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LARS Contract Report 022881

Tasks 7 and 8: EDGE DETECTION AND REGISTRATION RESEARCH
6: Area Estimation Research
1: Sampling and Aggregation Research

Quarterly Progress Report and Presentation (Dec. 1, 1980 to Feb. 28, 1981)
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Purdue University
Laboratory for Applications of Remote Sensing
West Lafayette, Indiana

Principal Investigator: Marvin E. Bauer

for
NASA Johnson Space Center
Houston, Texas

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SR TASK 7

RBV EDGE DETECTION RESEARCH

QUARTERLY REPORT

MARCH 2, 1981

Carlos Pomalaza–Raez

PREPARED FOR
NASA JOHNSON SPACE CENTER
HOUSTON, TEXAS

OBJECTIVE

Evaluate the application of edge detection algorithms of various kinds and complexity to RBV imagery.

ALGORITHM SELECTION FACTORS.

- Numerical complexity.
- Nature of the particular analysis.
- Quality of the results obtained on test data on areas that contain typical field patterns.

NATURE OF THE RBV DATA

- Resolution: 20x20 mt.
- Electromagnetic spectrum band: .500–.800 um.
- Test area sites:
    - (a) Iowa (Des Moines)
    - (b) South Carolina (Georgetown)

A common neighborhood used by several algorithms is,

$$\begin{matrix} b_1 & b_2 & b_3 \\ b_4 & b_5 & b_6 \\ b_7 & b_8 & b_9 \end{matrix}$$

denote $\mathbf{b}$, the image intensity vector as

$$\mathbf{b} = (b_1 \ldots b_9)$$

The application of most algorithms involve the scalar product of $\mathbf{b}$ with particular weighting vectors.

DESCRIPTION OF SOME ALGORITHMS

SOBEL GRADIENT

$$dx = \mathbf{b} \cdot \mathbf{w}_1$$
$$dy = \mathbf{b} \cdot \mathbf{w}_2$$

where $\mathbf{w}_1$ and $\mathbf{w}_2$ are defined as

$\mathbf{w}_1$

1	0	-1
2	0	-2
1	0	-1

$\mathbf{w}_2$

1	2	1
0	0	0
-1	-2	-1

ROBERT's GRADIENT.

0	0	0
0	1	0
0	0	-1

0	0	0
0	0	1
0	-1	0

KIRSCH's GRADIENT

Evaluate the "contrast function,

$$\max\left(1, \max_{i=1}^{8} |\mathbf{b}.\mathbf{w}_i|\right)$$

where $\mathbf{w}_1 \ldots \mathbf{w}_8$ are

5	5	5		5	5	-3		5	-3	-3		-3	-3	-3
-3	0	-3		5	0	-3		5	0	-3		5	0	-3
-3	-3	-3		-3	-3	-3		5	-3	-3		5	5	-3

-3	-3	-3		-3	-3	-3		-3	-3	5		-3	5	5
-3	0	-3		-3	0	5		-3	0	5		-3	0	5
5	5	5		-3	5	5		-3	-3	5		-3	-3	-3

FREI and CHENG

- Define an "edge" subspace by finding a set of orthogonal basis vectors, ($\mathbf{w}_1$,.... $\mathbf{w}_e$).
- Complete the basis with 9−e "nonedge" basis vectors.
- Project the image sub−area intensity values $\mathbf{b}$ onto the edge subspace.
- Evaluate the angle between $\mathbf{b}$ and its projection onto the edge subspace by

$$\theta = \arccos \left(\sum_{i=1}^{e} (\mathbf{b}.\mathbf{w}_i)^2 \Big/ \sum_{j=1}^{9} (\mathbf{b}.\mathbf{w}_j)^2 \right)^{1/2}$$

