Analysis and Improvements to the WSR-88D Storm Cell Tracking Algorithm

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1. Introduction

a. Motivation

Studies on the efficacy of storm tracking algorithms have focused upon tracking the centroids of the radar features as identified by a separate identification algorithm. Therefore, the tracking skill becomes dependent upon the behavior of the identification algorithm. In addition, the tracking results are often compared against tracks that are determined by small quantities of subjective, human analyzes of radar images. These human analyzes, while useful, still depend upon a subjective determination of the features to track.

This project seeks objectivity by simulating storm tracks. The simulated storm tracks are then passed to the tracking algorithms, independent of any identification algorithms. Therefore, an 'apples-to-apples' comparison can be made between different algorithms. In addition, because of the ease of generating simulated tracks, the algorithms can be extensively studied in a variety of storm scenarios.

b. Definitions

An 'object' is the term for a real-world body that is desired to be identified and tracked. A 'feature' is the computer-vision of an 'object,' usually obtained from some sort of identification process. A key difference between an object and a feature is that a feature could be the result of noise in the data, while an object physically exists. $Z(t)$ is the set of features reported for time t. A 'track' is the set of features, at most one from the set $Z(t)$ for each t. Ideally, a track would contain only the features for a particular object, or would contain only a single reported feature that occurred from noisy data. Lastly, a 'hypothesis' is a set of tracks which covers the entire set of features for all t. For an arbitrary set of $Z(t)$, it is possible there exists multiple hypotheses that satisfy the data constraints.

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c. Algorithms

While a multitude of tracking algorithms could be studied with this approach of simulating storm tracks, only two particular algorithms were examined in this exploratory study: the Storm Cell Identification and Tracking (SCIT) and the Multiple Hypothesis Tracker (MHT) algorithms. Future work will examine other storm-cell tracking algorithms in a similar fashion.

Any algorithm to be used for storm cell tracking must satisfy certain requirements. First, the algorithm must not require *a priori* knowledge of the number of tracks. Second, tracks must be able to enter and exit the domain. Third, tracks may be initiated and terminated at any time, at any location. Lastly, tracks may evolve independently of each other (i.e. - no rigid-body assumptions). These requirements ought to be self-evident when considering the observed behaviors of unorganized, scattered storm cells and organized storms moving with a passing frontal boundary.

1) SCIT

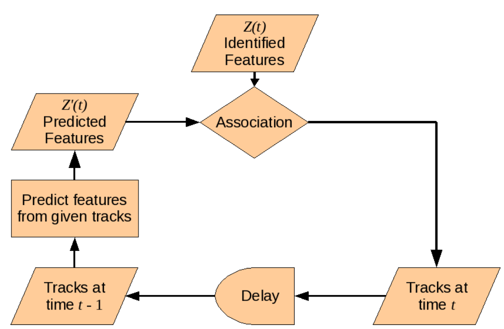

Fig. 1. Flowchart of the SCIT tracking algorithm.

The SCIT algorithm (Johnson et al. 1998) was choosen for study because it is currently used as the storm tracker for the WSR-88D system. SCIT satisfies the requirements mentioned above. This algorithm uses a greedy, nearest-neighbor approach to perform associations of the centroid of the identified features across time. At each iteration, a storm track has a predicted location for where the algorithm expects to find a feature. Each of the identified features at time t is associated with the track that has the closest predicted feature, without exceeding a distance threshold. For each identified feature that was left unassociated, new tracks are initiated. This process is diagrammed in Figure 1.

2) Multiple Hypothesis Tracking

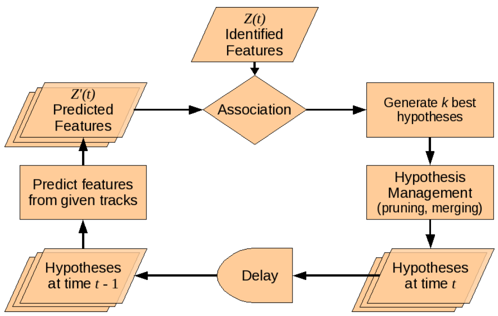

Fig. 2. Flowchart of the MHT tracking algorithm.

A multitude of tracking algorithms were reviewed, particularly the algorithms listed in the 2006 paper by Yilmaz, Javed, and Shah. The generic algorithm that satisfied the aforementioned requirements was "Multiple Hypothesis Tracking" (Cox and Hingorani 1996). This tracking approach considers the time-associations globally, in contrast to the sequential, order-dependent approach of SCIT. Also, MHT is capable of 'correcting' its tracking decisions in subsequent iterations as more data is available, which is a desirable property for adaptive sensing and historical reanalyzes. While not used for this study, MHT can also utilize additional information about the feature to reduce tracking ambiguities (i.e. - 'texture' data).

