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Tornado Speed Estimation from a Laterally Captured Video Sequence using Machine Learning

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SUMMARY:
This paper presents a novel approach to estimate the rotational speed of a tornado or similar rotating structure that is observed from a lateral field of vision. In the current research a Machine Learning (ML) based video processing algorithm is developed to measure the speed of the tornado. The methodology to identify the motion and estimate the speed from video inputs has been discussed. The different objects taken in this experiment have been simulated into cylindrical and conical shapes with known rotational speeds using Python. The details of processing, measurement, calibration, and result assessment have been discussed in detail. The algorithm presented works well with stationary axes of rotation and translation motion is not considered. The same can be extended to combine both rotational and translation motion which then can be used for real tornadoes. This will help aiding the existing more expensive RADAR based techniques with Video based techniques.

Keywords: Video Processing, Machine Learning (ML), Tornado, Rotating Structures

1. INTRODUCTION

Rotational motion in wind is a widely studied phenomenon from a long time. This makes way for understanding the consequences of spinning of the Earth, developing useful machines and devices like means of transportation, fans and turbines and defining trajectory of planets. The importance of this field is further enhanced by the fact that various natural disasters like cyclones and tornados also occur in rotational motion while traversing translational path. This gives us motivation to find ways to estimate the speed of such systems.

If top view is considered, as in case of a cyclone imagery obtained through remote sensing, the motion appears like a circular disc. Image processing-based approach to find the speed of such motions have been worked on previously (Kong and Ghosh, 2000).

In this work, similar motion when observed from a lateral view has been discussed. A tornado is such a structure that is composed of rotating winds, and when observed from sides, appears like a giant rotating cylinder or cone. A video processing-based approach to find the rotational speed of such a system is proposed. This will help in exploiting the current advancements in camera technology and machine learning, and assist researchers to work with less expensive equipment compared to currently used RADAR based systems.

2. MEASUREMENT PRINCIPLE

A tornado is so violent that it uproots objects in its path which then rotate within the wind structure at essentially the same speed as the tornado itself. As a tornado consists of winds which are less identifiable to be tracked, an object in stuck in the tornado can be taken as a reference. This object can be tracked from a video of the tornado, with the help of machine learning algorithms and the results can be processed to estimate the speed.

In this work, the tornado is modelled and simulated as a right circular cylinder and again as right circular cone, with a 3-D spherical object as the reference object. The trajectory of the reference object resembles a helical structure, as an object gets stuck in a tornado and moves upwards similar to a helix.

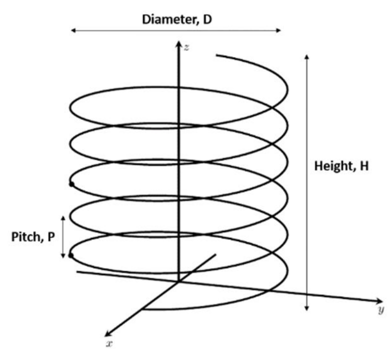

Figure 1. Cylindrical Helix

The path traversed by the reference object is used to calculate the distance covered in observed number of frames, which is then converted to speed in miles per hour. The measurement of distance covered is explained as follows:

2.1. Cylindrical Tornado Model

For a cylindrical tornado model, the reference object traverses a circular helical path. The arc length of this path gives the distance traversed by the object. For a general circular helix, with diameter *D* and pitch *P*, the arc length for a height of *H*, is given by Eq. 1

$$l = \frac{H}{P} \times \sqrt{(\pi D)^2 + P^2} \tag{1}$$

The image processing unit can measure the diameter of the rotating cylinder. The reference object is assumed to be at the edge of the parent structure; hence, we take the same value as diameter of the helix. The distance between the observed x-locations of the reference object at two extremes can also be used to calculate the same. In both cases, diameter is given by Eq. 2.

$$D = (x_2 - x_1) \tag{2}$$

The pitch of the helical path, is calculated from the mean height, i.e., average z-location value of the reference object obtained from *n* rotations observed, as shown in Eq. 3

$$b = \frac{1}{n} \times \sum_{i=1}^{n} z_i \quad (3)$$

2.2. Calculation of Distance and Time from Camera and Image Properties

The reference object motion properties like distance travelled and time taken are obtained through video processing in terms of pixels and frames respectively. We convert these into standard units before speed calculation.

