Wind Engineering Joint Usage/Research Center
FY2025 Research Result Report

Research Field: Cross-disciplinary/interdisciplinary collaboration type
Research Year: FY2025
Research Number: 252016 (Joint Research Assignment number)
Research Theme: Design and Development of a Platform Independent GUI for Predicting the Wind Speed of Tornado-borne debris from the Onsite Captured Video

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*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage.

1. Research Aim

This research aims for the design and development of a user friendly, platform independent, Graphical User Interphase (GUI) that estimates and predict the speed of the tornado-borne debris by using object identification techniques in video processing from the captured tornado videos. Further, classification of different types of debris, and their sizes can be done using the machine learning algorithms with increased database. Thus, the impact force of these debris on building structures can also be estimated. For this the Tornado Simulator facility at TPU can be utilized under both stationary conditions as well as translational motion conditions, for varying boundary conditions.

2. Research Method

Determining the impact of tornado-borne debris in an active tornado using conventional methods are very challenging and sometimes very risky during on-field conditions. So, to determine it automatically at the same time in a user-friendly manner, in the current research an ML integrated video processing technique is used to identify the debris that are captured within the tornado, next to estimate the velocity of the flying debris and thereby determining the speed of the tornado. A detailed study of the different types of tornado borne debris are done both in the Japanese and the Indian scenario and the suitable model of those debris are modelled for the tornado simulator environment that can exactly mimic the actual tornado debris.

This report focuses mainly on three main objectives

- To classify different types of debris and model them
- To design and develop a user friendly, platform independent, Graphical User Interphase (GUI) to estimate the speed of tornado
- To predict the speed of the tornado-borne debris by using object identification techniques in

video processing from the captured tornado videos (using advanced video processing techniques)

1. Study on Tornado borne debris in Japan and Indian Tornadoes

As per the NHK World (Japan) report (until 2022) on an average 23 tornadoes hit Japan every year. Although tornadoes and other severe winds hit a limited area, they can cause extensive damage in a short time, collapsing buildings and utility poles and blowing away cars. Intensity is measured based on the damage. Speed measurement is difficult & expensive and even the equipment gets damaged. Conventional speed estimation from the damage estimation from the aftermath of tornado using the Enhanced Fujita Scale or EF Scale, became operational on February 1, 2007, which is a revised of original Fujita Scale. But the EF scale is a set of wind estimates based on qualitative analysis of the damage. Tornado-related damage is surveyed and is compared to a list of Damage Indicators (DIs) and Degrees of Damage (DoD) and from that, a rating (from EF0 to EF5) is assigned. But it is also observed that tornado lift up/uproots objects in its path (debris) and these ddebris rotate within the wind structure (tornado funnel) at essentially the same speed as the tornado itself. This led to an observation that the object stuck in the tornado can be taken as a reference of motion in a video and trace the object using object recognition in video processing and finally estimation of speed of the traced object in the video using Video processing techniques can reduce the risk in the assessment of tornado speed. Thus, in the current research windspeed estimation directly from speed measurement, using advanced video processing techniques offers cheaper, quantitative and safe solution. But this requires a detailed study on the characteristics of on different types of debris that can be captured in the tornado funnel is necessary. So, in the initial part of the current research, an extensive study on the tornado debris in both Japan and Indian scenario is performed.

The following topics are covered during this survey:

- Summarize common tornado-borne debris types observed in India and Japan
- List typical materials and provide representative solid and loose densities
- Modelling of most commonly occurring debris
- Simulate the different type of debris in the Tornado Simulator
- Analyze the speed of different types of debris by using Video processing Techniques

1.1 Wind-borne debris classification

Classification used in debris flight and impact studies is as follows:

- Compact (dense objects: bricks, concrete, vehicles).
- Sheet (thin materials: roofing, siding, metal sheets).

- Rod/linear (poles, lumber, elongated objects).