- The image sub−area is considered as containing and edge element if θ is small, i.e. , thresholding the value of

$$\sum_{i=1}^{e} (\mathbf{b}.\mathbf{w}_i)^2 /(\mathbf{b}.\mathbf{b})$$

ORTHOGONAL SET OF BASIS VECTORS

– Edge subspace

isotropic average gradient

$$\begin{matrix} 1 & \sqrt{2} & 1 \\ 0 & 0 & 0 \\ -1 & -\sqrt{2} & -1 \end{matrix} \qquad \begin{matrix} 1 & 0 & 1 \\ \sqrt{2} & 0 & -\sqrt{2} \\ 1 & 0 & -1 \end{matrix}$$

ripple

$$\begin{matrix} 0 & -1 & \sqrt{2} \\ 1 & 0 & -1 \\ -\sqrt{2} & 1 & 0 \end{matrix} \qquad \begin{matrix} \sqrt{2} & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & -\sqrt{2} \end{matrix}$$

– Line subspace

line

$$\begin{matrix} 0 & 1 & 0 \\ -1 & 0 & -1 \\ 0 & 1 & 0 \end{matrix} \qquad \begin{matrix} -1 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & -1 \end{matrix}$$

discrete laplacian

$$\begin{matrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{matrix} \qquad \begin{matrix} -2 & 1 & -2 \\ 1 & 4 & 1 \\ -2 & 1 & -2 \end{matrix}$$

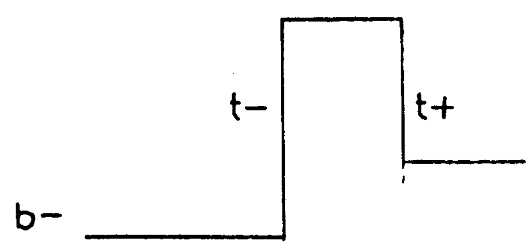
– Average

$$\begin{matrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{matrix}$$

HUECKEL ALGORITHM

- Optimal values of an ideal edge–line to the image intensity values in a small circular neighborhood

- The ideal edge is determined by a 6–tuple of parameters, three parameters determine the intensity levels (b– , t– ,t+ as shown in figure below) and the other three parameters determine the position, orientation and width of the line.



- The fitting process consist of determining the value of the six parameters for a best fit with the image intensities ,i.e. when,

$$N = \| b - S(\text{tuple}) \| \text{ is minimum}$$

S is an ideal edge image.

–The minimization process is approximated by expansion of the input image disk and the edge–line in an orthogonal Fourier series. The minimization is then approximated by choosing a tuple such that,

$$N = \sum_{I=0}^{8} (a_i - s_i)^2$$

where,

a_i are the coeficients of expansion for the image and
s_i are the coefficients for and ideal edge–line.

–The reasons for using only the first nine terms of the expansion are:

(a) Higher order terms correspond to noise in the image and should be ignored.
(b) An analytical solution to the minimization problem is found using nine terms.

PLANS FOR NEXT QUARTER

- Finish implementation of selected algorithms.
- Testing of algorithms on RBV data.

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- W. Frei and C. Chen, "Fast Boundary Detection: A Generalization and a New Algorithm. " IEEE Trans. on Computers. October 1977, pp.988–998.
- M.H. Hueckel, "A Local Visual Edge Operator which Recognizes Edges and Lines" J. Assoc. Comput. Mach. 20, 1973,pp. 634–647.
- M.H. Hueckel, "An Operator which Locates Edges on Digitized Pictures" J. Assoc. Comput. Mach. 18, 1971, pp. 113–125 .
- R. Kirsch, "Computer Determination of the Constituent Structure of Biological Images," Comput. Biomed. Res. 4, 1971, pp. 315–328.

SR TASK 8

REGISTRATION RESEARCH

QUARTERLY REPORT

MARCH 25, 1981

PAUL E. ANUTA

PREPARED FOR

NASA JOHNSON SPACE CENTER

HOUSTON, TEXAS

OBJECTIVES

1. INVESTIGATE THE PROBLEM OF REGISTRATION OF IMAGERY HAVING DIFFERING RESOLUTIONS. SPECIFIC CASE OF INTEREST IS RBV-MSS REGISTRATION. DEVELOP PREPROCESSING AND CORRELATION MODULES FOR THIS CASE FOR INCLUSION IN JSC REGISTRATION PROCESSOR.

