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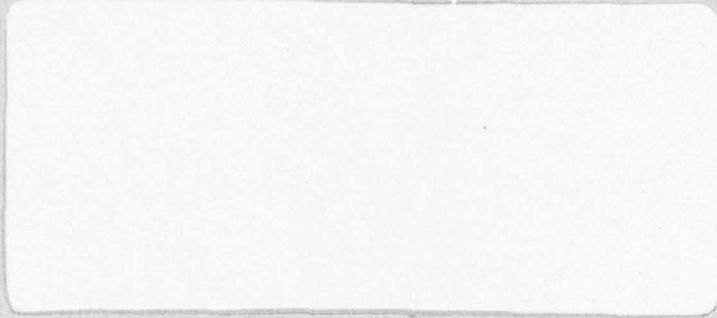
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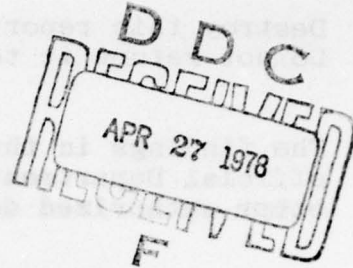
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DIRECT ELECTRONIC TRANSFORMS
FOR FEATURE EXTRACTION

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Final Report

1 April 1978

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Prepared For

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
Fort Belvoir, Virginia 22060

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FORT BELLEVILLE, VIRGINIA 22060

PREFACE

This report contains a description of a direct two-dimensional image transform system using Walsh functions. A discussion of the hardware and the performance testing of the system are included.

The report was done under Contract Number DAAK 70-77-C-0049 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060. The Contracting Officer's Representative (COR) was Dr. Pi-Fuay Chen.

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CONTENTS

Section	Title	Page
	PREFACE	ii
	ILLUSTRATIONS	iv
	TABLES	vi
1.0	INTRODUCTION	1
2.0	TECHNICAL DISCUSSION	2
2.1	General	2
2.2	Two-Dimensional Walsh Transforms	2
2.3	Conceptual Design of Two-Dimensional Walsh Transform Hardware	4
3.0	EQUIPMENT DESIGN AND TEST	8
3.1	General	8
3.2	Equipment Description	8
3.3	System Performance	14
3.4	Potential System Improvements	15
4.0	CONCLUSIONS	22
5.0	RECOMMENDATIONS	23
	REFERENCES	24

ILLUSTRATIONS

Figure	Title	Page
1	Walsh functions $wal(k,x)$ $wal(m,y)$ in Cartesian coordinates for $k,m = 0...7$ in the interval $-1/2 < x < 1/2$, $-1/2 < y < 1/2$. Black areas represent +1, white areas -1..	3
2	Walsh functions $wal(k,r^{1/2})$ $wal(m,\alpha/2\pi)$ in polar coordinates for $k,m = 0...7$ in the interval $0 < r < 1$, $0 < \alpha < 2\pi$. Black areas represent +1, white areas -1..	5
3	Functional diagram of the Direct Image Transform System	9
4	Construction of the Plasma Panel	11
5	Size and layout of the Plasma Panel	12
6	Generator for space variable Walsh functions using products of the shifted Rademacher functions $wal(2^S,x)$. A, half-adder; C, stage of a shift register or counter.	13
7	Pulse diagram for the generator of Figure 6	13
8	Displayed transforms of $wal(1,0)$ and $wal(0,1)$ as shown in Figure 1. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$	16
9	Displayed transforms of $wal(3,0)$ and $wal(0,3)$ as shown in Figure 1. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$	17
10	Simple test image and its transform. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$	18

Figure	Title	Page
11	Simple test image and its transform. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$	19
12	Simple test image and its transform. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$	20

TABLES

Number	Title	Page
1	Cartographic Features	6

DIRECT ELECTRONIC TRANSFORMS FOR FEATURE EXTRACTION

1.0 INTRODUCTION

This is the final report for Contract Number DAAK 70-77-C-0049. This was a one-year fixed price contract to build special purpose research and development hardware that would establish the feasibility of cost-effective direct Walsh transformation of two-dimensional images. The two-dimensional Walsh functions were to be in Cartesian coordinates and the system built was to be compatible with a computer to be added at a later date.

This report describes the hardware system that was built along with its operation and performance. Section 2.0 contains a short discussion of the orthonormal set chosen for transformation. Section 3.0 describes the hardware system, its test, and potential improvements that might be made. Section 4.0 contains conclusions about the system and Section 5.0 contains some recommendations for future work using the system.

2.0 TECHNICAL DISCUSSION

2.1 General

In the area of pattern recognition, success or failure depends upon the set of features extracted from the data to be used for classification. The generally unsatisfactory results experienced to date in this field reflect either a poor choice of features or the inability to extract enough features to allow discrimination between classes.

A general approach for obtaining what are hopefully useful features is to obtain an orthogonal transform of the patterns and to attempt classification based on the pattern's transform coefficients. Hopefully each class of pattern will have a few dominant transform coefficients that will allow for a high probability of correct classification. An approach to ensuring a few dominant coefficients would be to match the image processing to the image features of interest. In the laboratory case this seems rather obvious. If you want to detect circles, attempt to correlate the image against a set of circles. If you want to find checkerboards, correlate the image against a set of two-dimensional binary functions, etc.

Obviously, this approach will run into difficulties if the basic features of each class differ widely. Attempting to identify a single transform set whose shape closely matches that of each widely different class might be impossible. However, if the classes have certain basic features in common this might be exploitable with the proper choice of transform. This is the basic concept behind this contract, i.e., to build an economical, efficient system that employs a transform set whose characteristics closely match those of the patterns of most interest - man-made structures.

2.2 Two-Dimensional Walsh Transforms

Two-dimensional Walsh functions in Cartesian coordinates are shown in Figure 1. These functions should be most adept at