Different types of common debris that are identified from different tornadoes during past few decades in India and Japan are as follows:

- Vehicles/automotive parts
- Wood (lumber, rafters)
- Roofing (metal sheets, shingles)
- Glass (windows),
- Concrete
- Brick
- Vegetation and green waste,
- Light plastics
- household items
- other construction materials.

Few examples:

1. The Ichihara Tornado (Typhoon Hagibis, 2019) and tornadoes in the Kanto region

- **Vegetal / natural debris**

  Early in tornadic events, lighter items like vegetation (leaves, branches, small trees) are lofted first. In the Ichihara case, the first Tornadic Debris Signature (TDS) was inferred to be vegetated debris.

- **Destroyed man-made structures**

  After heavier damage, debris from buildings: wood components, roofing materials, wall panels, metal roofing or cladding, glass, small masonry pieces. In Ichihara, the clearest radar TDS reflected destroyed structural materials.

2. In Tochigi prefecture (Northern Kanto, 2012 tornado)

- **Road / pavement materials:** Post Tornado reports asphalt strips from roads being peeled up and scattered.
- **Mixed debris clouds:** After the strongest winds, there's a mix: pieces of masonry, broken concrete, roofing sheets, glass, etc. Also effect of falling-out: densest debris tends to fall quickly; lighter stays aloft longer. Radar signatures from Japan confirm heavy/dense debris drops out sooner, light debris remains aloft.
- **Concrete & masonry:** In stronger tornadoes (F3+), Japanese reinforced concrete or masonry buildings suffer cracks, partial collapse, or complete failure of non-structural walls. From Northern Kanto (2012) report: wooden residence turned over, concrete foundation pulled up, reinforced-concrete building damaged heavily.

3. India has fewer detailed radar-studies of Tornadic Debris Signatures, but damage surveys tell us

about what debris is common:

- **Traditional building materials**: Mud, unreinforced brick, clay tile roofs, thatch, lightweight materials. Many houses fatal to damage are of unreinforced brick or masonry, sometimes with tile or corrugated metal roofing. e.g. in the Basirhat-Bongaon tornado (1983) huts destroyed, concrete buildings severely damaged.
- **Corrugated metal sheets / tin roofing**: Very common in rural and semi-urban areas for roofs and walls; often torn off, produce sharp projectile hazards. Also reported in relief/disaster reports – flying sheets cause injuries.
- **Wood / timber**: Doors, windows, furniture, rafters, thatch structures. These often become missiles or fragments. Uprooted trees and branches are major debris sources.
- **Vegetation**: Trees uprooted, branches, leaves, etc. These provide earlier / lighter debris similar to what's seen in other countries.
- **Masonry fragments & concrete**: In stronger tornadic events, even masonry houses suffer collapse, so brick and concrete fragments are thrown. Also concrete slabs may shift. E.g. in the Nepal tornado (near India) concrete slabs shifted; trees snapped.
- **Road / infrastructure materials**: Poles, signs, utility infrastructure; sometimes sections of pavement (less common than lighter roofing or sheet metal). Electric poles, wooden posts, tubewells get uprooted.

1.2 List typical materials and provide representative solid and loose densities

Category	Shape / Form	Density Approximation	Aerodynamic Effects / Lofting Potential
Vegetation	leaves, small branches	low density, irregular shape	high drag, stays aloft longer, low mass
Wood items	rafters, boards, furniture	moderate density, elongated/flat shapes	medium drag, may rotate or tumble, intermediate loft height
Sheet metals / roofing	flat sheets, metal roofing, tiles	moderate-high density, thin, high aspect ratio	can be lifted easily if edge catches wind, high wind pressure needed to flatten and launch, spin or flutter
Glass / window panes	flat, fragile	high density per area but breaks up, fragment sizes vary	fragment-size matters; small pieces high drag; larger breakables less aerodynamic; shattering complicates modelling
Brick / concrete fragments	blocky, irregular, high mass	high density	low loft height, falls quickly; large fragments may not travel far unless very strong winds
Infrastructure (poles, signs)	rod/linear shapes	depending on material (wood, steel) high density & length	rods might align with flow or spin or get thrown; risk of penetration; initial lifting threshold higher

Table – I

Typical debris, its material, shape and form, its density approximation and its aerodynamic effects are listed in Table-I.