2. DEVELOP PREPROCESSING AND CORRELATION PROCESSORS FOR REGISTERING MSS IMAGERY TO A MAP REFERENCE.

3. REVIEW METHODS AVAILABLE FOR REGISTRATION OF AIRPHOTO TO MSS DATA AND RECOMMEND ANY MODIFICATIONS TO CURRENT PROCEDURES IN USE AT JSC.

PROGRESS DURING QUARTER

1. RBV DATA SET EXAMPLES ACQUIRED. LARS REFORMATTING SOFTWARE CHECKED AND APPLIED TO THE CCT'S. DATA TAPES REFORMATTED TO LARSYS FORMAT.

2. RBV, MSS AND MAP DATA ORDERED FOR SELECTED TEST SITE AND DATE: SEPT. 12, 1980, SEGMENT 893, WEBSTER CO., IOWA.

3. OPTIMUM PREPROCESSING FILTER SOLUTION DERIVED FOR CORRELATION OF IMAGERY HAVING DIFFERENT RESOLUTION.

4. SUB-PIXEL EDGE DETECTION APPROACHES INVESTIGATED FOR THE LOW RESOLUTION (MSS) IMAGE. EDGE DETECTION FOR RBV IMAGERY IS BEING INVESTIGATED IN TASK 7.

DATA SET ACQUISITION

EXAMPLE RBV DIGITAL DATA FOR TASKS 7 AND 8

EXAMPLE 1: RBV DATA FROM FRAME 30730-15104 ON MARCH 4, 1980 OVER COASTAL SOUTH CAROLINA. C AND D TAPES HAD PROBLEMS AND COULD NOT BE USED. A AND B FRAMES ACQUIRED BUT HAD BAD DATA ON LEFT HALF OF SUBFRAME. GOOD DATA AVAILABLE FOR GEORGETOWN, S.C. COASTAL AREA IN B SUBFRAME.

EXAMPLE 2: RBV DATA FROM FRAMES 30885-16060 AND 30885-16062 ON AUGUST 6, 1980 OVER DES MOINES, IOWA. COVERS SUPERSITE SEGMENT 893 NEAR FT. DODGE, IA. SEGMENT 893 SELECTED AS PRIMARY TEST SITE. SUBFRAMES A AND D COULD NOT BE READ. SEGMENT 893 IN SUBFRAME A.

SELECTED TEST DATA: SCENE 830922-16095 ON SEPT. 12, 1980 WAS SELECTED AND ORDERED. RBV AND MSS DATA TO BE OBTAINED FOR THIS DATE FOR SEGMENT 893.

SOLUTION FOR REGISTRATION PROCESSOR FOR IMAGES WITH DIFFERENCE RESOLUTIONS

BASED ON MODEL IN FIGURE 1

COMPOSITE CORRELATOR OUTPUT[1]

