POTENTIAL APPLICATION OF ARTIFICIAL NEURAL NETWORK (ANN) TO WIND EXTRACTION BASED ON CLOUD MOTION IN SATELLITE IMAGES

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Wind extraction from satellite images

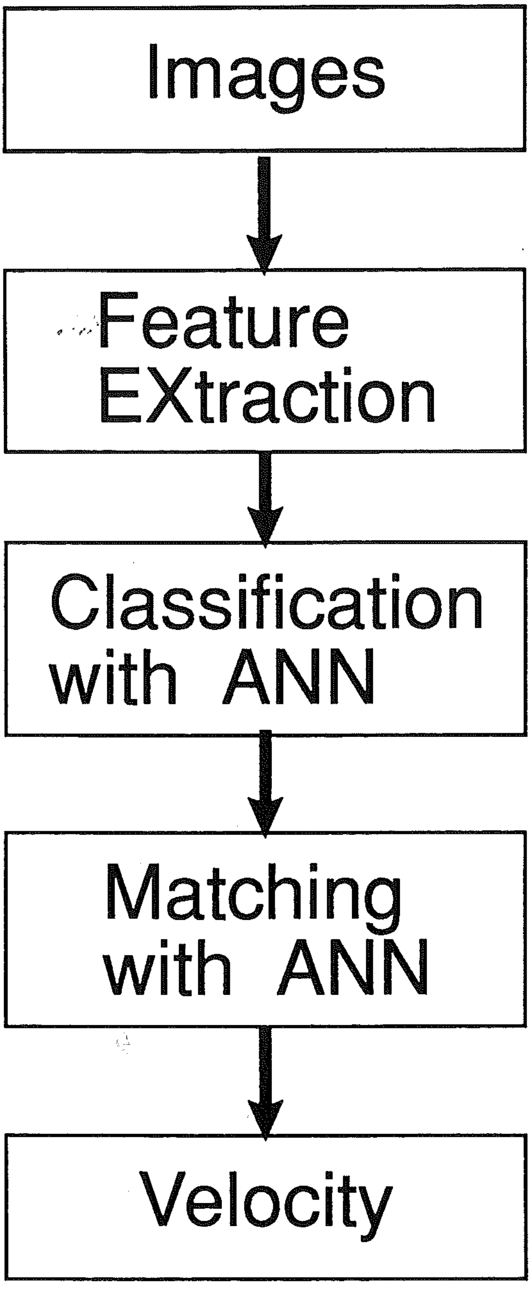
- Requires massive data processing and learning.
- Needs fast processing algorithm to assist human detection
- Artificial neural network (ANN) approach
    1. parallel processing ability
    2. capability of learning
    3. graceful degradation of performance under conditions of ambiguity
    4. easy to be executed in real-time

Two-Stage Procedure for Wind Extraction Based on Cloud Motion

Stage 1. ANN Classification
- to determine cloud type.

Stage 2. ANN Matching
- to determine the displacement/velocity

Wind Extraction Using ANN

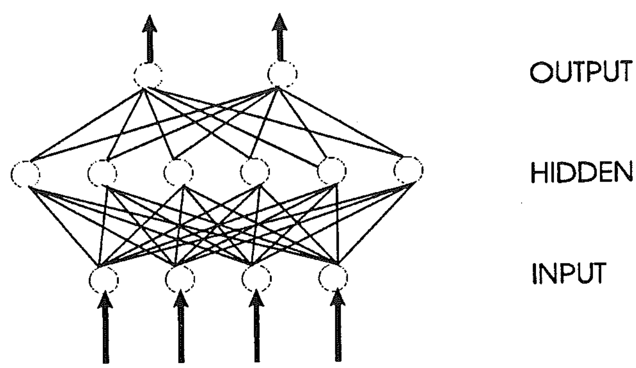


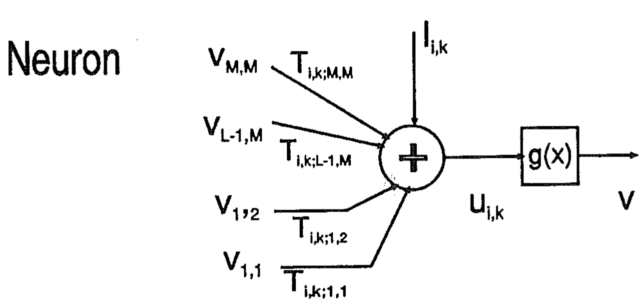
Artificial Neural Networks (ANN)

- Computing systems consist of networks of independent processing elements (neurons) that are highly interconnected.
- Processing is performed through interaction between neurons.
- Learning is achieved through updating their interactions (weights).