The corresponding material densities are listed in Table-II

Material	Solid density (kg/m³)	Loose C&D density (approx. kg/m³)
Dry softwood lumber (solid)	500	297
Dry hardwood lumber (solid)	700	297
Concrete (solid)	2400	1101
Brick (solid)	1920	1794
Glass (solid)	2500	—
Steel (solid)	7850	—
Corrugated metal roofing (thin sheet - equivalent solid)	2700	—
Vegetation / green waste (loose)	400	237
Asphalt shingles (loose)	800	712

Table-II

Modelling for different debris is shown in Table-III

Real Debris Type	Suggested Simulator Material	Reason / Considerations
Vegetation (branches, leaves)	lightweight foam, dried twigs / small sticks, paper, thin cardboard, artificial foliage	these simulate irregular shape and low density; foam or balsa wood for lightweight; leaves or leaf-like materials for fragments
Sheet metal roofing	thin aluminum or tin sheets (e.g. 0.5-2 mm), plastic-coated metal, lightweight composite panels	metallic sheen, reflective, realistic flutter; can be scaled down; risk of sharp edges so safety provisions needed
Roofing tiles / shingles	ceramic tile fragments, clay tiles (scaled or broken), thin clay / terra cotta shards, asphalt shingles (scaled)	approximate shape and fragility; for fragments, weaker materials; can pre-break them to get fragment behavior
Brick / concrete fragments	small blocks, plaster/cement blocks, lightweight concrete bricks, fired clay bricks scaled; or using gypsum or concrete "chunks"	density matches better; for safety scale, use smaller pieces; watch mass and safety flying – strong winds required to move them
Glass	acrylic or polycarbonate sheets cut into small panes or fragments; safety glass (if precautions taken)	lighter-weight safer substitutes; shards if needed must obey safety; transparent to simulate real visual effects sometimes helpful
Rails / rods / poles / signposts	small diameter steel rods or bars, wooden dowels, PVC pipes (scaled)	linear shapes, heavier; simulate bending, rotational dynamics, translation under wind; must be robust to avoid breakage

Table - III

Fundamental Scaling considerations:

Quantity	Scaling rule (relative to full scale)	Implication
Length	1/100	Each object is 100× smaller.
Area	$(1/100)^2 = 1/10{,}000$	Cross-section becomes 10,000× smaller.
Volume / Mass	$(1/100)^3 = 1/1{,}000{,}000$	A real object's full mass must be reduced roughly 1,000,000× for dynamic similarity.
Velocity scaling (Froude scaling)	(V_m = V_f / \sqrt{100} = V_f / 10)	Model winds must be ~10× slower for dynamic (gravity-based) similarity.

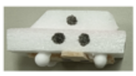
Based on this the debris are modelled and the few cases are taken into consideration for estimating the velocity of the tornado Fig.1 and Fig.2.

1	WINDOW1	W1
2	WINDOW2	W2
3	DOOR	W3
4	BROKEN ROOF	W4
5	ROOF1	W5
6	ROOF2	W6

	Weight in milli gm	Volume in mm3	Density in kg/m3
W1	6	625	9.6
W2	8	625	12.8
W3	14	1250	11.2
W4	26	2500	10.4
W5	46	4000	11.5
W6	55	5000	11
		Average	**11.08**

Fig 1.

Weight of real car (approx.) : Mustang: 1950 kg.
Jeep : 2146 kg.
SUV : 1500 kg.
Volume of real car (approx.) : Mustang: 9.699 m^3.
Jeep : 8.39 m^3.
SUV : approx. $9m^3$.