MHT treats the tracking problem as a global maximum finding problem. At each iteration, the MHT algorithm updates a list of hypothetical tracks, which are sorted by their calculated likelihoods. To limit the combinatorial explosion that can occur, only the k-best hypotheses are generated. Also, MHT employs techniques to 'prune away' the most unlikely hypotheses. This process is diagrammed in Figure 2.

2. Method

a. Code Source

This project seeks to analyze the tracking algorithms, independent of any identification methods. The original code for the SCIT and MHT algorithms came from the NWS's website for the WSR-88D Common Operations and Development Environment and Ingemar Cox's website , respectively. The tracking portion of SCIT was then reimplemented as an independent Python module. The MHT source code, written in C++, required minor changes for storm cell tracking purposes.

b. Simulation

The 'storm' tracks were generated by performing random walks. These tracks have random starting location, speed, and direction. The duration of the storm tracks is also randomly determined. 'Occlusions' (or 'false-mergers') of nearby storm cells can also be simulated by removing a feature from one of the occluding tracks.

Four track scenarios were used to test the trackers. Each scenario had 40 simulations, and each simulation had 50 storm tracks spanning 12 frames. This would be comparable to one hour of radar reflectivities from a WSR-88D station.

The scenarios were combinations of occlusion (Occlusion vs. Non-Occlusion) and organization (Organized vs. Unorganized). Occlusions are typically the result of noise in radar reflectivities, causing nearby storm cells to appear as one cell. Well-organized storm systems produce cells that propagate roughly parallel, while unorganized, scattered storms do not move in relation to other storm cells.

c. Measuring Results

By breaking up the tracks into a list of line segments, a contingency table for the decisions of the algorithms was made. An association that was correct is a 'hit' (H), while incorrect would be a 'false alarm' (FA). A missed association is a 'miss' (M), while a correct lack of an association is a 'correct null' (N). The Heidke Skill Score (HSS), using (1), was then calculated for each simulation, providing a quantitative basis for algorithm comparison.

$$HSS = \frac{2(H * N - FA * M)}{(H + M)(M + N) + (H + FA)(FA + N)}. \quad (1)$$

Values range from $-\infty$ to 1, with scores greater than 0 meaning that the model performed better than a random model.

3. Results & Discussions

A sample of four tracking results – one from each scenario tested – is shown by Figures 3, 4, 5, and 6. In each figure, the output from each algorithm – SCIT on the left, MHT on the right – operating on the same input is shown. In these figures, green indicates a correct tracking decision by the algorithm. An incorrect association is indicated by a red line, while a dashed, gray line indicates the association that should have been made by the tracking algorithm. The average, bootstrapped skill scores and the 95% BCa confidence intervals (Efron and Tibshirani 1994) are depicted in Figure 7.

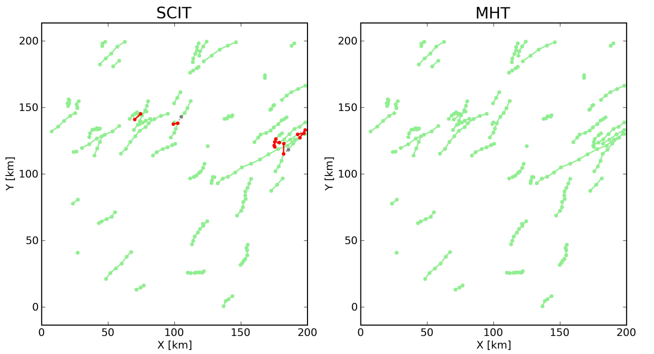

Fig. 3. A tracking result for the organized, non-occluded scenario.

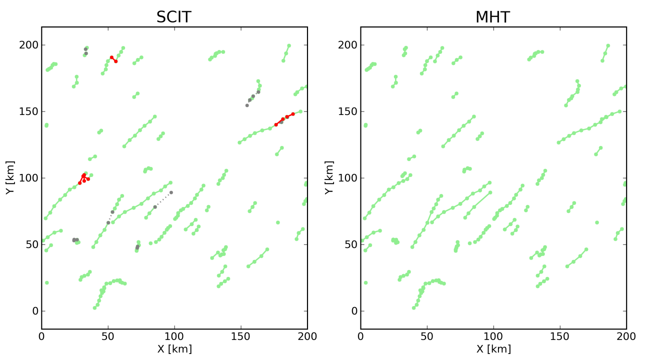

Fig. 4. A tracking result for the organized, occluded scenario.