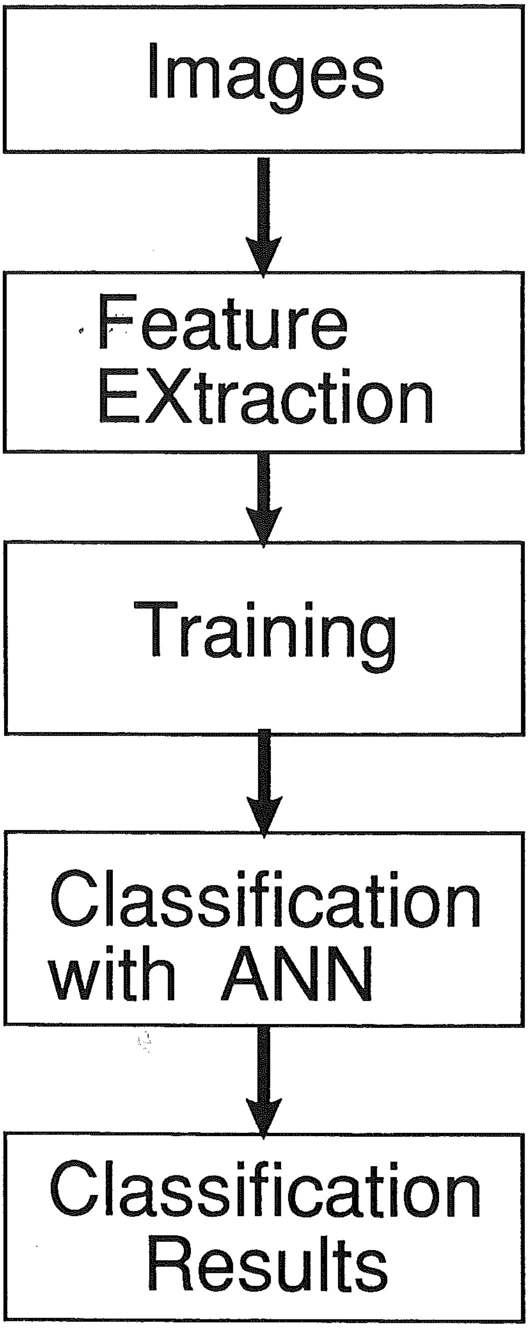
ANN Topology

$$U = TV + I$$
$$V = g(U)$$





ANN Classification



Classification with ANN

1. Classification based upon multi-source measurements, e.g., SSMI

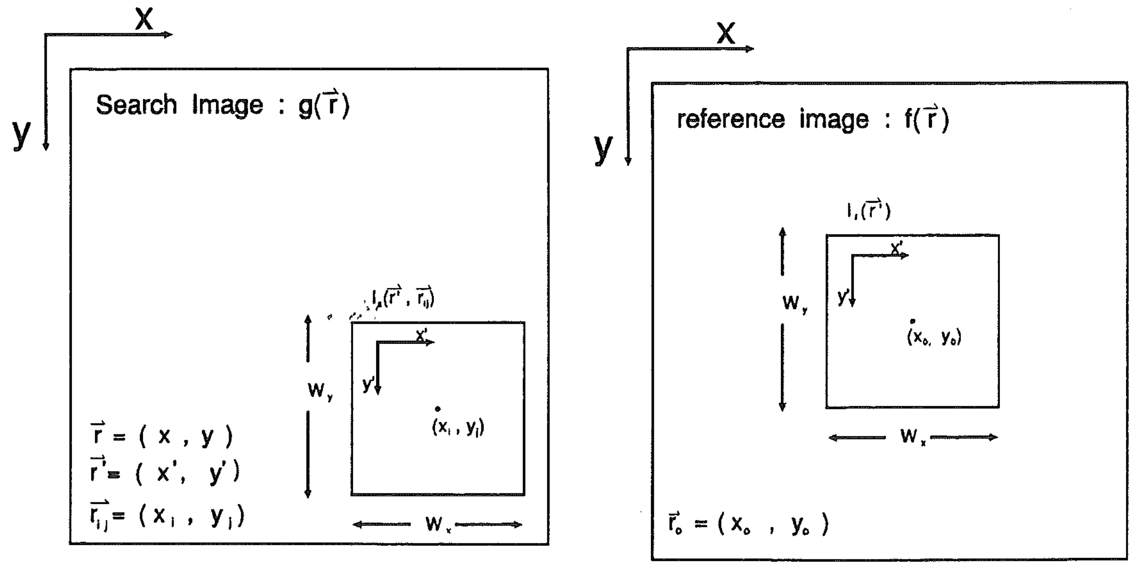
SSMI measurement classification characteristics							
Input: SSMI measurements (brightness temperature) at different channels							
frequencies and polarizations	19 H	19 V	22 V	37 H	37 V	85 H	85 V
Output surface features:			Non-Sm	R-Ocean	Snow	R-Land	Desert