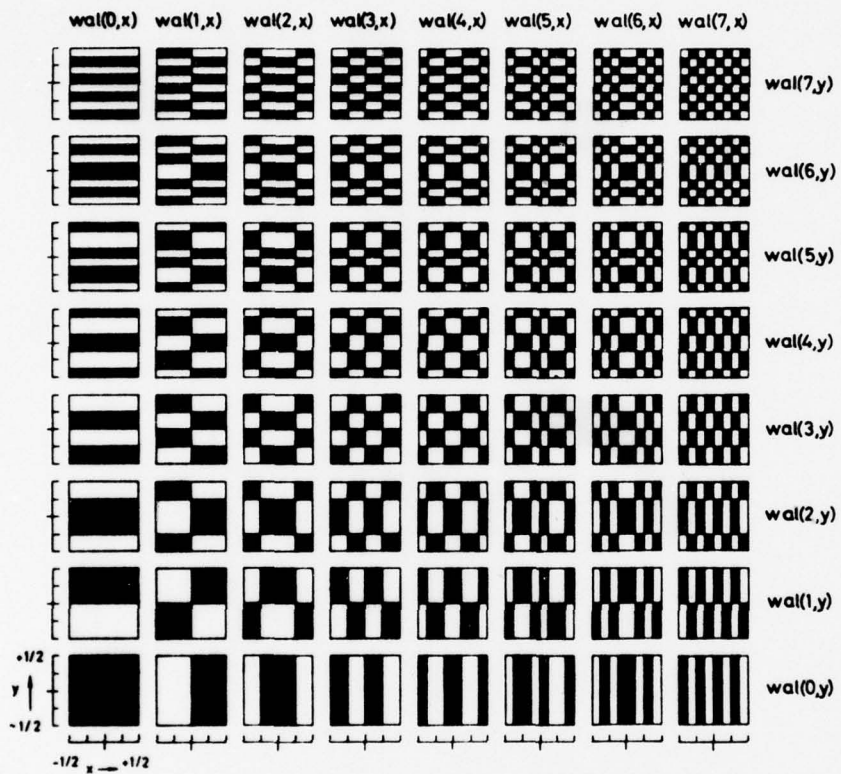


Figure 1. Walsh functions $wal(k,x) wal(m,y)$ in Cartesian coordinates for $k,m = 0 \dots 7$ in the interval $-1/2 < x < 1/2, -1/2 < y < 1/2$. Black areas represent +1, white areas -1.

detecting straight lines, rectangles, and squares. The two-dimensional Walsh functions in polar coordinates shown in Figure 2 should be most adept at detecting circles, discs, or rings. The best choice of a set of functions to transform topographic images depends upon what shaped features we are most interested in recognizing.

The cartographic features listed in Table 1 that are best matched by the two-dimensional Walsh functions shown in Figures 1 and 2 are the man-made features. Certainly buildings, dams, airports, urban areas, and suburban areas are better matched by these Walsh functions than by a set of two-dimensional Fourier functions.

2.3 Conceptual Design of Two-Dimensional Walsh Transform Hardware

An obvious approach to obtaining the two-dimensional Walsh transform of images in Cartesian coordinates would be to digitize the image, digitize each two-dimensional Walsh function and, in a computer, multiply the two, point-by-point, to obtain the Walsh coefficient of that image to each Walsh function. Once the required coefficients have been obtained they could be evaluated in a computer. However, the speed and cost of such an approach would be prohibitive, as the number of required Walsh coefficients exceeds a few.

An overall more satisfactory approach might be to develop a two-dimensional binary device that would allow a Walsh function to be produced on its surface; this could be a receiving (photodiode) array or a radiation (light) source array. If the device is a photodiode array, the light image of a pattern focused on the array will produce the appropriate Walsh coefficient only if the outputs of the diodes corresponding to the light (or dark) areas of each Walsh pattern in Figure 1 are

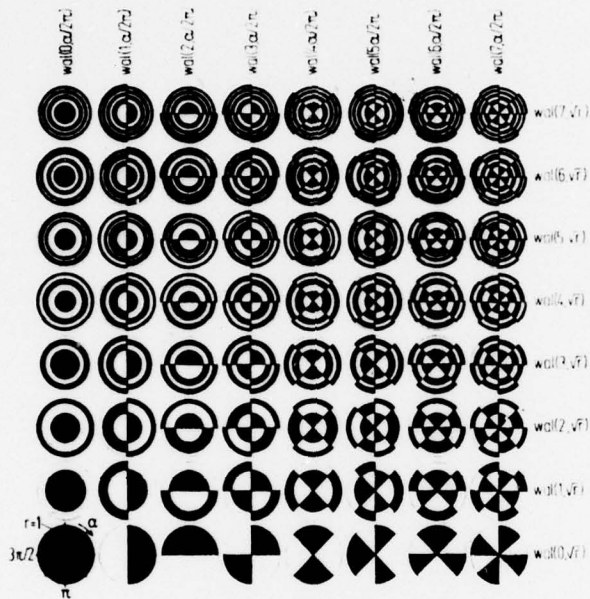


Figure 2. Walsh functions $wal(k, r^{\frac{1}{2}}) wal(m, \alpha/2\pi)$ in polar coordinates for $k, m = 0 \dots 7$ in the interval $0 \leq r < 1$, $0 \leq \alpha < 2\pi$. Black areas represent +1, white areas -1.

CARTOGRAPHIC FEATURES

Point Features

Isolated buildings
Storage tanks
Quarry or borrow pit
Tunnel entrance

Line Features

Rivers and streams with water
Drainage channels without water
Canals
Dual highways
Primary roads
Secondary roads
Unpaved roads and trails
Transmission lines
Pipe lines
Levees
Dam
Rapids and falls
Bridges
Shoreline (large water body)
Airport

Area Features

Large rivers (water on left and water on right)
Lakes
Wash and river bars
Forest
Scrub
Marsh and swamp
Mangrove
Orchard and vineyard
Urban area
Suburban area
Industrial area
Railroad yard
Cemetery

summed together. If the device is a light source lit like the Walsh functions in Figure 1, then the summation of the light intensity transmitted through a transparency of the pattern will be the Walsh coefficient of that pattern for that Walsh function. Either type of device can produce the Walsh coefficients of transparencies of images.

Major considerations in designing such a device are its speed, compatibility with a computer, flexibility, spatial resolution, and cost. Section 3 discusses the equipment built by URC on this contract.

3.0 EQUIPMENT DESIGN AND TEST

3.1 General

This section describes the direct image Walsh transform system equipment both functionally and by subsystem. The tests that were conducted are described and potential improvements to the system are discussed.

3.2 Equipment Description

A functional diagram of the direct image Walsh function transform is shown in Figure 3. The heart of the system is the plasma panel which consists of 512 X-direction electrodes and 512 Y-direction electrodes sandwiching a neon gas. When the proper voltage is applied across an X-electrode and a Y-electrode by the electrode driver amplifiers, the neon gas discharges producing a small light at the intersection of the electrodes. By controlling the 512 X-electrode driver amplifiers and the 512 Y-electrode driver amplifiers with a spatial Walsh function generator logic circuit, two-dimensional Walsh functions can be lit up on the plasma panel. If the system is designed properly it can be switched rapidly from one Walsh function to another in order, for example, from wal(0,0) to wal(0,1) to wal(0,2) to ... wal(0,511) to wal(1,0) to wal(1,1) to ... wal(511,511) as shown in Figure 1.