2.2.1. Distance

If the object travels l_p pixels on an image of pixel density p dots per inch (*dpi*), the distance l (in *cm*) is given by Eq. (4)

$$l = 2.54 \times \frac{l_p}{p} \quad (4)$$

2.2.2. Time

Let the reference object takes f_l frames to cover one arclength, and the frame rate of video capture be f_r (in frames per second or fps). Then the time t (in seconds) is given by Eq. (5)

$$t = \frac{f_l}{f_r} \quad (5)$$

2.3. Speed Estimation

The distance, l and time, t obtained through Eq. (4) and (5) can be used to obtain the speed in *cm/s*, Eq. (6) and can further be converted into desired units (*kmph* or *mph*).

$$v = 2.54 \times \frac{l_p \times f_r}{p \times f_l} \quad (5)$$

3. EXPERIMENTAL SETUP AND RESULTS

To test the proposed method, a series of tornado videos were simulated with Python based programming language, vpython. These include a tornado modelled as a central cylindrical rotating body as shown in Fig. 2, with variations of reference objects shape, size and path. Similar variations were used with a conical model of the tornado. The equations of helical path are updated accordingly. The lateral view capturing is done through screen recorder at different frame rates, to give more scalable results.

3.1. Results from test video

The test video was captured at frame rate, f_r of *40fps*. The object was observed to travel an arclength, l_p of *1058px* in *24* frames (f_r). The pixel density, p of each image frame is 150dpi. The speed thus obtained is given by Eq. (6) and (7)

$$v = 2.54 \times \frac{1058 \times 40}{150 \times 24} \quad (6)$$

$$v = 29.86\ cm/sec \quad (7)$$

On conversion, the estimated speed is obtained as *0.668mph*. This value is significantly lower than an actual tornado. An EF-0 Tornado rotates at a speed of *65-80 mph*. As the frame rate of available video capturing unit had limited frame rate, the experiment was done with a low-speed simulations.

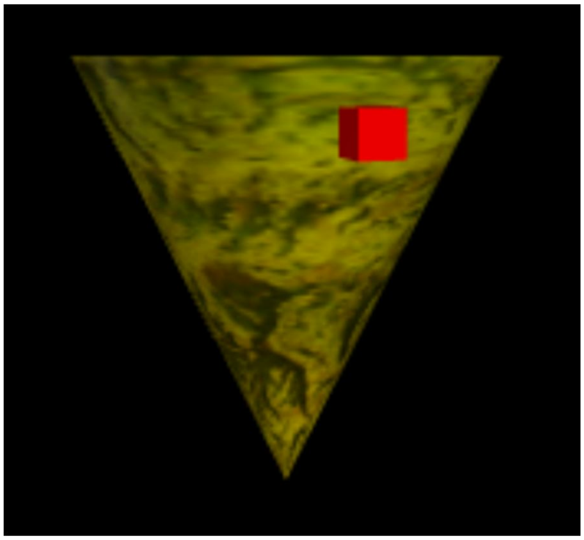

Figure 2.

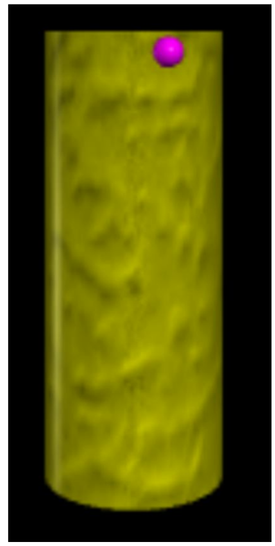

Figure 3.

Figure 2. A cylindrical tornado with spherical reference object, simulated through vpython.
Figure 3. A conical tornado with cubical reference object, simulated through vpython.

4. CONCLUSIONS

In this paper a method to estimate the speed of rotation of a body when viewed from lateral perspective is proposed. While the various relations discussed here are good for other methods of tracking as well, the use of video processing is emphasised as a low-cost medium that eases the effort of observation and calculations. This technique gives good estimate of a modelled tornado, and will be further extended to more realistic tornado models to obtain precise relations and parameters and calibrate the system.

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