- ➢Density of Vehicle (approx.) = $200 kg/m^3$ to $250 kg/m^3$
- ➢Tornado scale is 1:100
- ➢Model material is Balsa Wood or Foam
- ➢Density of Balsa Wood or Foam
- ➢Balsa Wood : $0.11 g/cm^3$ – $0.16 g/cm^3$ = $110 kg/m^3$ to $160 kg/m^3$

Fig.2.

2. Design and develop a user friendly, platform independent, Graphical User Interphase (GUI) to estimate the speed of tornado

The training data set can include tornado simulator-based videos recorded under different conditions such as:

1. Different size and shape of debris
2. Different Boundary conditions
3. Stationary Tornado
4. Translational Tornado

The methodology used for identifying the flying debris from the captured high definition video is shown in the flowchart given in Fig.3. The mathematical explanation is also given along with. The detailed output are shown in the result section.

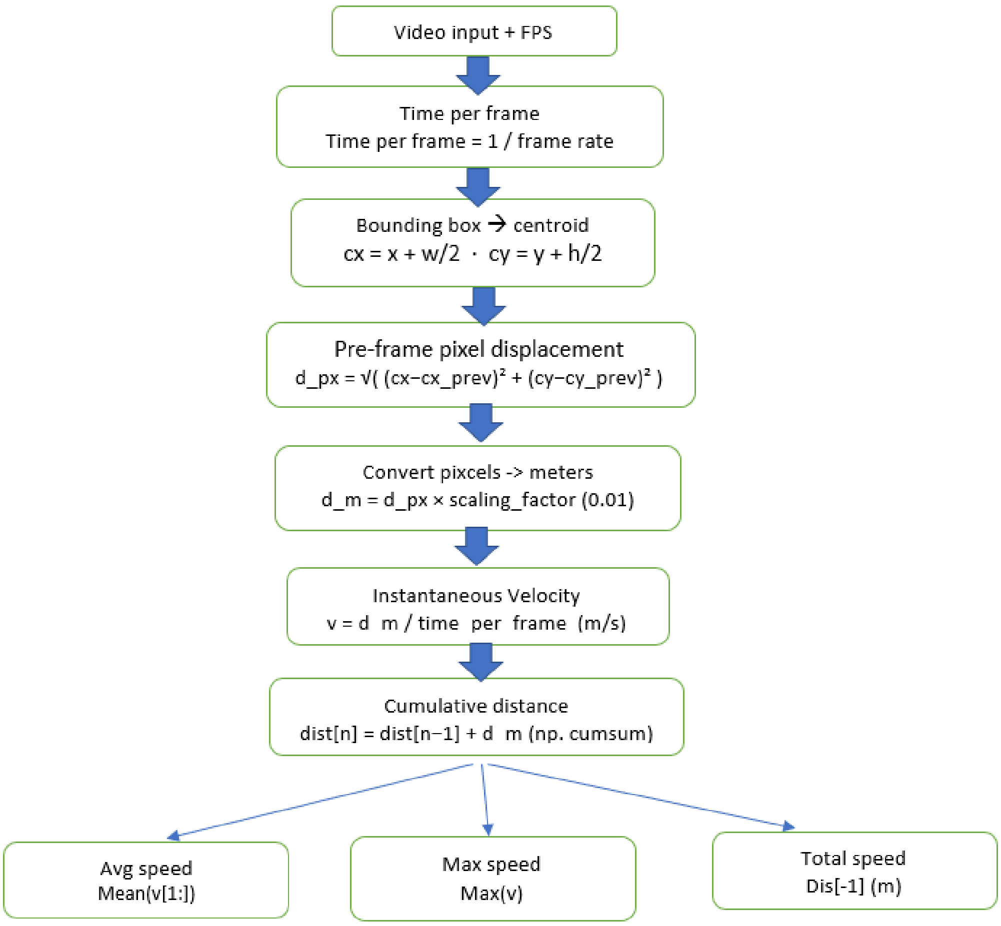


Fig.3.

