Makes the image darkest.

127-Leaves the image unchanged.

0-Makes the image brightest.

Also, by modifying the offset the user can compensate for fixed offsets that occur at the input to the digitizer. The offset can also be used in conjunction with gain to maximize the dynamic acquisition of the digitizer. The default setting for the offset value is 128 (image is not changed).

A.2 How to Create an Executable Program

A.2.1 Software Requirements

- Microsoft C compiler, linker, libraries and include files.
- MVLIB library for MV-1 Frame Grabber.
- WEAR.C program (listing is given in section B.1)

A.2.2 How to Compile the Program

After making the necessary changes on the program, the user can compile the program by using the Microsoft C as follows.

≻cl /AL /c WEAR.C

Make sure that there is no error found during compiling and there is a program named WEAR.OBJ is createdin the directory. A.2.3 How the Link the Program

The linker that comes with Microsoft c compiler is used to link the routines. The following statement should be entered by the user.

≻link WEAR,,,MVLIB;

The result will be an executable program named "WEAR.EXE". When it is executed on the computer by typing WEAR, the program will ask for the external parameters, and will start executing the program.

B.1. Program Listing

```
/* PROGRAM LISTING */

/* PREPROCESSOR DIRECTIVES */

#include <stdio.h>
#include <malloc.h>
#include <dos.h>
#include <stdarg.h>
#include "mvregs.h"
#include "mvstruct.h"
#include "mvmacro.h"
#include "struct.h"
#include "macro.h"
#include "param.h"
#include "junk.h"

/* GLOBAL DECLERATIONS */
short ctell=0, ptell=0;
unsigned char val, b[50];


/* ***** MAIN FUNCTION ***** */

main()
{

/* LOCAL VARIABLE DECLERATIONS */

FILE  *fp;
char  a[10], y1;
int   icol, irow, i, l1, l2, l3, m1, m2, m3;
int TRUE1 = 0;
int channel, dcrestore, dcoffset, offset, gain, sync, sample, tv;
float  b1[50], sum1, c[250], m, pl;

/*  IMAGE AQUSITION  */

/* This is the first part of the program.
In this part the following steps are carried out;
  Intializing the board
Preprocessing Functions
Frame Acqusition and data management */

/* Map the hardware

Registerer Base Address: 300H
Memory Base Address: 90000H
Configuration: Dual
```

```
*/

/*  Assigning default values for preprocessing functions  */

channel = 1;
dcrestore = 1;
offset = 1;
gain = 1.5;
sync = 0;
sample = 0;
tv = 0;

acq: {
{
{
        system("cls");

/* Stores MV-1 base addreses */
mv_base();

mv_intlev();

mv_param();

/* Downloads a logic cell array code */
mv_loadlca();

/* Initializes both the In-Line Look-Up Tables(ILUTs)
and display Look-Up Tables(DLUTs). */
mv_lutinit();

/* Downloads the VSC and MV1 register images to each board */
mv_sysinit();


printf("THE DEFAULT VALUES FOR PREPROCESSING FUNCTIONS\n");
printf("%d Channel\t\t\n", channel);
printf("%d DC Restoration\t\t\n", dcrestore);
printf("%d DC Offset value\t\t\n", dcoffset);
printf("%d Gain\t\t\n", gain);
printf("%d Master timing\t\t\n", sync);
printf("%d Sample source clock\n", sample);
printf("%d TV Standard\n", tv);

printf("\n DO YOU WANT TO CHANGE ANYTHING\n\n");
y1 = getchar();
if ((y1 == 'y') || (y1 == 'Y')) TRUE1 = 1;

while(TRUE1)
{
printf("\n Select the input cahnnel");
printf("\n 1 = BNC input cahnnel");
```

```
printf("\n 2 = DB15 channel 1");
printf("\n 3 = DB15 channel 2");
printf("\n 4 = DB15 channel 3\n\n");
scanf("%d", &channel);
mv_channel(channel);

printf("\n Set DC Restoration level");
printf("\n 1 = ON & 0 = OFF\n");
scanf("%d", &dcrestore);
         mv_dcrestore(dcrestore);

printf("\n Set DC offset value(black level)");
printf("\n 255 Makes the image darkest");
printf("\n 127 Leaves the image unchanged");