A black and white (opaque and transparent) transparency of the image to be transformed is laid on the surface of the plasma panel. The neon light pattern from the plasma panel shining through the transparency is collected by the lens and projected on the active surface of the photomultiplier tube. The output voltage from the photomultiplier tube is proportional to the intensity of the light (the Walsh coefficient of the transparency) shining on it. The Walsh coefficient voltage is normalized and interfaced to the Z-axis of the storage display scope. As the plasma panel displays each two-dimensional Walsh function, the corresponding Walsh coefficient of the transparency is displayed on the scope

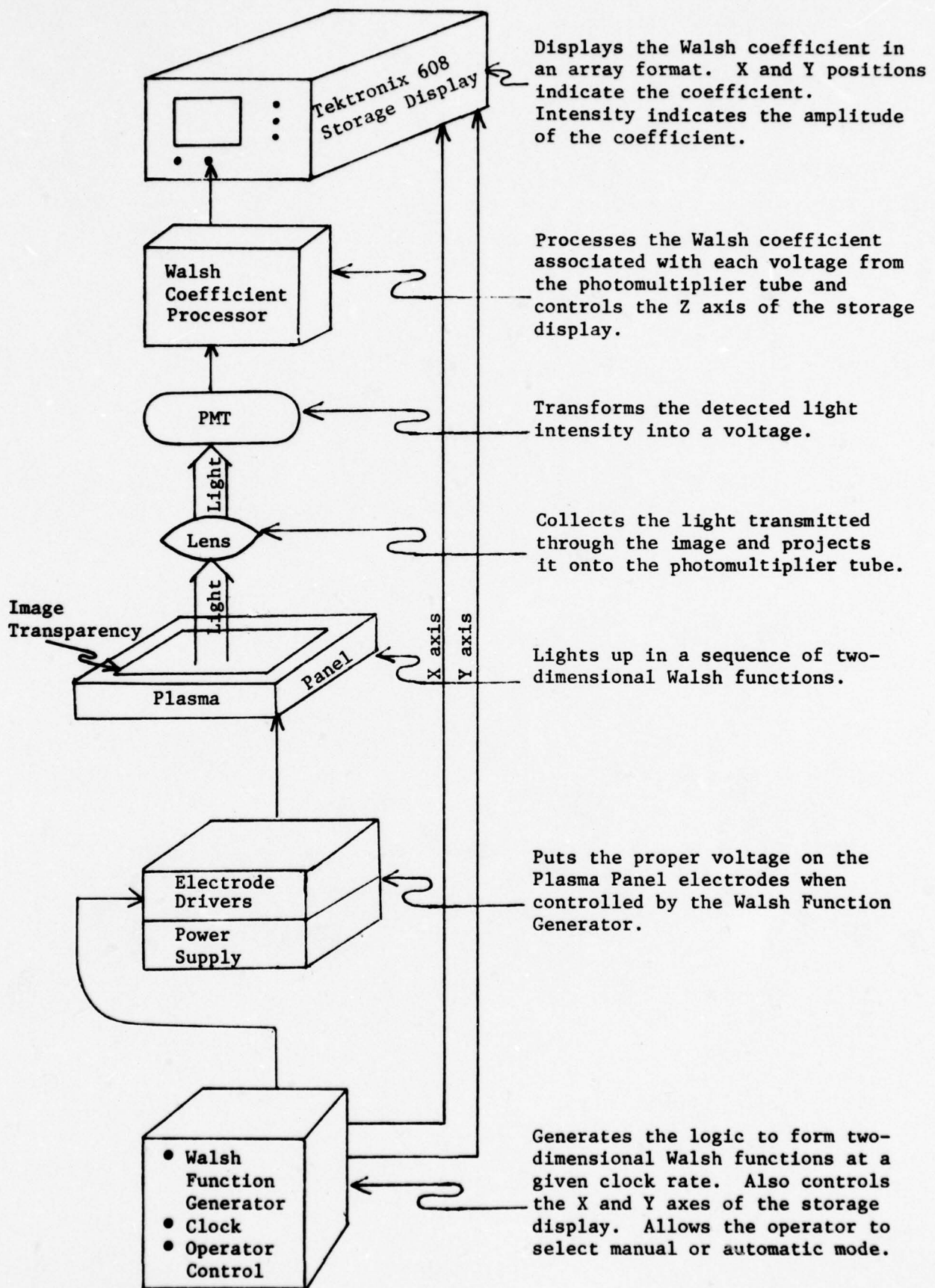


Figure 3. Functional diagram of the Direct Image Transform System

as an element of an array of coefficients, for example, the coefficients corresponding to wal(0,0) through wal(0,511) are displayed as a horizontal row of dots across the top of the screen where the intensity of each dot is proportional to the value of that Walsh coefficient. The coefficients corresponding to wal(1,0) through wal(1,511) are displayed as the next row of coefficients on the display, and so on.

At the operator's option, the system may be manually stepped through one Walsh function at a time, or, at the throw of a switch, it will automatically measure all 512^2 Walsh transform coefficients of the transparency at its clock rate of 32000/second or about 8.2 seconds to determine all 512^2 coefficients.

For convenience and to save space, the system is mounted in a standard 19-inch by 6-1/2-foot cabinet with casters.

The plasma panel is a standard commercially available device whose construction is shown in Figure 4. It should be noted that the electrodes on each glass plate are covered by a dielectric making the tube, in effect, a capacitor. When the voltage on an X- and a Y-electrode is large enough to make the neon gas break down, a current flows across the tube collecting a surface charge on the dielectric which eventually reduces the potential across the gas to the point where the gas can no longer be maintained as a plasma and the light goes out. The size and layout of the particular panel model used for this system is shown in Figure 5. As can be seen, the 1024 X- and Y-electrodes terminate on all four sides of the panel. The active area over which the two-dimensional Walsh functions are displayed is approximately 8-1/2 inches by 8-1/2 inches.

Each of the plasma panel's 1024 electrodes is driven by its own amplifier that can either put 0 or approximately 125 volts on the electrode. Control of each amplifier such that the appropriate Walsh functions are displayed in order, is obtained by a logic circuit such as that shown in Figures 6 and 7 for