2. Classification based upon texture information of the images

Input Feature:	Output Classes
mean, standard deviation, contrast, angular moments, homogeneity, entropy, etc.	Stratocumulus Cumulus Cirrus

Classification accuracy for SSMI					
Classified	Actual surface				
	Non-Sm	R-Ocean	Snow	Desert	R-Land
Non-Sm	82.18%	0	0.05%	5.06%	19.02%
R-Ocean	15.04%	97.56%	2.93%	0	1.95%
Snow	0	0	97.02%	16.54%	0
Desert	0.02%	0	0	78.4%	0
R-Land	2.75%	2.44%	0	0	79.02%
Overall Accuracy:	88.27%				

Matching with correlation method



Definition of image coordinates.

The mean square error between the two normalized images is

$$D(\vec{r}) = \frac{1}{N}\sum_{\vec{r}'}^{N}[\frac{1}{\sigma_r}(I_r(\vec{r}') - m_r) - \frac{1}{\sigma_s(\vec{r})}(I_s(\vec{r}',\vec{r}) - m_s(\vec{r}))]^2$$

A match exists when $D(\vec{r})$ is minimum. Expanding above equation, a cross-correlation is expressed as

$$\rho(\vec{r}) = \frac{1}{N}\sum_{\vec{r}'}^{N}(I_r(\vec{r}') - m_r)\,(I_s(\vec{r}',\vec{r}) - m_s(\vec{r}))^2/\sigma_r\sigma_s(\vec{r})$$

As $\rho(\vec{r})$ reaches its maximum value, a match is obtained. The displacement vector $(\vec{r})$ or the velocity can be obtained.

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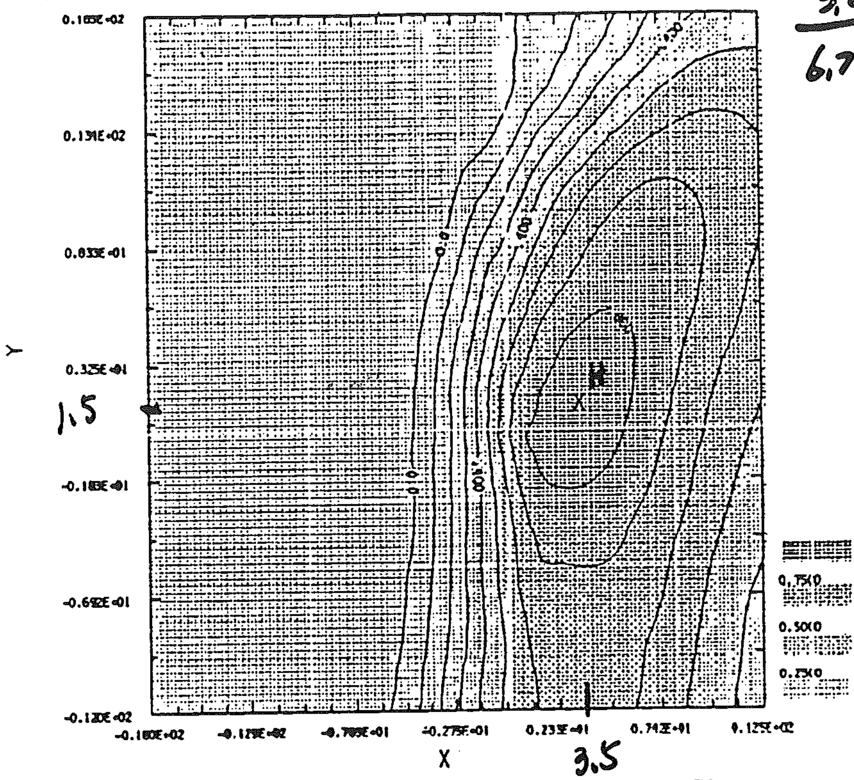
ST_XRO_DZNE_V18Z3P0-DZNE_V22Z3P0

