"Overview of an Artificial Intelligence System

for Gust Front Recognition and Tracking"*

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1. INTRODUCTION

This paper gives a brief overview of the concepts and strategies used in the WX1 system for automated detection, tracking, and prediction of gust fronts. WX1 is an artificial intelligence-based system for recognizing low-altitude wind shear hazards, such as gust fronts and microbursts, from weather radar data. In contrast to conventional pattern recognition systems, WX1 uses multiple lines of reasoning and multiple information sources. The objective of this approach is to realize the twin goals of a high detection rate and a low false alarm rate. Initial results will be presented demonstrating the ability of the system to recognize, track, and predict gust fronts over extended time sequences of Doppler radar data.

The two most important sources of low-altitude wind shear are gust fronts and microbursts. Of the two, microbursts are much more dangerous and have been implicated in several recent major commercial airline crashes. Microbursts and microburst detection will be discussed in a companion paper (Campbell, 1986).

A gust front is the leading edge of a storm outflow. When a storm downdraft hits the ground and spreads out forward along the ground, a gust front is formed. The interface between the outflow leading edge and surrounding air causes convergent wind shear and turbulence. Gust fronts are not as dangerous as microbursts, but are important because of turbulence and because the gust front often presages a wind shift that can impact runway operation. Delays due to wind shifts can cause large cumulative economic losses. The CLAWS projects revealed that when controllers were given advance warning of impending wind shifts, they were able to plan for much more efficient runway utilization (McCarthy and Wilson, 1985; Stephenson, 1985).

2. GENERAL PRINCIPLES

2.1 The Problem

The problem of extracting useful information from radar weather data is a challenging one. Radar data is noisy, has frequent signal dropouts, and is subject to ground clutter, velocity aliasing, and second-trip echoes.

The radar signature of a gust front varies quite widely; a gust front's strength, shape, size, and duration varies from case to case. A gust front may or may not have one or more of the following: a reflectivity thin-line, a region of enhanced spectral width, or a region of convergent radial shear. Even if the signature is clear to a human observer, it might be sufficiently irregular or contaminated by clutter, second-trip, or other problems to hinder efforts at machine analysis.

2.2 The Solution

Several researchers have attempted to build systems for detecting gust fronts from Doppler weather data (Uyeda and Zrnic, 1984; Harris et al, 1985). These are sophisticated pattern recognition systems that locate areas of apparent radial or azimuthal shear. Their primary fault is that they are narrow-based, relying on one main source of information which is processed using a single, predetermined algorithm.

These conventional pattern recognition systems can do fairly well, especially under good conditions such as high quality data and gust fronts with strong radial shear. However, to perform reliably under variable conditions, a more advanced system is needed.

WX1 is designed to consistently detect and track gust fronts as well as to be very resistant to false alarms. WX1 is broad-based, using multiple information sources and multiple lines of reasoning in order to avoid being dependent on any one particular scheme. The following are the three primary design principles of WX1.

1) _Multiple sources of information._ In certain cases, the shear line in the velocity field is clearer than the thin-line in the reflectivity field; in other cases, the opposite is true. For best results, it seems obvious that a system should use the information in both fields. The difficulty lies in making effective use of the added information. The same is true for other types of information, such as the spectral width field. Currently WX1 uses only radar data, but this principle could be extended to non-radar information sources such as ground stations and synoptic information.

2) _Multiple lines of reasoning._ To make the ideas of 1) work, WX1 uses multiple pattern recognition algorithms to extract features out of the radar data. WX1 does not depend on any one algorithm to interpret a given information source. For example, WX1 has two different shear algorithms which it runs on the velocity field. Neither works all the time, but by using them together the system can detect some shears that it would otherwise miss. As with 1) the difficulty comes from having to deal with this added complexity.