Facility usage at TPU: Making use of the above Tornado-simulator facilitates along with the high definition video camera helped us in building huge databases for implementing the AI/ML model which in turn gives us more accurate estimation of debris impact force. For the current research we have collected the two main cases of videos. The usage of high-speed stereo cameras for capturing the video aided in accurate estimation of the velocity of the debris. More the cases taken more accurate and faster will be the results.

4. Research Result

The usage of Python program has improved the computational time compared to any other software used (with reference to the previous research work performed) and also provide a platform independent programing environment. Finally, a Graphical user Interphase (GUI) is designed using Python coding, making the process of identification and estimation of speed of the debris much quicker and safer. The automated and user-friendly process reduced the risks involved in the conventional methods.

The designed GUI is shown in Fig.4.

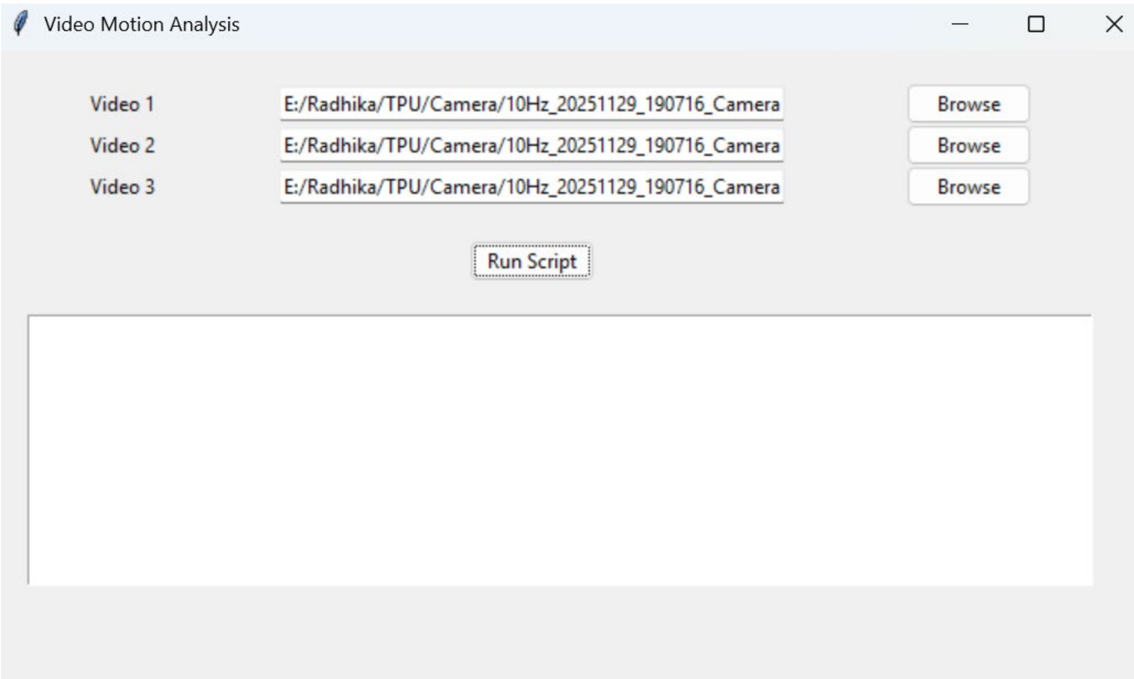


Fig. 4.

Once the video in three are added to the GUI, the three different videos taken at the same time in three different angles will be shown as given in Fig.5. Once the debris (parked vehicle in the current case) has been identified, it will trace the path in two dimensional directions, which is also shown in the GUI in Fig.5.

