MICROBURST RECOGNITION: AN EXPERT SYSTEM APPROACH *

Steven D. Campbell

Lincoln Laboratory
Massachusetts Institute of Technology
Lexington, Massachusetts

1. INTRODUCTION

Expert systems have gained much recent attention as a means for capturing the performance of human experts in specialized fields of knowledge. Areas in which expert systems have been successfully developed include such varied applications as mass spectrogram interpretation, disease diagnosis, geological data analysis and computer configuration (Hayes-Roth et al, 1983).

The assumption behind these applications is that a body of specialized knowledge is possessed by the human expert. Expert systems attempt to capture this knowledge in an explicit form, such as a set of heuristic rules, and employ mechanisms to apply this knowledge to solve problems in the domain of expertise. Using this approach, expert systems have been able to successfully perform tasks which previously could only be carried out by human specialists. Moreover, expert systems have in some cases been able to attain levels of performance equalling that of humans (Buchanan and Shortliffe, 1984).

This paper describes an expert system-based approach to the problem of recognizing microbursts from Doppler weather radar data. A prototype system based on this approach is currently being developed at Lincoln Laboratory for automated recognition of low-altitude wind shear hazards. This system, called WX1, employs artificial intelligence and computer vision techniques to emulate the symbolic reasoning and visual processing capabilities of a radar meteorologist.

2. SYSTEM DESIGN

The WX1 system consists of two elements: an expert system element and a radar image processing element (Campbell and Olson, 1985). The radar image processing element employs pattern recognition techniques to extract features from radar data. The expert system element carries out symbolic reasoning on these features using a set of rules expressing meteorological knowledge about wind shear phenomena.

A set of microburst recognition rules has been developed for the WX1 system. These rules express models of microburst structure, and link these models to radar observables. Figure 1 shows a model expressing a microburst model proposed by Fujita (1985). This model consists of a surface divergence, middle-altitude rotation and upper-level convergence. These phenomena are linked to observed radar signatures. For example, a surface divergence can be recognized from a velocity couplet signature, a positive radial shear region, or both signatures.

Table 1 shows a simplified example of how the model of Figure 1 can be implemented as rules. The first rule is an English translation of a rule for recognizing velocity couplets. The rule checks for positive and negative velocity regions which are less than 4 km apart, and which have a velocity difference greater than 10 m/s. When a velocity couplet is recognized, the second rule is triggered. This rule checks that the couplet has the appropriate orientation for a divergent outflow. The third rule is triggered when the divergent outflow is close to the surface and therefore labels it as a surface divergence signature.

Similar rules check for surface divergence signatures indicated by regions of positive radial shear. When a surface divergence is recognized from both a velocity couplet and a positive radial shear region, the two signatures are merged together. Other rules check for middle-altitude rotation and upper-altitude convergence signatures

The final rule in Table 1 is triggered when surface divergence, middle-altitude rotation and upper-altitude convergence signatures occur. When these signatures overlap, the rule declares that a surface microburst has been recognized.

This simple example illustrates how rules can be used to recognize wind shear phenomena. It can be seen that modifying the system's knowledge base is easily accomplished by the addition, deletion or modification of rules.

The WX1 system is currently implemented on a Symbolics 3670 Lisp machine. The expert system is implemented in YAPS (Yet Another Production System), a production rule language similar to OPS5 (Allen, 1982). The radar image processing element is implemented with extensive use of the Flavors object-oriented programming system (Weinreb et al, 1983).

---

* This work was supported by the System Engineering Service of the Federal Aviation Administration under Interagency Agreement DTFA01-83-Y-10579. The information presented does not necessarily reflect the official view or policy of the FAA.