3) _Model-based classification and interpretation._ This is the key step that is needed to make effective use of the principles of 1) and 2). WX1 contains structural models that relate meteorological phenomena to features observed in the radar data. In addition to modelling meteorological phenomena, the system also contains models for common sources of false alarms such as high noise or second-trip echoes. This model-based classification scheme enables WX1 to distinguish between real events and spurious artifacts. For example, the presence of an apparent shear line will not lead to the declaration of a gust front if WX1 determines that it matches the model for second-trip echos.

3. SYSTEM DESIGN

The WX1 system incorporates an architecture that integrates numeric signal processing with symbolic reasoning (Campbell and Olson, 1986; Olson, 1985). WX1 is implemented as a production rule-based expert system coupled to a powerful image processing system. The two sections communicate using a query/answer paradigm. The expert system sends requests for information or processing that are acted on by the image processing system.

3.1 Image Processing System

The image processing system of WX1 handles all numerical image processing and pattern recognition operations on the radar images. There are several different types of operations that this unit performs. On command from the expert system, the image processing system can run one of several pattern recognition algorithms such as calculating the radial and azimuthal shear fields or finding possible reflectivity thin-lines through shape analysis of reflectivity features.

A typical pattern recognition algorithm, such as the radial shear algorithm, is made up of three basic steps. The first step is to preprocess the data field by convolving with a smoothing filter to reduce noise. The second step is to calculate the desired derived product, such as the radial shear field. The last step is feature extraction, where individual features are extracted from the data field and then passed to the expert system for further processing.

3.2 Expert System

WX1's expert system provides the decision making capability that would normally be performed by a human radar meteorologist. The expert system plays two main roles. First, it controls and directs the numerical processing carried out by the image processing system. Second, it interprets the results of the lower-level processing, using the model-based classification scheme described above.

The expert system is made up of three main parts: the rule database, the fact database, and the inference engine. The fact database holds WX1's dynamic knowledge; it is a collection of assertions that reflect what WX1 knows about the current situation. The rule database is a collection of "IF <fact pattern> THEN <action>" production rules which holds WX1's static knowledge, i.e., its meteorological expertise. The function of the inference engine is to run the system; it determines which rules are relevant to the current set of facts, chooses a rule from that set, and runs it, repeating as long as there are relevant rules.

The meteorological models mentioned above are expressed as rules in the expert system. To get a feel for how this works, the following are two stylized rules which are analogous to rules used in WX1.

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IF there is a shear region and
   there is a relectivty thin-line and
   they overlap
THEN hypothesize a gust front

IF there is a shear region and
   the region is lined up with the radar beam
THEN hypothesize a second-trip artifact.
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4. INITIAL RESULTS

4.1 April 13, 1981

This example contains a gust front that is observed both as a shear line in the velocity field and as a reflectivity thin line. This data is from the National Severe Storms Laboratory in Norman, Oklahoma. It shows a large eastward moving squall line of the kind that are fairly typical in that region of the country.

The reflectivity field is shown in Fig. 1, the velocity field is shown in Fig. 2. The detected reflectivity thin-line is shown in Fig. 3. The shear line is not very strong, but it is aligned favorably with the radar, so it is detected as well, as shown in Fig. 4. WX1 determines that they overlap, and combines them into a single high confidence gust front. If the pattern recognition algorithms had detected only one of the two features, WX1 still would have detected the gust front. However, WX1 would have less confidence in the result; if there had been evidence for another hypothesis, WX1 might decide the second hypothesis was more likely.

This case demonstrates WX1's ability to detect gust fronts reliably over many volume scans of Doppler weather radar data, and to generate accurate predictions of the gust front's future position. This case is from the National Center for Atmospheric Research's 1985 CLAWS project.

Figure 5 shows the reflectivity and Fig. 6 shows the velocity of the first volume scan of a sequence. There are 14 volume scans of data, covering 78 minutes. Figure 7 shows the gust front as detected in all 14 scans. Figure 8 shows a prediction for the position of the gust front at the time of the 14th scan, based on the results from the first four scans.