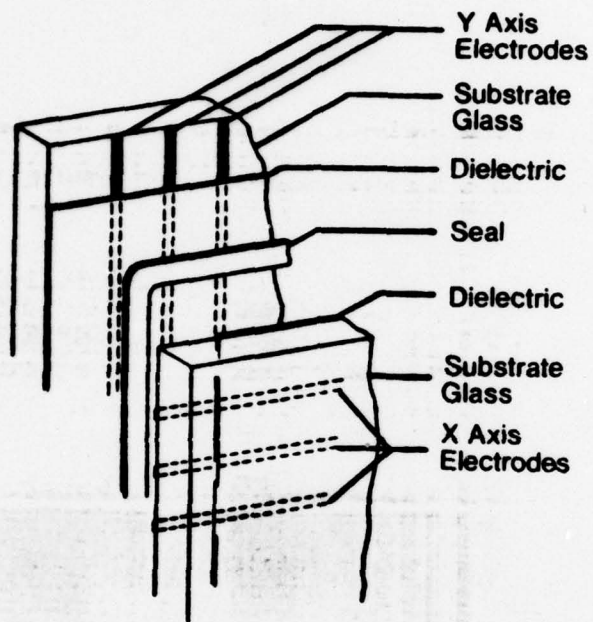
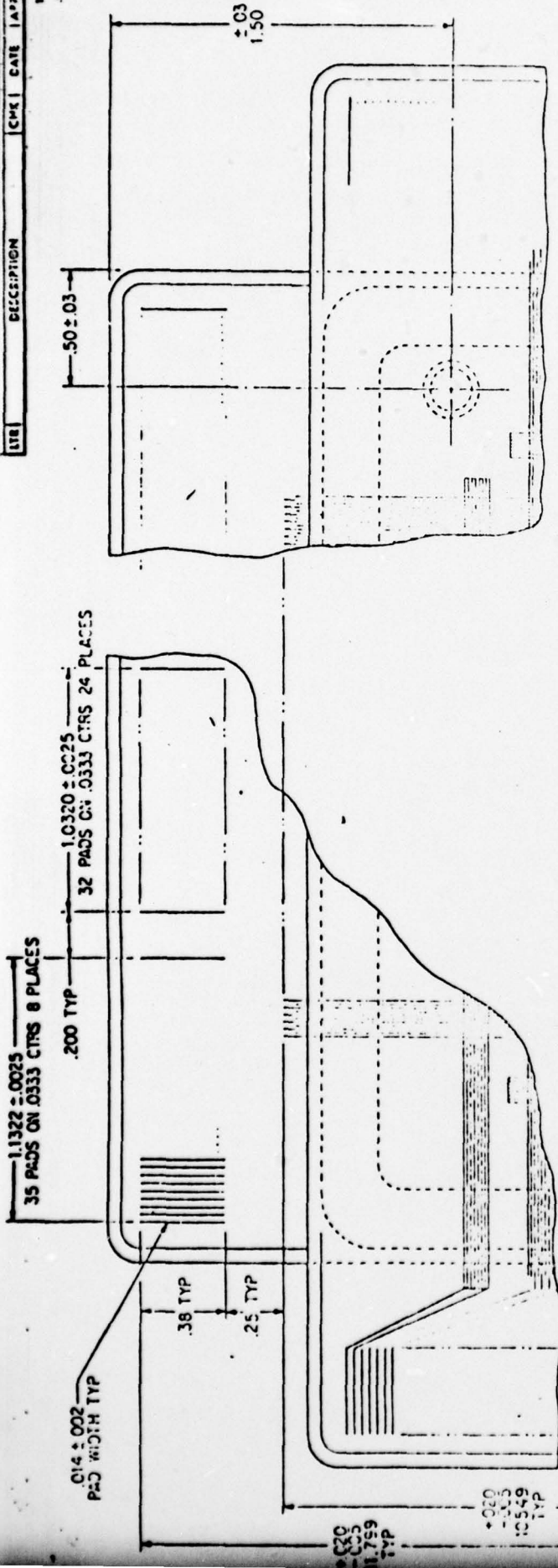
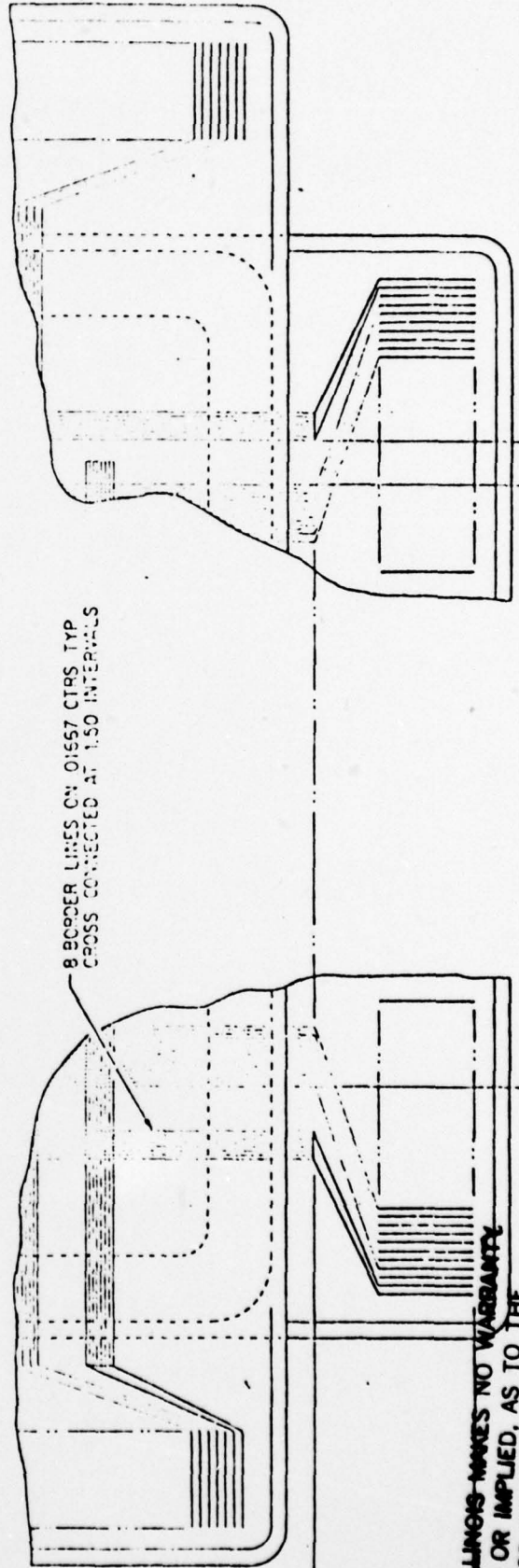


Figure 4. Construction of the Plasma Panel.



VIEW A

VIEW C



VIEW B

VIEW D

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Figure 5. Size and layout of the Plasma Panel.

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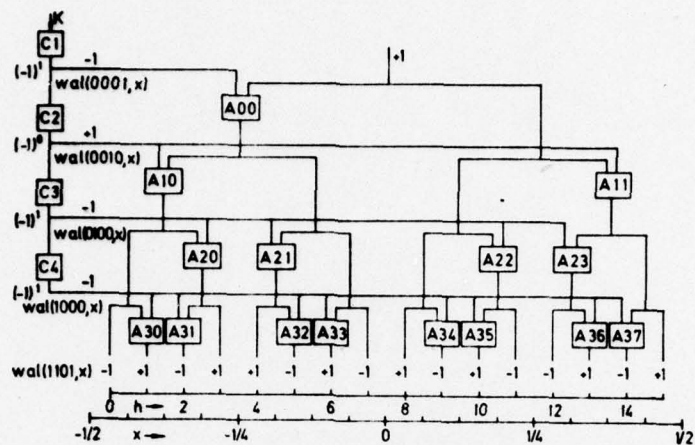


Figure 6. Generator for space variable Walsh functions using products of the shifted Rademacher functions $wal(2^s, x)$. A, half-adder; C, stage of a shift register or counter.
 $wal(1101, x) = wal(1000, x) wal(100, x) wal(1, x)$.

