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

Y. M. Fleming Lure, H. Y. Michael Yeh, and Charles P. Arnold

Caelum Research Corporation
11229 Lockwood Dr.,
Silver Spring, MD 20901
(TEL) (301) 593-1748
(FAX) (301) 593-3951
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

Images

Feature Extraction

Classification with ANN

Matching with ANN

Velocity
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).

\[
\begin{align*}
U &= TV + I \\
V &= g(U)
\end{align*}
\]

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ANN Classification

Images

Feature EXtraction

Training

Classification with ANN

Classification Results
Classification with ANN

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

<table>
<thead>
<tr>
<th>SSMI measurement classification characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input: SSMI measurements (brightness temperature) at different channels</td>
</tr>
<tr>
<td>frequencies and polarizations</td>
</tr>
<tr>
<td>Output surface features:</td>
</tr>
</tbody>
</table>

2. Classification based upon texture information of the images

<table>
<thead>
<tr>
<th>Input Feature:</th>
<th>Output Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean, standard deviation, contrast, angular moments, homogeneity, entropy, etc.</td>
<td>Stratocumulus Cumulus Cirrus</td>
</tr>
</tbody>
</table>

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### Classification accuracy for SSMI

<table>
<thead>
<tr>
<th>Classified</th>
<th>Actual surface</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Sm</td>
<td>R-Ocean</td>
<td>Snow</td>
<td>Desert</td>
<td>R-Land</td>
</tr>
<tr>
<td>Non-Sm</td>
<td>82.18%</td>
<td>0</td>
<td>0.05%</td>
<td>5.06%</td>
<td>19.02%</td>
</tr>
<tr>
<td>R-Ocean</td>
<td>15.04%</td>
<td>97.56%</td>
<td>2.93%</td>
<td>0</td>
<td>1.95%</td>
</tr>
<tr>
<td>Snow</td>
<td>0</td>
<td>0</td>
<td>97.02%</td>
<td>16.54%</td>
<td>0</td>
</tr>
<tr>
<td>Desert</td>
<td>0.02%</td>
<td>0</td>
<td>0</td>
<td>78.4%</td>
<td>0</td>
</tr>
<tr>
<td>R-Land</td>
<td>2.75%</td>
<td>2.44%</td>
<td>0</td>
<td>0</td>
<td>79.02%</td>
</tr>
</tbody>
</table>

**Overall Accuracy:** 88.27%

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Matching with correlation method

**Definition of image coordinates.**

The mean square error between the two normalized images is

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

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

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

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_V1823P0-DZNE_V2233P0

PEAK: 00.8539 at = 03.5000 01.5000 km
AREA: Xd -28.0 34.5 Yd 30.0 92.5
WINDDH: Xv -10.0 22.0 Yv 42.0 74.0

ST_XRO_DZNE_V2023P0-DZNE_V2423P0

PEAK: 00.8352 at = 03.5000 01.5000 km
AREA: Xd -28.0 34.5 Yd 30.0 92.5
WINDDH: Xv -10.0 22.0 Yv 42.0 74.0

\[
\frac{3.8 \text{ km}}{6.75 \text{ min} } = 900 \% \\ 67^\circ \\
\frac{3.8 \text{ km}}{6.41 \text{ min} } = 990 \% \\ 67^\circ 
\]
MAYPOLE

17:23 MDT
2.7 km
June 16, 84

17:29 MDT
3.7 km
Matching with ANN

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

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

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

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

where

- \( D(\vec{r}) \): MSE between pair of images
- \( r^{\text{edge}} \): displacement of the edge of the target
- \( \vec{r} \): displacement of each pixel or target
- \( \kappa \) and \( \lambda \) are the constants to adjust the importance of each term.

\( \Delta r \) denotes total shift between two image frames.

The interconnection strengths and bias inputs can be obtained as

\[ T_{i,j,k,l} = -48\lambda \delta_{i,l} \delta_{j,m} \delta_{k,n} + 2\lambda \sum_{s}^{N} \delta_{i,j,l,m} \delta_{k,n} \]

and

\[ I_{i,j,k} = -\frac{1}{M - 1} \sum_{p=1}^{M-1} (\Delta I_{i,j,k,p})^2 + \kappa(\Delta r_{i,j,k,p}^{\text{edge}})^2 \]

**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

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

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:

- 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.

- 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.

- 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


GOES EAST SCHEDULE FOR ERICA.

<table>
<thead>
<tr>
<th>RAPID SCAN PERIODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>01:30 - 02:00</td>
</tr>
<tr>
<td>04:30 - 05:00</td>
</tr>
<tr>
<td>07:30 - 08:00</td>
</tr>
<tr>
<td>13:30 - 14:00</td>
</tr>
<tr>
<td>16:30 - 17:00</td>
</tr>
<tr>
<td>19:30 - 20:00</td>
</tr>
</tbody>
</table>

Figure 1.