5. SUMMARY

This paper has presented the ideas underlying WX1, an artificial intelligence based system for detecting low-altitude wind shear hazards. WX1 uses an expert system to interpret and classify the results produced by multiple low-level pattern recognition algorithms. Preliminary results demonstrate that WX1 is capable of tracking gust fronts over long periods of time and forecasting their future positions.

ACKNOWLEDGEMENTS
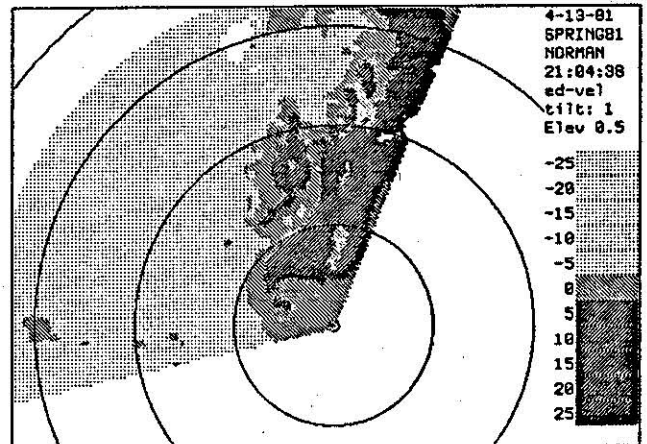
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Fig. 1. Reflectivity Field.
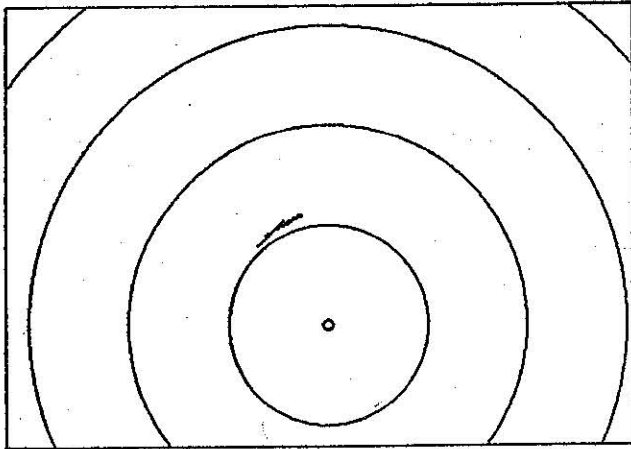(40 km. range rings)

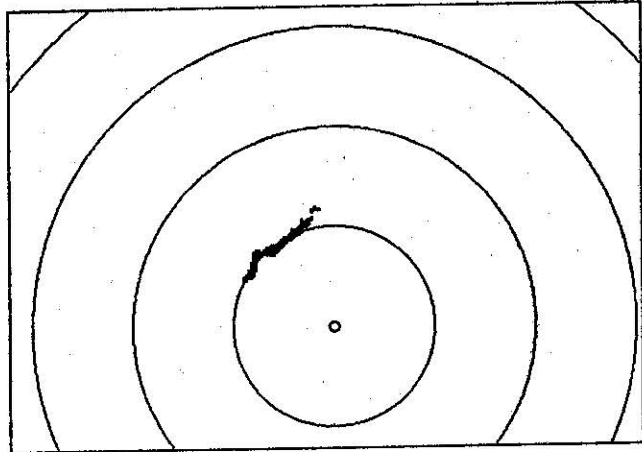Fig. 2. Velocity Field.