PEAK: 00.8539 at = 03.5000 01.5000 km

AREA: Xd -28.0 34.5 Yd 30.0 92.5

WINDOW: Xw -10.0 22.0 Yw 42.0 74.0



$\frac{3,8 \text{ km}}{6,75 \text{ min}} = 9,40$ m/s

67°

0d

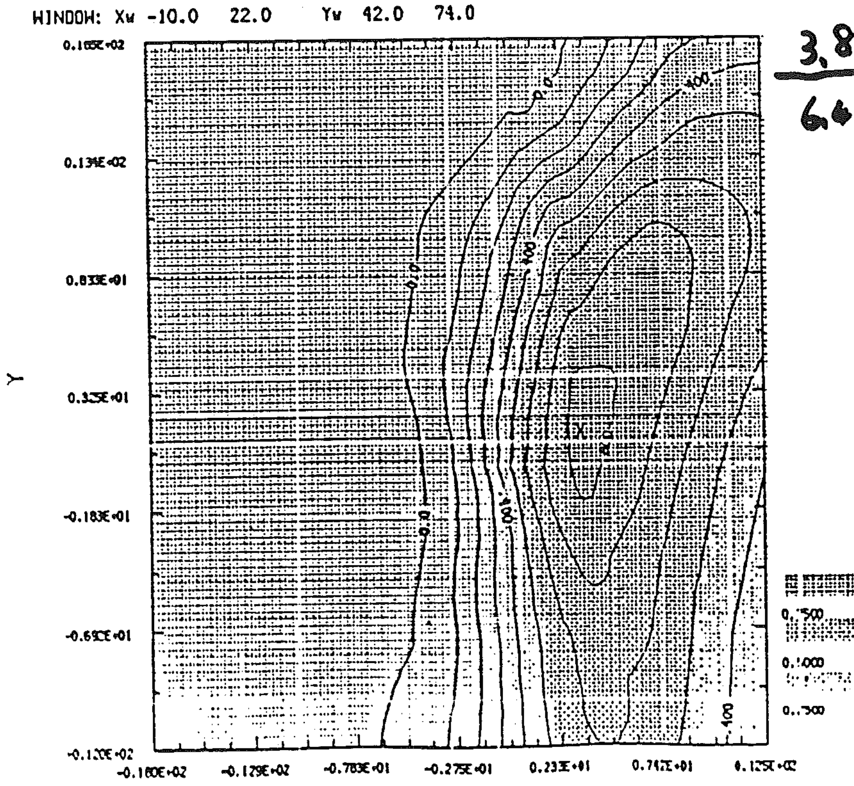
CONTOUR FROM 0.00000E+00 TO 1.0000 CONTOUR INTERVAL OF 0.10000 PT(3,3)= -0.35773