$$Z(X,Y) = G(X,Y) + N(X,Y)$$

$$G(X,Y) = F(X,Y) \circledast H(X,Y)$$

$$N(X,Y) = \Delta P(X,Y) \circledast H(X,Y)$$

WHERE

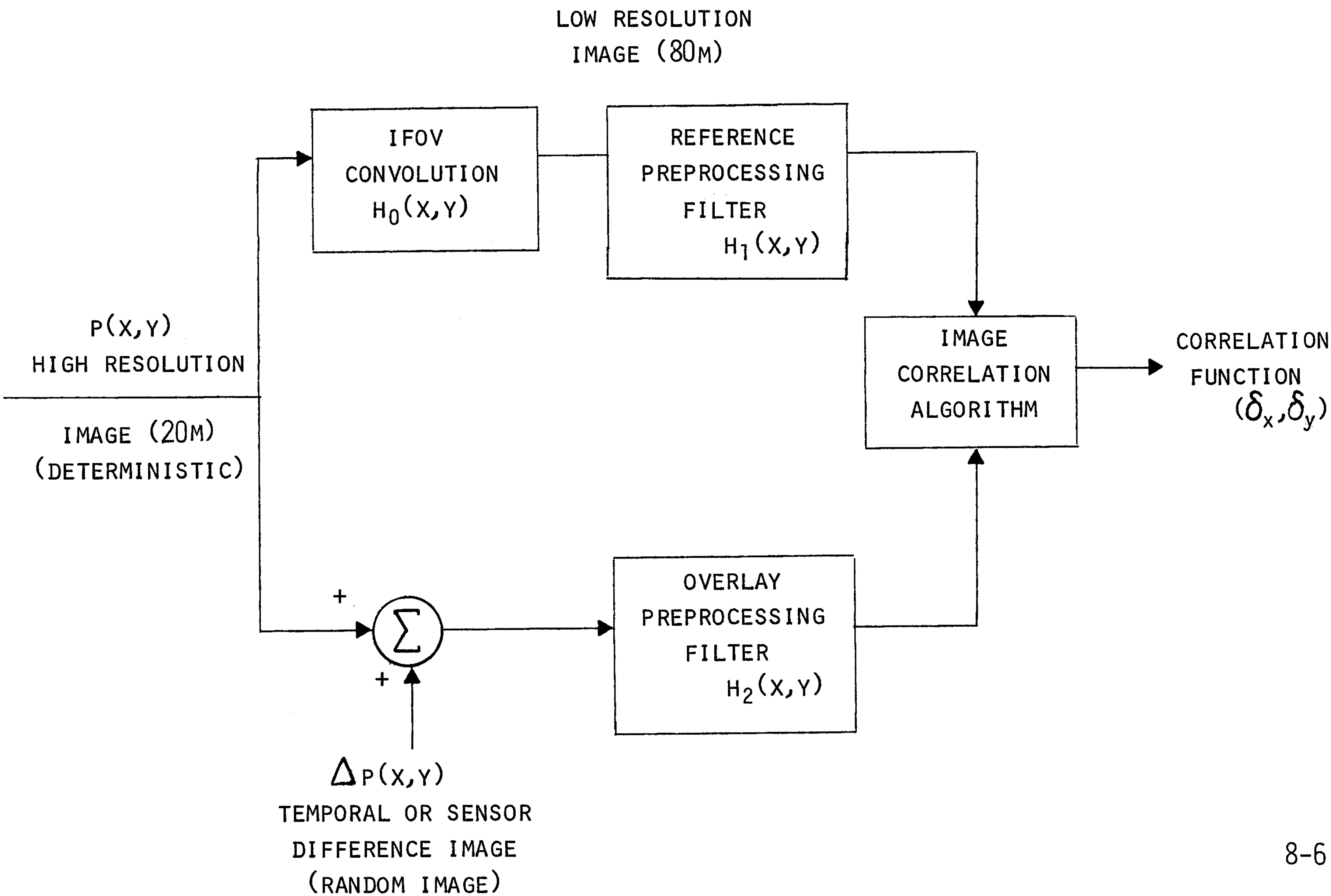
$Z(X,Y)$ = OUTPUT CORRELATION FUNCTION POSITION OF PEAK REPRESENTS MISREGISTRATION SHIFT

$F(X,Y)$ = DETERMINISTIC REFERENCE IMAGE

$\Delta P(X,Y)$ = TEMPORAL OR SENSOR DIFFERENCE IMAGE

$H(X,Y)$ = FILTER (PREPROCESSED IMAGE) TO BE CORRELATED WITH OVERLAY IMAGE

FIGURE 1. MODEL FOR ANALYSIS OF REGISTRATION WITH DIFFERENT RESOLUTIONS



THE MAXIMUM OF THE CORRELATION FUNCTION IS SOLVED FOR AND EXPRESSIONS FOR THE REGISTRATION ERROR ARE OBTAINED:

$$(\hat{\delta}_X - \delta_X) = \frac{G_{XY} N_Y - G_{YY} N_X}{G_{XX} G_{YY} - G_{XY}^2}$$

$$(\hat{\delta}_Y - \delta_Y) = \frac{G_{XY} N_X - G_{XX} N_Y}{G_{XX} G_{Y} - G_{XY}^2}$$