printf("\n   0 Makes the image brightest\n");
scanf("%d", &dcoffset);
  mv_offset(dcoffset);

printf("\n Set the designated gain value");
printf("\n 1 - The signal essentially remains the same");
printf("\n 1.5 - This amplifies the signal by a factor of 1.5");
printf("\n 2 - This amplifies the signal by factor of 2");
printf("\n 0.5 This halves the value of the signal\n\n");
scanf("%d", &gain);
mv_gain(&gain);

printf("\n Select the master timing source of the active boards");
printf("\n 0 - Internal timing synchrinization");
printf("\n 1 - External timing synchronization\n");
scanf("%d", &sync);
mv_sync(sync);

printf("\n Select the sample source clock");
printf("\n 0 - Sampling clock source is internal");
printf("\n 1 - Sampling clock source is external\n");
scanf("%d", &sample);
          mv_sample(sample);

printf("\n Select TV standard");
printf("\n 0 - Interlaced");
printf("\n 1 - Non-interlaced\n");
scanf("%d", &tv);
  mv_tvstandard(tv);

}
}

{
printf("YOU ARE IN CAMERA MODE PRESS FOR FRAME ACQUSITION\n\n");
getchar();
}
}
```

```
{
mv_view(2);
mv_frameacq(0);
mv_view(0);
}
}

for(;;) {
                printf("IS IMAGE QUALITY SATISFACTORY? (YES)  ");
   a[1] = getchar();
                if ( (a[1] == 'Y') || (a[1] == 'y') ) break;
        goto acq;
printf("\n");
                }

{
mv_bank(0);
}

{
mv_window(125,50,175,450);
}

printf("LAST STOP BEFORE SAVING    PRESS ANY KEY.....\n\n");
getchar();
        getchar();

printf("SAVING THE FILES......\n\n");
{
mv_save("rect","gul1",125,50,175,450);
mv_writefile("denek.img","rect","gul1");
mv_closefile("denek.img");
}

{
mv_clear(0);
}

{
mv_window(125,50,175,450);
mv_display("rect","gul1",125,50,175,450);
getchar();
getchar();
}


printf("SAVING THE IMAGE FILES WITH THE WINDOW\n\n");
{
mv_save("rect","gul1",125,50,175,450);
/* mv_writefile("denek.img","rect","gul1");
mv_closefile("denek.img");*/
}
```

```
printf("TEMPORARY STOP....PRESS ANY KEY!\n\n");
getchar();

{
printf("DO YOU WANT TO SAFE THE IMAGES ON FLOPPY  ");
a[2] = getchar();
if ((a[2] == 'Y') || (a[2] == 'y'))
{
mv_dos("copy denek.img a:denek.img");
};
}

        {
{
printf("\nTAKING THE HISTOGRAM......\n\n");
mv_histo(0,125,50,175,450);
printf("SAVING THE HISTOGRAM INTO TEMPORARY LOOK UP TABLES....\n\n");
mv_eqhist();
printf("PASSING THE IMAGE FROM THE FILTER\n\n");
mv_interpret(0,125,50,175,450);
getchar();
getchar();
}

{
printf("WRITING TEMP. LOOK UP TABLES...\n\n");
mv_writelut(0,5);
printf("CLEARING THE SCREEN\n\n");
mv_clear(0);
printf("DISPLAYING THE HISTOGRAM\n\n");
mv_displut(0);
getchar();
}
        }

/* {
printf("PRESS ANY KEY TO GET THE IMAGE BACK\n\n");
        getchar();
printf("CLEARING THE SCREEN\n\n");
mv_clear(0);
mv_display("rect","gul1",125,50,175,450);
} */

{
printf("\nTAKING SECOND HISTOGRAM.....\n\n");
mv_histo(0,125,50,175,450);
printf("SAVING THE HISTOGRAM INTO TEMPORARY LOOK UP TABLES\n\n");
mv_eqhist();
printf("PASSING IMAGE FROM THE FILTER AGAIN");
mv_interpret(0,125,50,175,400);
}
```

```
{
ctell=0;
ptell=1;
for(icol=1; icol<=250; ++icol) {
sum1 = 0;
for(irow=1; irow<=49; ++irow) {
mvset(irow+125,icol+150);
val = inp(base|VSCXYI|bank);
l1 = val/100;
l2 = val/10;
l3 = val/1;
m1 = l3 - 10*l2;
m2 = l2 - 10*l1;
m3 = l1;

pl = ((100*m3) + (10*m2) + (m1))/2.55;

sum1 += pl;
}


c[icol] = sum1/50;
printf("AVERAGE VALUE FOR COLUMN=%d is %6.2f\n", icol, c[icol]);
}
}

{
if((fp=fopen("data.dat", "w"))==NULL) {
printf("CAN NOT OPEN FILE\n");
exit(1);
}
for(i=1; i<=250; ++i) {
fprintf(fp, "%f\n", c[i]);
}

fclose(fp);
}

}




 void dispvect(int num1, float dum1[])

{
int  k;
for (k=0; k <= num1; ++k) {
printf("value of %d is %6.2f", k, dum1[k]); }
return;
}
```

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