ST_XRO_DZNE_V20Z3P0-DZNE_V24Z3P0

PEAK: 00.8352 at = 03.5000 01.5000 km

AREA: Xd -28.0 34.5 Yd 30.0 92.5

WINDOW: Xw -10.0 22.0 Yw 42.0 74.0



$\frac{3,8 \text{ km}}{6,41 \text{ min}} = 9,90$ m/s

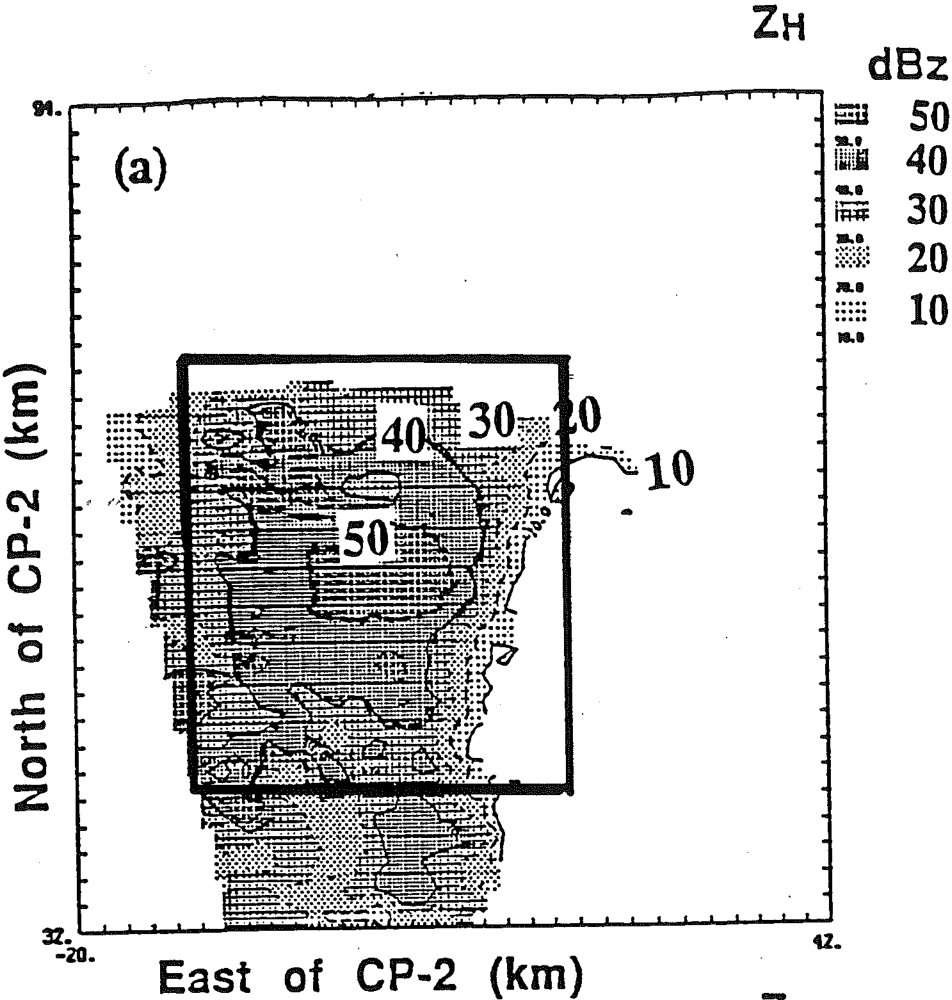
67°

0d

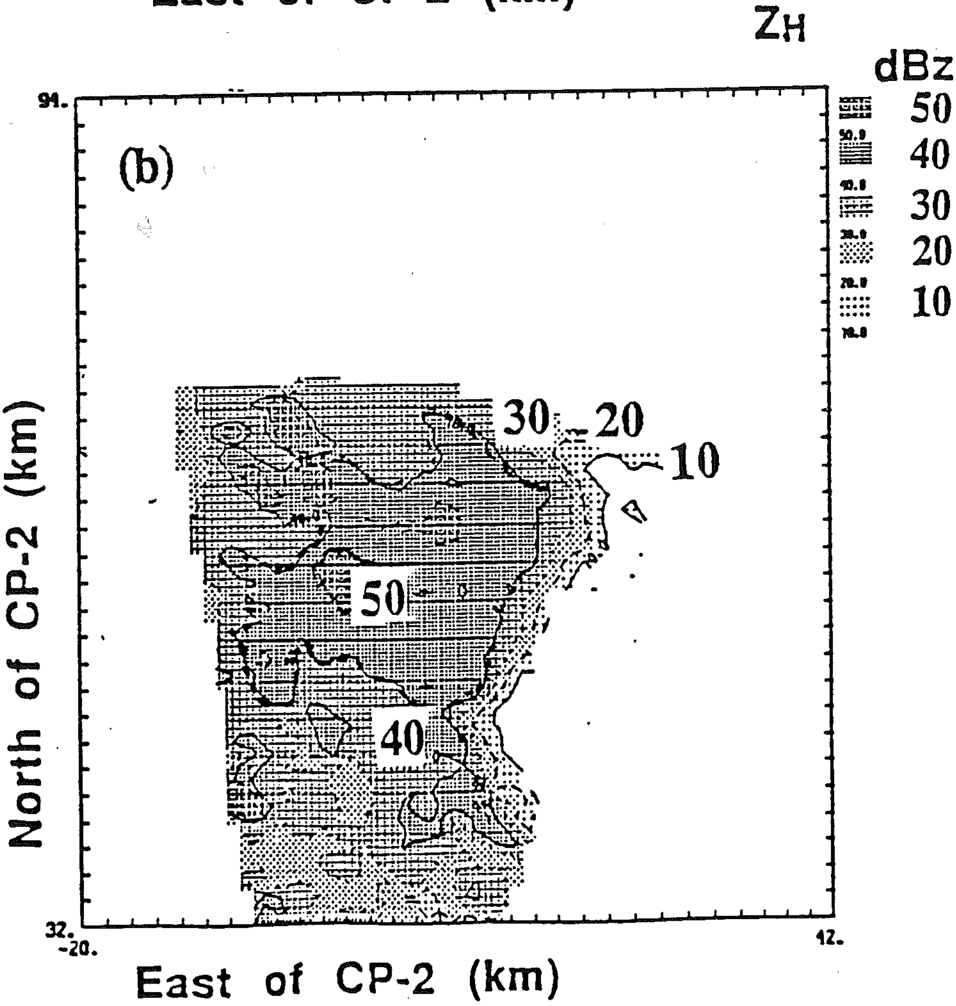
CONTOUR FROM 0.00000E+00 TO 1.0000 CONTOUR INTERVAL OF 0.10000 PT(3,3)= -0.31381