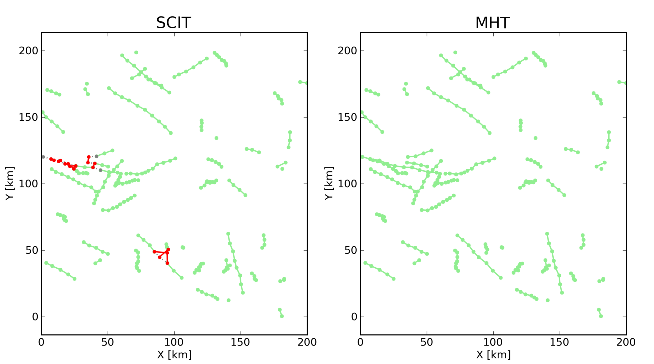

Fig. 5. A tracking result for the unorganized, non-occluded scenario.

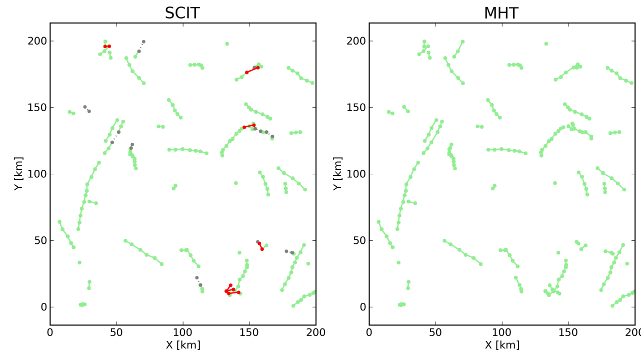

Fig. 6. A tracking result for the unorganized, occluded scenario.

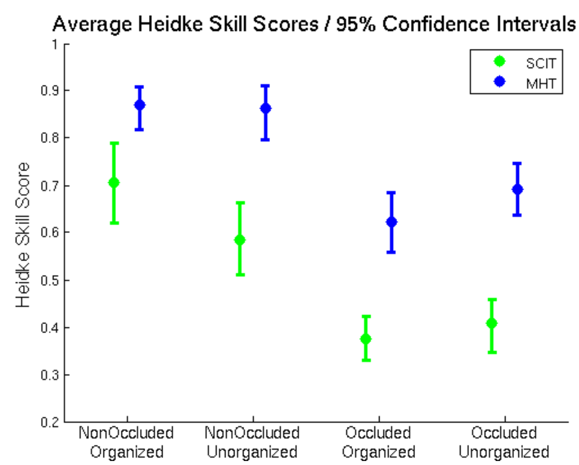

Fig. 7. Plot of the average Heidke Skill Score of each tracker algorithm in each of the four track scenarios. The 95% confidence interval for the average skill score is depicted by the error bars.

According to these Heidke Skill Scores, MHT represented a significant improvement over SCIT. SCIT performed best when the features to track were never occluded. Occlusions significantly impacted the skill of the SCIT algorithm. The organization of the storm motion does not appear to be as much a factor in impacting the skill of the trackers as the presence of occlusions in the data.

4. Conclusions

Both algorithms performed quite well over a variety of scenarios, however, SCIT suffered significantly from occlusions in the simulated tracks. MHT performed better in each scenario. SCIT's degradation was because it does not support 'coasting' a track in the case of a missed detection of an object. Therefore, any occlusions will cause SCIT to mistrack an object. This can then result in a number of different degenerative behaviors, the worst of which is a type of 'track-stealing' where a track is associated with the wrong feature, which, in turn, causes the feature that should have been assigned to that track to then be assigned to a wrong track. The MHT algorithm did not degrade significantly from occlusions because it can 'coast' a track, which allows it to defer the termination of a track for a few frames. It is also possible that MHT's performance can be improved with better parameterization.

More importantly, the approach of analyzing the efficacy of storm tracking algorithms by using simulated storm tracks was demonstrated. This approach is desirable because of its ability to thoroughly test and compare the ability of the algorithms to track objects.

Acknowledgements

This work was primarily supported by NOAA/NSSL under cooperative agreement of NA17RJ1227. We greatly appreciate the discussions and inputs from Michael Richman, Valliappa Lakshmanan and Mark Laufersweiler.

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