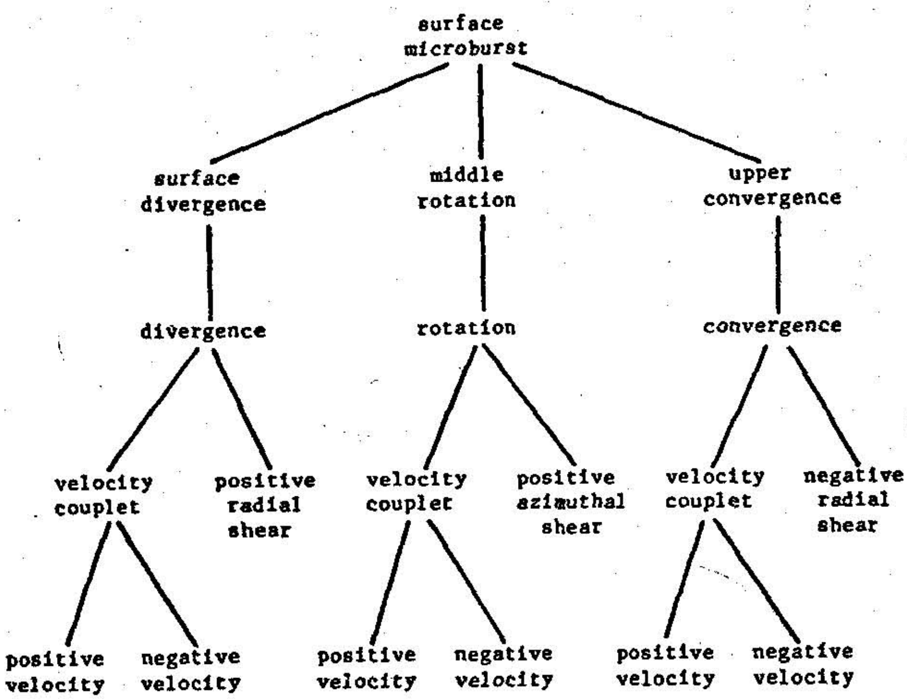

Fig. 1. Model of a Surface Microburst.

Table 1. Simplified Example of Rules for Microburst Recognition.

```
( If    feature FP is a positive-velocity feature
        feature FN is a negative-velocity feature
        distance between FP and FN is less than 4.0 km
        velocity difference between FP and FN is greater than 10 m/s
  Then  FP and FN are a velocity couplet )

( If    VC is a velocity couplet
        orientation of VC indicates divergence
  Then  VC is a divergence signature )

( If    DS is a divergence signature
        altitude of DS is less that 0.3 km
  Then  DS is a surface divergence signature )

( If    SD is a surface divergence signature
        MR is a middle-altitude rotation signature
        UC is a upper-altitude convergence signature
        overlap exists between SD and MR
        overlap exists between MR and UC
  Then  SD, MR and UC are a surface microburst signature )
```

3. INITIAL RESULTS

Figure 2 shows initial results of the microburst ruleset operating on data collected at Denver during the Joint Airport Weather Study (JAWS) project (Wilson et al, 1984). The radial velocity data from the CP-2 radar at 1606 MDT on 29 June 1982 is shown for the surface elevation scan. According to information supplied by the National Center for Atmospheric Research (NCAR), three microburst events, denoted F, G and H, were present during this time. The locations of these microbursts at the time of peak intensity are indicated by the larger circles in each volume scan. Microburst F reached maximum intensity at 1603 MDT, while the other two microbursts reached peak intensity at 1606 MDT.

For this volume scan, the WX1 system processed four tilts of data at elevation angles of 0.0, 0.5, 1.3 and 2.5 degrees. Each recognized microburst event is shown by a rectangle indicating the approximate extent of the surface outflow and a small circle indicating the center of the event. As can be seen, the microburst events recognized by the system agree reasonably well with the events identified by NCAR.

To illustrate how the system matches radar signatures from multiple tilts to the model of Figure 1, the recognition results for microburst G will now be described. For this microburst, a surface divergence signature was identified in tilt 1 from a large positive radial shear region. Two more divergence signatures were recognized in the next tilt from small radial shear regions at 0.4 km altitude. For tilt 3, the system identified a cyclonic rotation signature at 1.1 km altitude from a positive azimuthal shear region. For tilt 4, the system found three convergence signatures from negative radial shear regions at 2.0 to 2.2 km altitude, plus two more rotation signatures.

The ruleset initially recognized the microburst from the surface divergence signature of tilt 1 and one of the rotation signatures of tilt 4. It then discovered that the other signatures described above were consistent with the model. These additional signatures were combined with the first two signatures to form the recognized microburst. By combining multiple signatures in this fashion, the robustness of the system is increased. For example, any one of the signatures except for the surface divergence could have been missing and microburst G still would have been recognized.

The performance of the microburst ruleset is currently being refined using a set of 25 known JAWS microbursts. The system results are scored for each volume scan in terms of 1) microbursts recognized or not recognized and 2) false alarms due to ground clutter, second trip echoes, etc. The objective of this effort is to achieve a quantitative evaluation of system performance, including recognition probability and false alarm rate.

4. SUMMARY

This paper has described how expert system techniques can be applied to the problem of recognizing microburst wind shear hazards. The approach used in the WX1 system involves augmenting a conventional rule-based expert system with a specialized capability for processing radar images. A set of heuristic rules has been developed for recognizing microburst events. These rules express symbolic models which link microburst structure to radar observables.

Preliminary results have been presented illustrating the ability of the microburst ruleset to recognize JAWS microburst events. A quantitative assessment of system performance is currently in progress.

5. ACKNOWLEDGEMENTS

The author wishes to thank Dr. John McCarthy, Cathy Kessinger, Rita Roberts and Jim Wilson of the National Center for Atmospheric Research (NCAR) in Boulder, CO for their assistance in supplying Doppler radar data and microburst information from the JAWS and CLAWS projects. NCAR is supported by the National Science Foundation. The author also wishes to thank Dr. James Evans and the staff of the Terminal Doppler Weather (TDWR) program at M.I.T. Lincoln Laboratory for their assistance in supplying radar data and computer processing support.

6. REFERENCES

Allen, E.M., 1982: YAPS: Yet Another Production System. TR-1146, Maryland Artificial Intelligence Group, Department of Computer Science, University of Maryland.