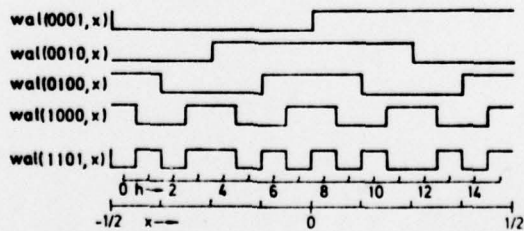


Figure 7. Pulse diagram for the generator of Figure 6.

16 electrodes. The half-adders A are arranged according to the functions $wal(1,x)$ to $wal(1000,x)$ in Figure 6. The output voltages represent the function $wal(k,x)$ if the number k is stored in binary form in the counter stages C1 to C4.

A circuit of the type shown in Figure 6 with 512 outputs controls the X-axis amplifiers and one controls the Y-axis amplifiers. Each such circuit has nine stages of logic and nine corresponding counter positions, C1 through C9. If the 9-bit X-axis counter and 9-bit Y-axis counter are run in sequence, i.e., an 18-bit counter where the 9 least significant bits count for the X-axis and the 9 most significant bits count for the Y-axis, then the result will be two-dimensional Walsh functions. The analog equivalent of the X-axis counter value controls the X-position on the display where the corresponding Walsh coefficient is displayed. The same is done for the Y-axis counter and the Y-position on the display.

The output Walsh coefficient voltage from the photomultiplier tube is amplified, sampled and held, normalized, and interfaced to the Z-axis of the display. The normalization is required to correct the fact that the Walsh functions are binary with values of +1 and -1, but the plasma panel is binary with values of +1 (light) and 0 (dark).

The system display is a Tektronix 608 storage display. While this device is fast enough in its normal mode, it has only low contrast when run at the required speed of 32000 discrete coefficients per second in the storage mode.

3.3 System Performance

The system performance was checked by the qualitative evaluation of the transform of simple binary (opaque and transparent) images which were displayed on the storage scope. Two of these images were two-dimensional Walsh functions. Theoretically, the expected transform of these functions would be a single coefficient corresponding to the displayed Walsh function which is identical to the image. As shown in

Figures 8 and 9 this is exactly what was obtained with the system operated in both the manual and the automatic modes.

Three other simple shapes (a cross, a stripe, and a square) were transformed. These were chosen because the transforms of similar shapes had been calculated by other means. These shapes and the corresponding dominant features of their transforms are shown in Figures 10, 11, and 12. These transforms correlated well with the expected results. The Walsh transforms of these shapes do exhibit more non-zero coefficients than are shown in Figures 10, 11, and 12, however the magnitude of these additional coefficients was difficult to evaluate, due to the poor contrast on the display scope.

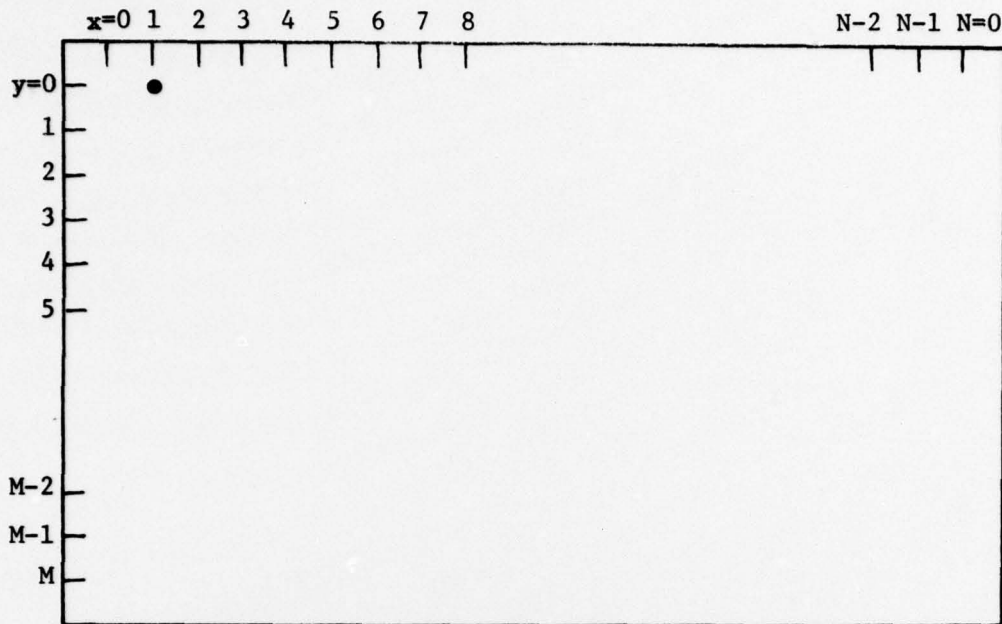
In general, the performance of the system is quite good. Theoretically-expected results are obtained and are repeatable. However, the display allows only qualitative evaluation of the transforms and a quantitative evaluation capability is desirable for future work.

3.4 Potential System Improvements

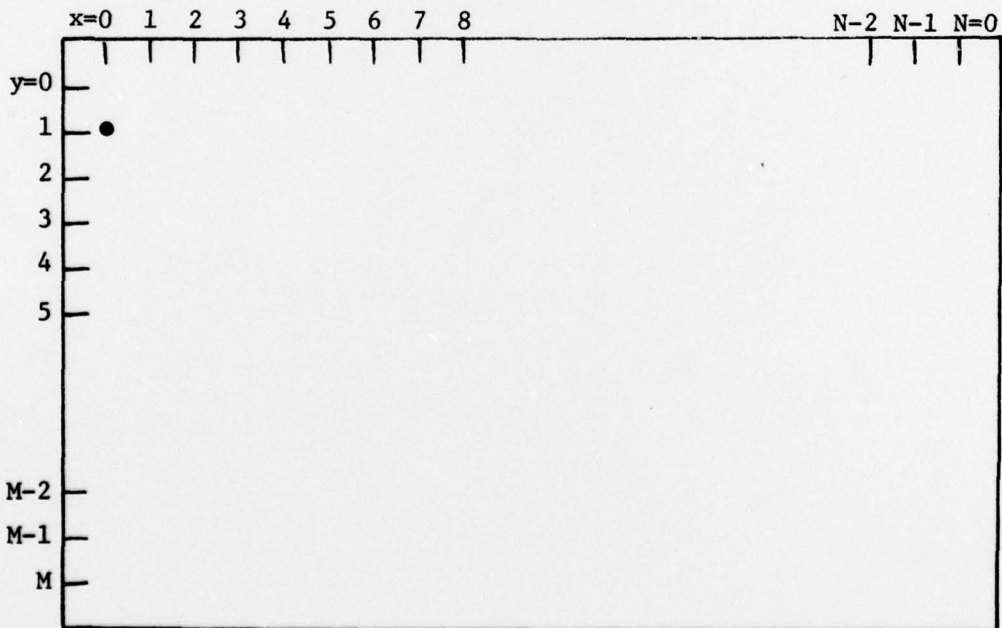
As with any piece of R&D equipment, as soon as it works, there are a number of modifications and improvements that one would like to make. This system is no exception.