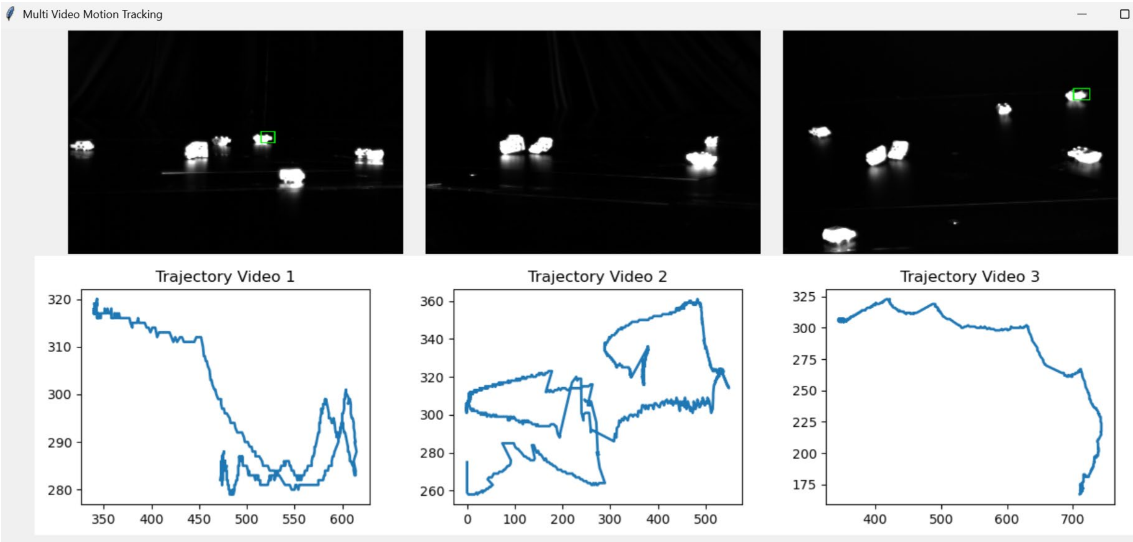


Fig.5.

A modified version of the GUI with automatic velocity estimation is also designed and developed and is shown in Fig.6.

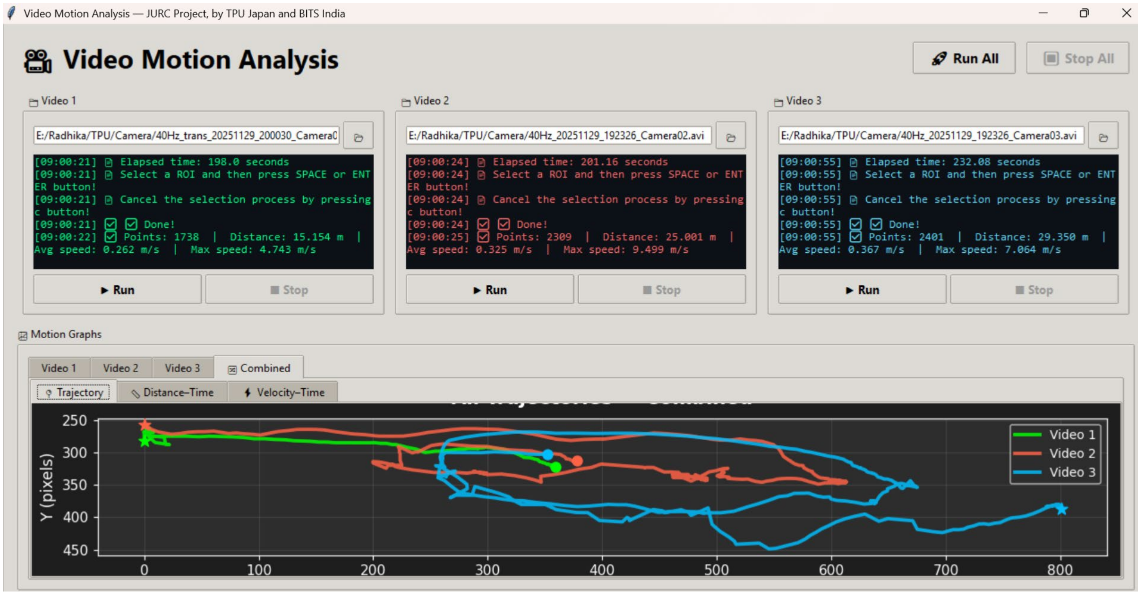


Fig.6.