Buchanan, B.G. and E.H. Shortliffe (eds.), 1984: Rule-based Expert Systems. Addison-Wesley.

Campbell, S.D. and Olson, S.H., 1986: WX1 - An Expert System for Recognizing Low-Altitude Wind Shear Hazards, Coupling Numerical and Symbolic Computing in Expert Systems, J. Kowalik (ed.). North-Holland.

Fujita, T.T., 1985: The Downburst. SMRP Research Paper Number 210, University of Chicago, Chicago, IL.

Hayes-Roth, F., D.A. Waterman and D.B. Lenat (eds.), 1983: Building Expert Systems. Addison-Wesley.

Weinreb, D., D. Moon and R. Stallman, 1983: Lisp Machine Manual. Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Fifth Edition.

Wilson, J.W., R. Roberts, C. Kessinger and J. McCarthy, 1984: Microburst Wind Structure and Evaluation of Doppler Radar for Airport Wind Shear Detection. J. Clim. and Appl. Meteor., 23, 898-915.

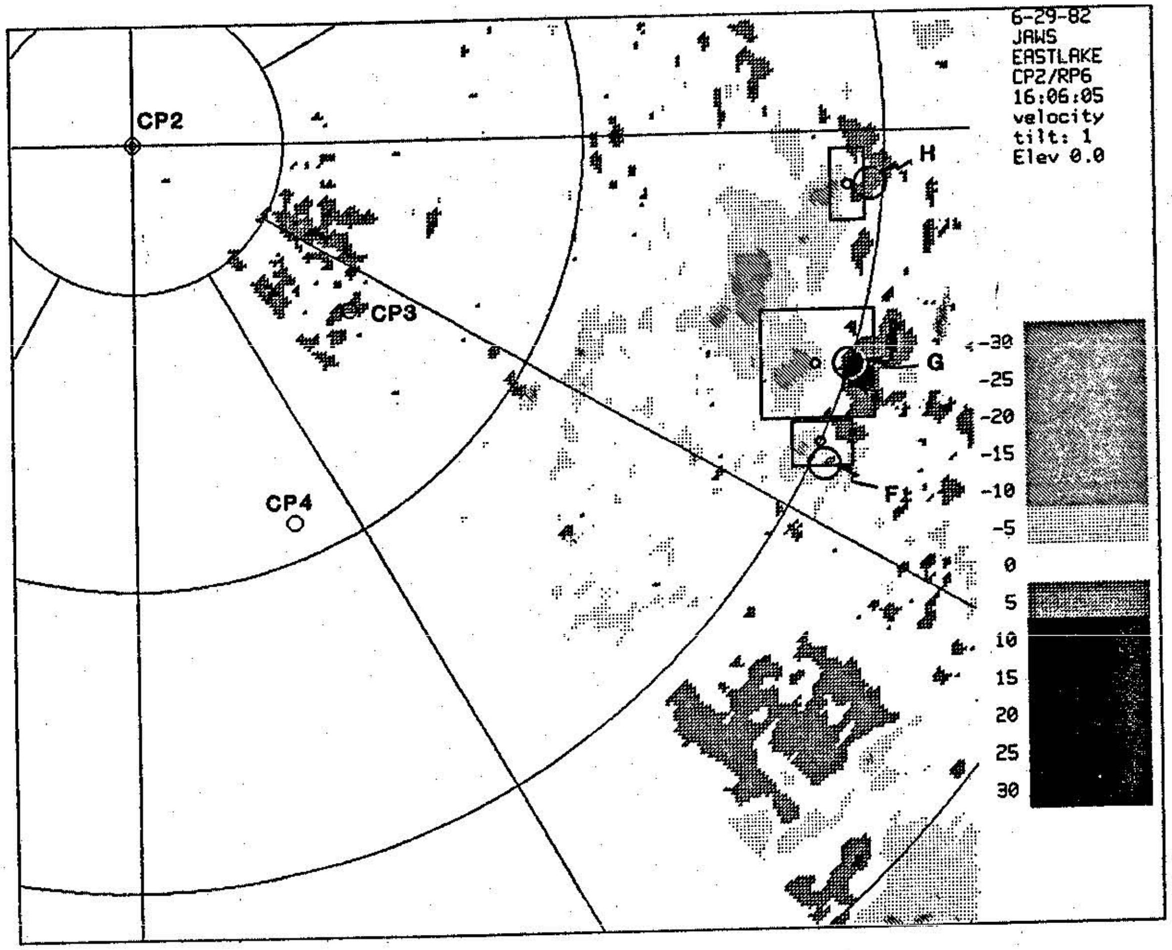

Fig. 2. Recognition Results for JAWS Data from 29 June 82 at 1606 MDT. (Radial velocity for surface elevation scan from CP-2 radar is shown. Locations of microbursts F, G and H are indicated by large circles. Microbursts recognized by WX1 system are indicated by rectangles showing approximate extent of surface outflow. Range rings are at 10, 30, 50 and 70 km.)