There are a number of improvements that could be made to increase the readability of the display. These include the following:

- Slow the system clock down by a factor of from 2 to 10 so that the Tektronix display will give more contrast, especially in the storage mode. This has been demonstrated.
- Provide more shaping of the voltages out of the photomultiplier tube. This will improve the accuracy of the coefficients in the sample and hold circuit. The result should be an improved output signal-to-noise ratio.

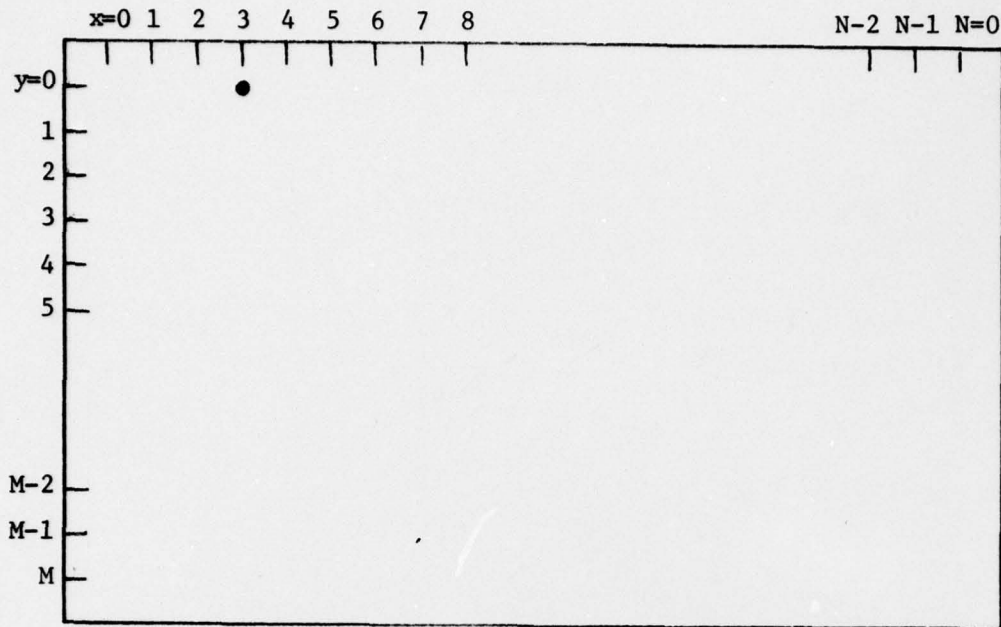


A. Displayed transform of wal(1,0)

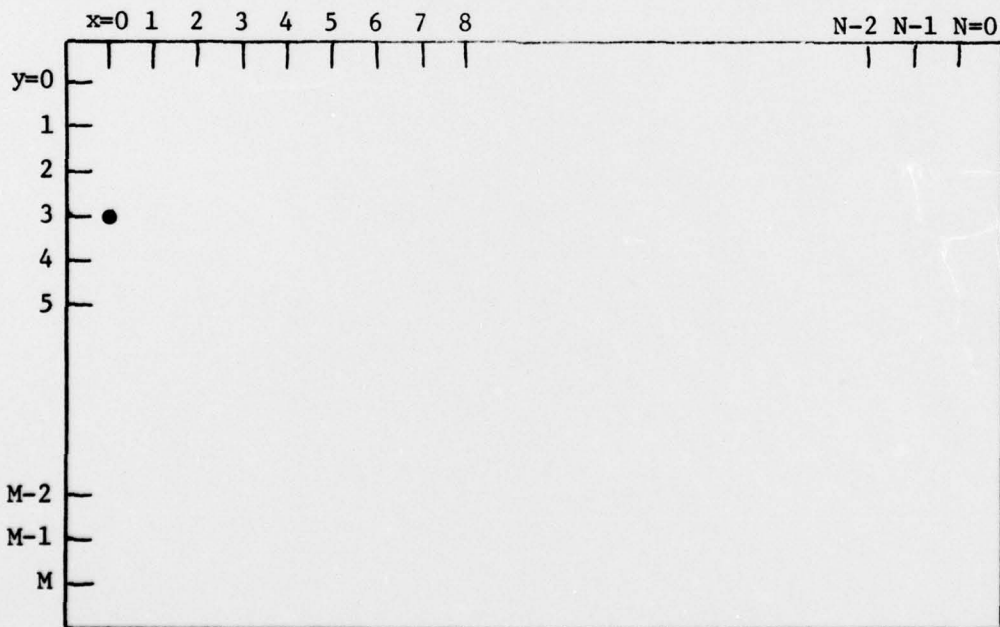


B. Displayed transform of wal(0,1)

Figure 8. Displayed transforms of wal(1,0) and wal(0,1) as shown in Figure 1. The display indexes correspond to the display position of the image coefficients of wal(x,y).