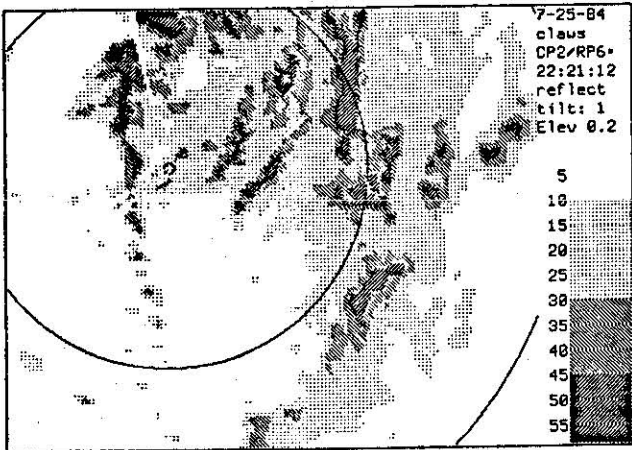Fig. 3. Detected Thin-Line.

Fig. 4. Detected Shear Line.

Fig. 5. Reflectivity Field.
(40 km. range rings)
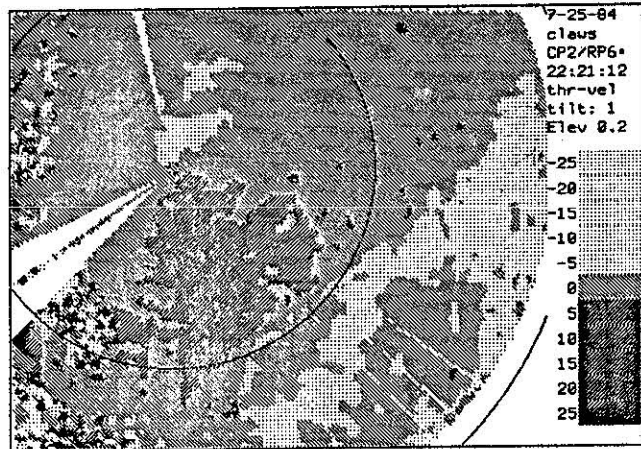
Fig. 6. Velocity Field.
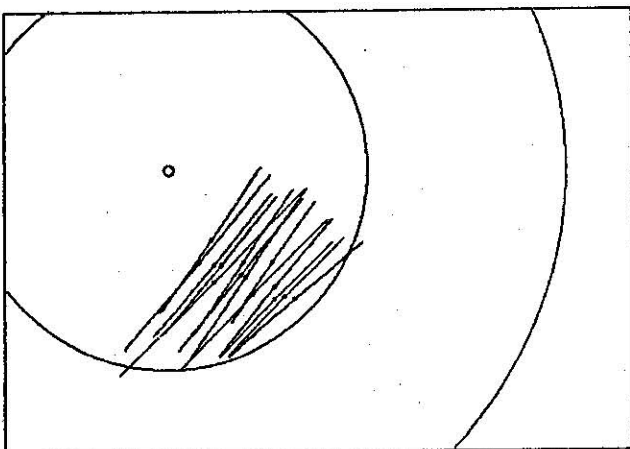
Fig. 7. Detected Gust Front in 14 Scans.

RESULTS, SCAN 14

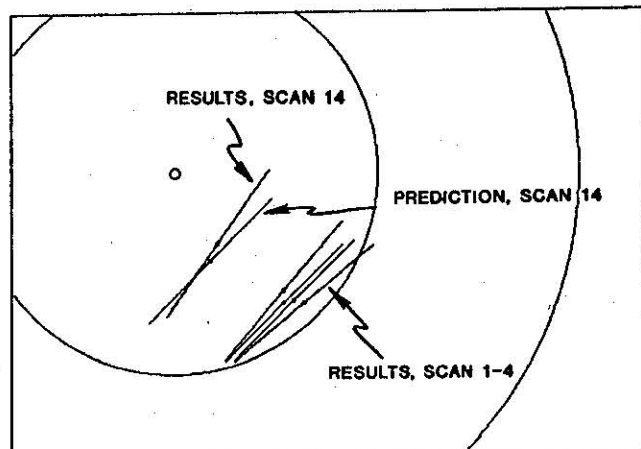PREDICTION, SCAN 14

RESULTS, SCAN 1-4

Fig. 8. Prediction for 14th Scan, Based on Results
of First Four Scans.