WHERE:

$\hat{\delta}$ IS THE ESTIMATED MISREGISTRATION

δ IS THE TRUE MISREGISTRATION

THE X,Y SUBSCRIPTS INDICATE THE X AND Y DERIVATIVES OF THE GIVEN FUNCTIONS.

THE VARIANCES OF THE REGISTRATION ERRORS ARE THEN DERIVED:

$$\overline{(\hat{\delta}_X - \delta_X)^2} = \frac{G_{XY}^2 \overline{N_Y^2} - 2G_{XY} G_{YY} \overline{N_Y N_X} + G_{YY} \overline{N_X^2}}{[G_{XX} G_{YY} - G_{XY}^2]^2}$$

$$\overline{(\hat{\delta}_Y - \delta_Y)^2} = \frac{G_{XY}^2 \overline{N_X^2} - 2G_{XY} G_{XX} \overline{N_X N_Y} + G_{XX} \overline{N_Y^2}}{[G_{XX} G_{YY} - G_{XY}^2]^2}$$

IT CAN BE SHOWN THAT THE FILTER WHICH MINIMIZES THE ERROR VARIANCE IS THE MATCHED FILTER, EXPRESSING THIS RESULT IN THE FREQUENCY DOMAIN:

$$H(u,v) = \frac{F^*(u,v)\ E^{-i2\Pi(u\,\delta_x + v\,\delta_y)}}{S_\Delta (u,v)}$$

WHERE:

$F^*(u,v)$ IS THE CONJUGATE OF THE FOURIER TRANSFORM OF THE REFERENCE IMAGE

$S_\Delta (u,v)$ IS THE SPECTRAL DENSITY OF THE CHANGE IMAGE.

EVALUATING THE TERMS IN THE VARIANCE EQUATIONS AND INCLUDING THE MATCHED FILTER RESULTS IN EQUATIONS USING SIGNAL-TO-NOISE AND BANDWITH EXPRESSIONS:

$$\overline{(\hat{\delta}_X - \delta_X)^2} = \frac{1}{B_X^2 \, SNR}$$

$$\overline{(\hat{\delta}_Y - \delta_Y)^2} = \frac{1}{B_Y^2 \, SNR}$$

THE KEY RESULT NEEDED HERE IS THAT THE OPTIMUM PROCESSOR IS THE MATCHED FILTER. THE FILTER IS BASED ON THE REFERENCE WHICH IS THE P(X,Y). HOWEVER, F(X,Y) IN THE ABOVE EQUATIONS IS THE LOW RESOLUTION IMAGE RESULTING FROM THIS CONVOLUTION OF AN IFOV:

$$F(X,Y) = P(X,Y) \circledast H_0(X,Y)$$

THUS THE OPTIMUM PROCESSOR FOR THE DIFFERENT RESOLUTION CASE IS F(X,Y) DECONVOLVED TO ELIMINATE THE EFFECT OF THE IFOV AND THEN USING THE RESULT IN THE MATCHED FILTER.