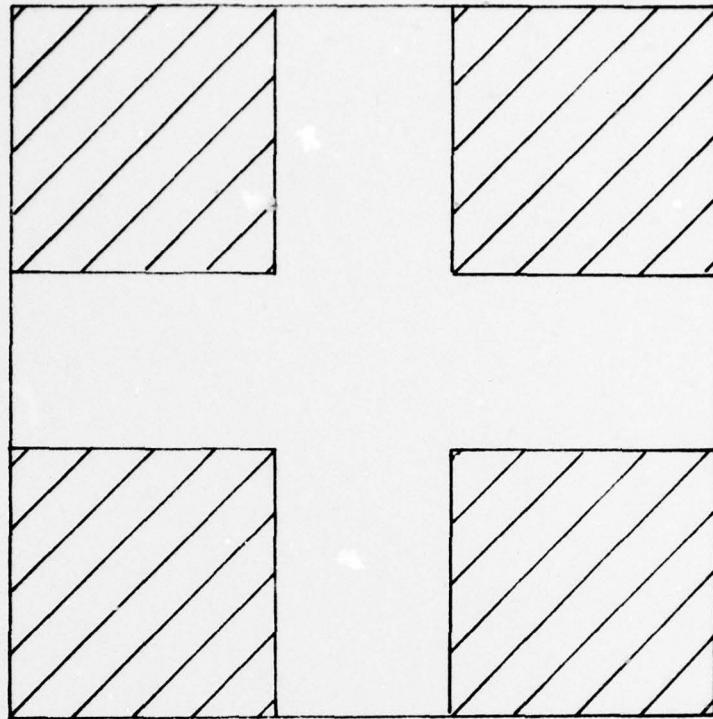


A. Displayed transforms of $wal(3,0)$

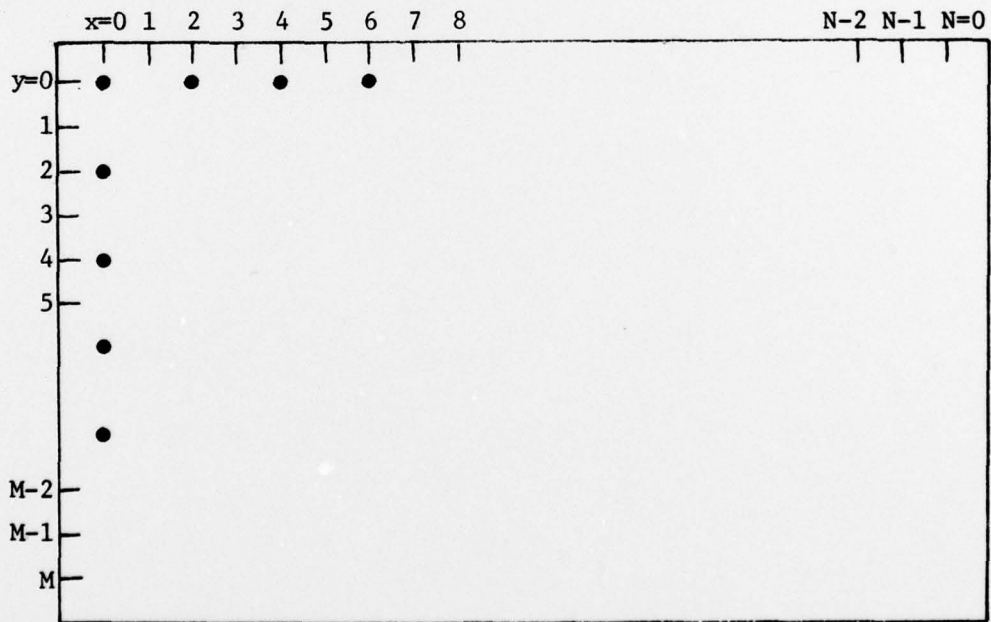


B. Displayed transforms of $wal(0,3)$

Figure 9. Displayed transform of $wal(3,0)$ and $wal(0,3)$ as shown in Figure 1. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$.

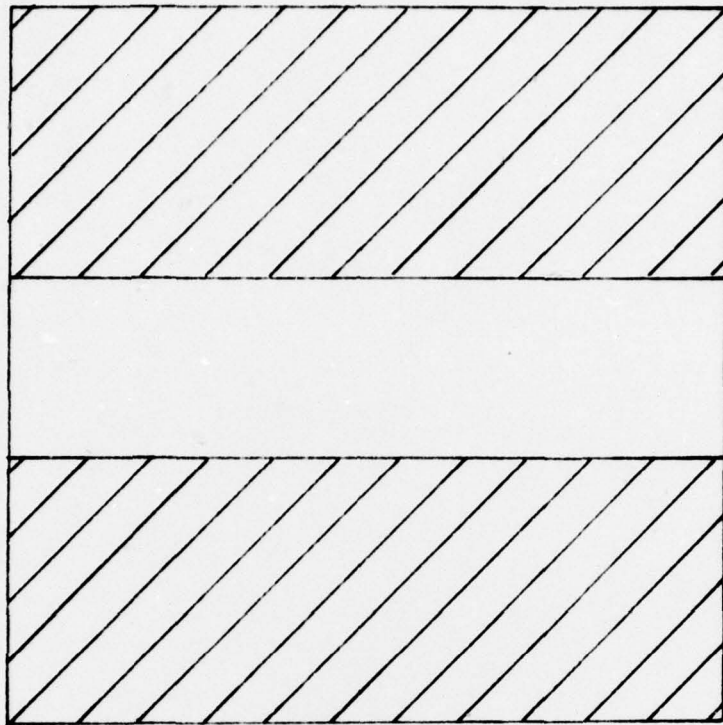


A. Simple image to be transformed

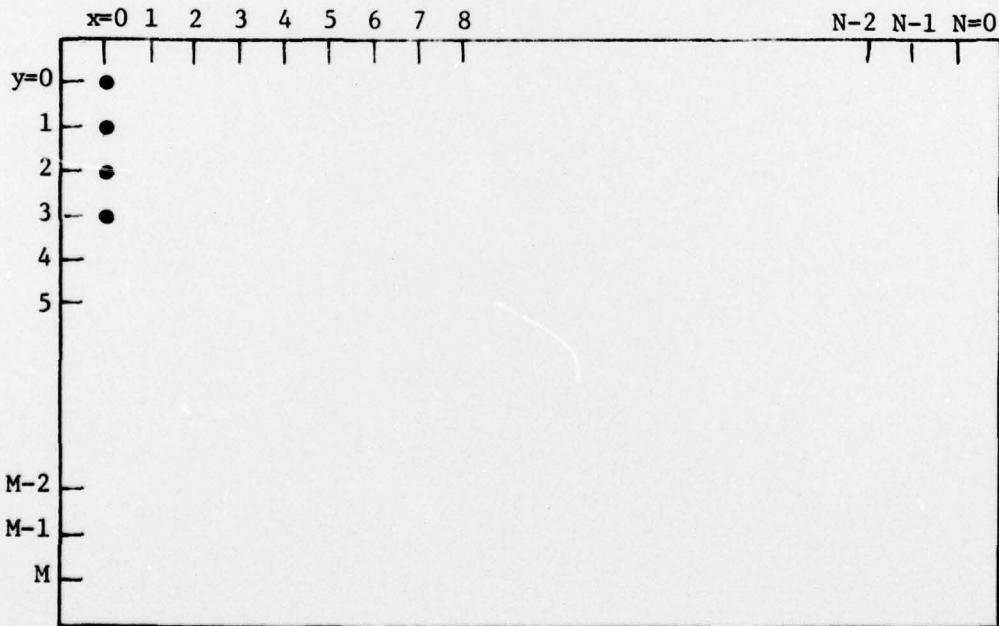


B. Dominant features of the displayed transform of the simple image shown above

Figure 10. Simple test image and its transform. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$.