Frequency in Hz	Expected Speed in m/s	Measured Speed in m/s
50	7.5	8.65
40	6	7.1
30	4.5	6.19
20	3	6.07
17	2.55	5.27
15	2.25	0.63
10	1.5	0.67

Table-IV

Inferences

The speed measurement at different cases has been considered and the results are given with a validation with the actual speed in Table-IV. It is observed that the automatically measured speed using the GUI showed almost close value with the actual speed of the tornado., even if there were only limited cases were used, More the cases taken into consideration better will be the accuracy.

Future Scope

- Translation Motion Tornadoes
- Different Type of debris: Vegetation, Poles (different Shapes), Sheets, Cladding structures, Solar Panels
- Different Boundary Conditions

5. Published Paper etc.

[Presentations at academic societies]

1. In ICST 2025, Sudha Radhika, Prof. Masahiro Matsui, Prof. Sabareesh Geetha Rajasekharan, Mr. Anbumani. P, Prof. Yukio Tamura "AI/ML based Video Sensing Technologies for Tornado Speed Determination and Prediction from the Windborne Debris Captured in the Tornado", at Utsunomiya, Japan

5. Research Group

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6. **Abstract (half page)**

Research Theme: Design and Development of a Platform Independent GUI for Predicting the Wind Speed of Tornado-borne debris from the Onsite Captured Video

Summary:
Determining the impact of tornado-borne debris in an active tornado using conventional methods are very challenging and sometimes very risky during on-field conditions. So, to determine it automatically at the same time in a user-friendly manner, in the current research an ML integrated video processing technique is used to identify the debris that are captured within the tornado, next to estimate the velocity of the flying debris and thereby determining the speed of the tornado. A detailed study of the different types of tornado borne debris are done both in the Japanese and the Indian scenario and the suitable model of those debris are modelled for the tornado simulator environment that can exactly mimic the actual tornado debris. The training data set can include tornado simulator-based videos recorded under different conditions such as:1) Different size and shape of debris, 2) Different Boundary conditions, 3) Stationary Tornado, 4) Translational Tornado. The speed measurement at different cases has been considered and the results are given with a validation with the actual speed in Table-IV. It is observed that the automatically measured speed using the GUI showed almost close value with the actual speed of the tornado., even if there were only limited cases were used, More the cases taken into consideration better will be the accuracy.

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Important・Figures

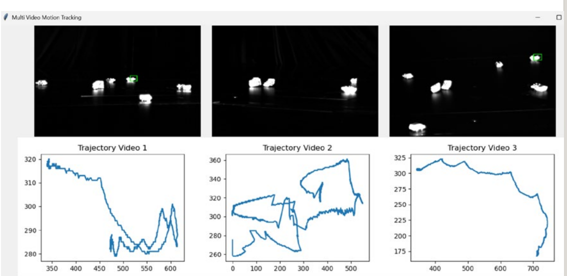
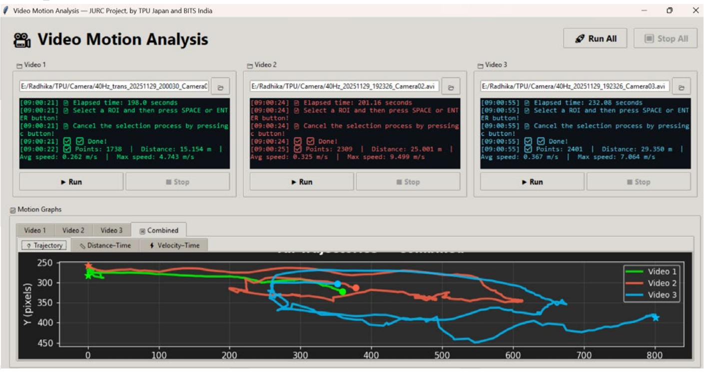


Fig. 5



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