THUS THE FILTERS FOR THE MODEL ARE A COMBINATION OF THOSE DERIVED FROM THE MATCHED FILTER AND FROM IFOV DECONVOLUTION:

$$H_1(X,Y) = H_\omega(X,Y) \circledast H_0^{-1}(X,Y)$$

$$H_2(X,Y) = H_\omega(X,Y)$$

WHERE:

$H_\omega(X,Y)$ IS A PREWHITENING FILTER WHICH IS THE REFERENCE IMAGE INVARIANT PART OF THE MATCHED FILTER

$H_0^{-1}(X,Y)$ IS THE IFOV DECONVOLUTION FILTER

FOR A CHANGE IMAGE WITH NEGATIVE EXPONENTIAL AUTOCORRELATION FUNCTION (REPRESENTATIVE OF LANDSAT TEMPORAL CHANGE) WITH PARAMETERS α AND β, THE PREWHITENING FILTER IS:

$$H_\omega(X,Y) = \frac{1}{2A\sqrt{\alpha\beta}}\left[\alpha\beta\,\delta(X,Y) + \beta\frac{D}{DX} + \alpha\frac{D}{DY} + \frac{D^2}{DXDY}\right]$$

DECONVOLUTION FILTERS ARE SOLVED BY NUMERICAL TECHNIQUES USING CONSTRAINED OPTIMIZATION. INTERPOLATION IS ALSO REQUIRED TO PRODUCE CLOSE SAMPLE SPACINGS IN THE DISCRETE CASE. INTERPOLATION AND DECONVOLUTION FILTERS WERE STUDIED BY CHU[2] AND RIEMER[3] AND RESULTS ARE AVAILABLE FOR NUMEROUS ASSUMPTIONS. A FILTER WHICH PRODUCES DECONVOLVED SAMPLES AT 20M SPACING FOR INPUT SAMPLES AT 80M SPACING (I.E., CREATE 3 NEW SAMPLES FOR EACH ORIGINAL) IS SHOWN IN FIGURE 2.

THIS FILTER IS CONVOLVED WITH THE DERIVATIVE FILTER TO PRODUCE THE COMPOSITE PREPROCESSING FILTER FOR THE LOW RESOLUTION IMAGE.

THE COMPOSITE FILTER IS BEING IMPLEMENTED AND WILL BE COMPARED TO EDGE DETECTION AND EDGE CORRELATION APPROACH.