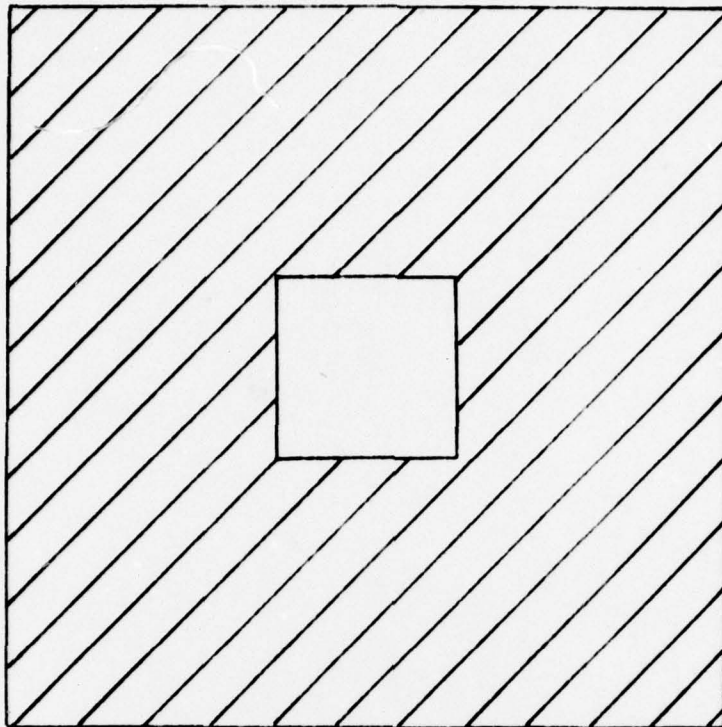


A. Simple image to be transformed

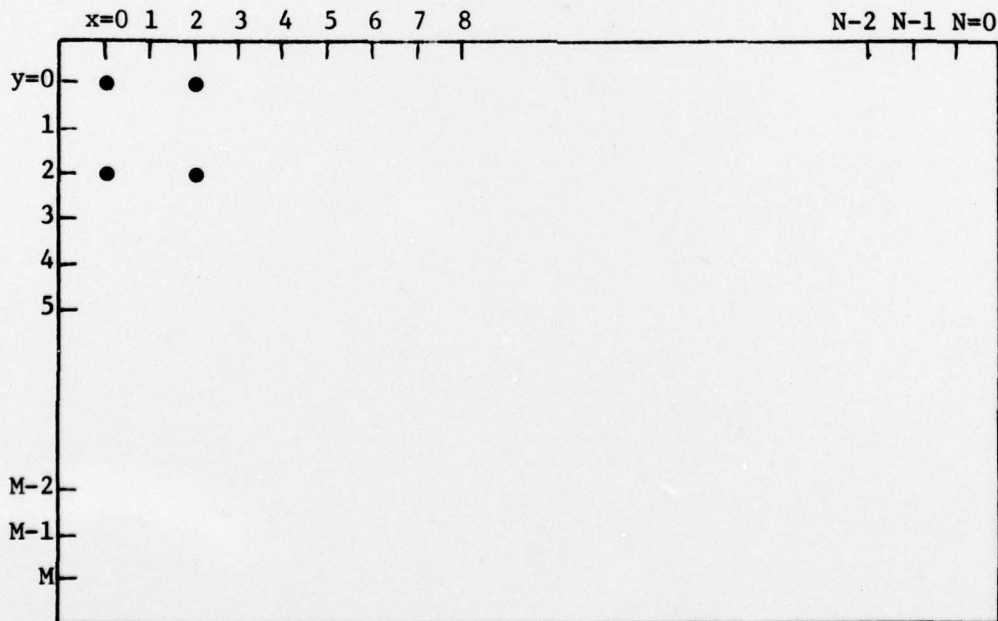


B. Dominant features of the displayed transform of the simple image shown above

Figure 11. Simple test image and its transform. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$.



A. Simple image to be transformed



B. Dominant features of the displayed transform of the simple image shown above

Figure 12. Simple test image and its transform. The display indexes correspond to the display position of the image coefficients of $wal(x,y)$.

- Investigate how uniformly the plasma lights each Walsh function in the automatic mode. If the lighting is not uniform, i.e., some points that should be lit are not lit, provide feedback to the high voltage power supply so that the power consumed by the panel remains constant throughout the transformation.

There are also a number of major modifications that might be desirable to make once the system operation and performance are more fully understood. These major modifications include the following:

- As shown in Figures 3 and 4, with the present system design, the image transparency is laid on the upper glass plate of the plasma panel. This puts the image about 0.25 inches away from the Walsh function formed by the lights in the panel. The result is a decrease in the spatial resolution of the Walsh function caused by the spreading of the lights over that 0.25 inches before reaching the image. This situation can be remedied by raising the image transparency above the plasma panel in Figure 3 and inserting a lens between it and the plasma panel. This lens could then be adjusted to image the light on the transparency yielding a spatial resolution of the Walsh function equal to the size of the individual light sizes focused on the transparency. The spreading would be effectively removed.

- As the images being used become complex and consist of many simple shapes spread over the area of the transparency it may become desirable to transform each shape independently for a high probability of correct classification. This could be done either by scanning the image using Haar functions to locate interesting areas of the image and then Walsh transforming each area found for classification, or by Walsh transforming each contiguous small section of the image looking for recognizable transforms. Both of these approaches would require some modification to the hardware and the addition of a computer to the system.

4.0 CONCLUSIONS

An R&D system for the direct transformation of images using two-dimensional Walsh functions in Cartesian coordinates has been built and tested. The system is capable of obtaining 512^2 Walsh coefficients of an image in approximately 10.5 seconds. Testing of the system has been very limited to date, due to time and available resource constraints. However, the system does produce Walsh transform coefficients that correlate very well with the theoretically-expected transform for all image shapes tested, and does it at a respectable SNR.

The system is new and requires more extensive testing before it can be accurately evaluated. However, its performance to date shows the feasibility of obtaining many Walsh coefficients economically and quickly to aid in image classification. The equipment should form the basis of an expanded program exploiting the system's capability and the technology in the future.

5.0 RECOMMENDATIONS

Undersea Research Corporation's recommendations concerning the system are that it be thoroughly tested and evaluated in its present configuration. The data resulting from such an evaluation will be qualitative due to the lack of a quantitative evaluation capability in the system. Minor cost-effective system improvements, such as those outlined in Section 3.4, should be made as soon as the requirement for them is clear.

The system should then be interfaced to a digital computer to give it a quantitative evaluation capability. In this configuration the system should be evaluated in detail for system performance improvements required, and the required improvements should be made. The capability of Walsh transforms to aid in image feature extraction should be thoroughly evaluated in this configuration. System additions, such as the dyadic correlation of the image transforms as a feature recognition aid or techniques for obtaining forms of the transforms that are independent of image translation and rotation, should be investigated both theoretically and experimentally using the system's software capability.

Major system modifications such as those outlined in Section 3.4 should be investigated with a quantitative transform evaluation capability along with the potential of multiple discrete transforms used in combinations. Only after these detailed quantitative evaluations should the resources required for major hardware modifications be spent.

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