MAYPOLE

17:23 MDT
2.7 km
June 16, 84



17:29 MDT
2.7 km



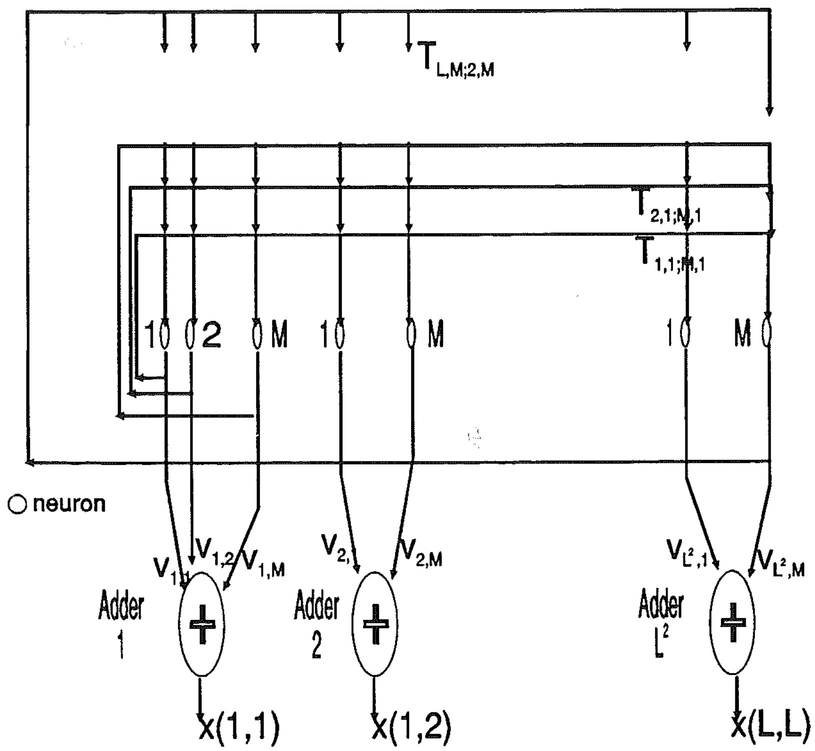
Method 1. Batch algorithm

The energy function of the neural network (with $N_r \times N_c \times (D+1)$ interconnected neurons) is defined as

$$E = -\frac{1}{2}\sum_{i,l,j,m}^{N_r^2 N_c^2}\sum_{k,n}^{D^2} T_{i,j,k;l,m,n} v_{i,j,k} v_{l,m,n} - \sum_{ij}^{N_r N_c}\sum_{k}^{D} I_{i,j,k} v_{i,j,k}$$

where

N_r and N_c are the sizes of the images,
D is the maximum displacement, and
v is the state of the neuron which represents the displacement of pixel (i,j).