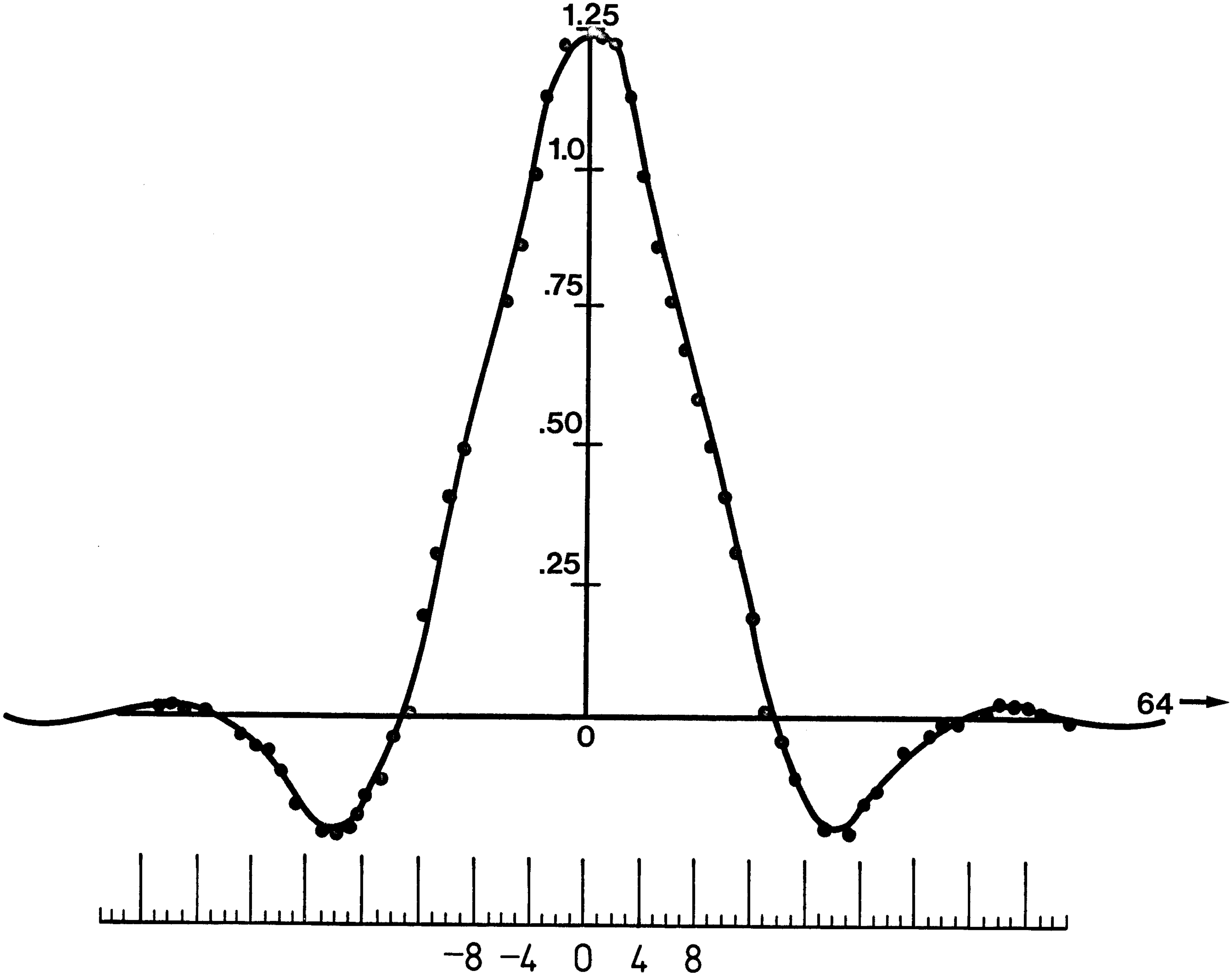


FIGURE 2. IFOV DECONVOLUTION FILTER EXAMPLE.

EDGE DETECTION FOR RBV-MSS REGISTRATION

THE OPTIMUM REGISTRATION PROCESSOR SOLUTION INDICATES THAT HIGH FREQUENCY ENHANCEMENT IS REQUIRED. AN ANALOGOUS OPERATION IS EDGE DETECTION. EDGE DETECTION FOR RBV IMAGERY IS BEING INVESTIGATED IN TASK 7. EDGE DETECTION FOR MSS TO PRODUCE MATCHING BOUNDARIES AT RBV RESOLUTION IS BEING PURSUED IN THIS TASK.

SUB-PIXEL MSS EDGE DETECTION

EDGE DETECTION FOR MSS AT 20M RESOLUTION REQUIRES PREDICTION OF BOUNDARIES BETWEEN PIXELS. THIS CAN BE DONE IN TWO WAYS:

1. INTERPOLATE MSS DATA TO THE HIGHER RESOLUTION AND APPLY EDGE DETECTION ALGORITHMS.
2. APPLY EDGE DETECTION ALGORITHMS AT THE LOWER RESOLUTION, THEN THIN THE EDGES TO THE HIGHER RESOLUTION.

PLANS FOR SECOND QUARTER

- Acquire concurrent MSS imagery for test RBV imagery.
- Implement and test composite IFOV/preprocessing filter on MSS data.
- Correlate RBV-MSS scene segments to evaluate enhancement approach.
- Define sub-pixel MSS edge detection algorithms to be tested.
- Acquire and digitize map document for Segment 893.

REFERENCES

1. Svedlow, M., C. McGillem, P. Anuta, "Analytical and Experimental Design and Analysis of an Optimal Processor for Image Registration," LARS Information Note 090776.

2. Chu, N., C. McGillem, "Methods and Performance Bounds for Constrained Image Restoration," LARS Information Note 061678.

3. Riemer, T., C. McGillem, "Optimum Constrained Image Restoration Filters," LARS Information Note 091974.