Suppose that M images are used for matching, the error function

$$E = \frac{1}{M-1}\sum_{k}^{D}\sum_{p}^{M-1}\left[D_{k,p}(\vec{r}) + \kappa(\Delta\vec{r}^{edge}_{p,k})^2\right] + \lambda\sum_{i,j}^{N_c N_r}\sum_{k}^{D}\sum_{S}\Delta\vec{r}^{2}_{i,j,k}$$

where

$D(\vec{r})$: MSE between pair of images

$\vec{r}^{edge}$: displacement of the edge of the target

$\vec{r}$: displacement of each pixel or target

κ and λ are the constants to adjust the importance of each term.

S denotes total shift between two image frames.

The interconnection strengths and bias inputs can be obtained as

$$T_{i,k;j,l} = -48\lambda\delta_{i,l}\delta_{j,m}\delta_{k,n} + 2\lambda\sum_{S}\delta_{i,j,l,m}\delta_{k,n}$$

and

$$I_{i,j,k} = -\frac{1}{M-1}\sum_{p=1}^{M-1}(\Delta I_{i,j,k,p})^2 + \kappa(\Delta\vec{r}^{edge}_{i,j,k,p})^2$$

Batch matching procedure:

1. Estimate the network input.
2. Set the initial state of the neurons.
3. Update the state of all neurons.
4. Check the energy function (E); if E does not change, stop, otherwise go back to step 3.

Real Time (Recursive) Algorithm:

When pth image becomes available, the bias input is updated by

$$I_{i,j,k}(p) = I_{i,j,k}(p-1) + \frac{1}{p}\Delta[-(\Delta I(p))^2 - \kappa(\Delta \vec{r}^{edge}(p))^2]$$

the weight is same as batch method.

Real time procedure:

1. Update the bias input.
2. Initialize the state of the neurons.
3. If new frame comes, go to step 1; otherwise, step 4.
4. Update the neuron state.

SUMMARY

Artificial Neural Networks (ANNs)

1. parallel processing ability
2. capability of learning
3. graceful degradation of performance under conditions of ambiguity
4. easy to be executed in real-time

Two stage procedure:

ANN Classification

ANN Matching: Batch and Real time algorithms

3. CONCLUSIONS

Conclusions based on analysis of the data to date are:

- o The velocity of satellite cloud track winds made using 5 minute imagery and automated tracking compare favorably with the winds observed by research aircraft. The heights assigned to jet level cirrus were not correct but improvement should be possible with current height assignment techniques.

- o Low level cloud motions in animated 5 minute imagery clearly locate surface storm center positions after they move out from under the major cloud shield of a storm.

- o Half-hour periods of 5 minute imagery every 3 hours should prove useful at marine forecast centers to update Significant Weather Advisories for shipping interests.

No evaluations of the 6 per day 15 minute interval satellite wind data sets have as yet been reported.

4. REFERENCES

Hadlock, R. and C.W. Kreitzberg, 1988: The Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA) field study: Objectives and plans. BAMS, 69, 1309-1320.

Hartnett, E. and C.W Krietzberg, 1990: ERICA Data Users Guide. ERICA Data Center, Drexel University, Philadelphia, Pa.

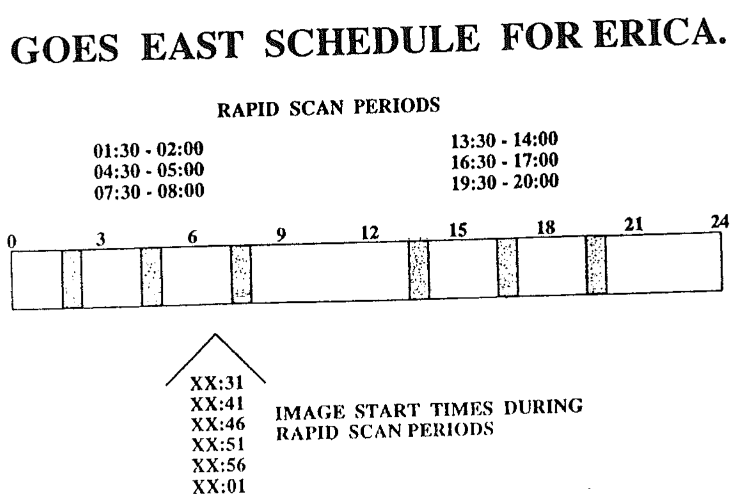


Figure 1.