Drone Cinematography summary

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Drone Cinematography

- **Unmanned Aerial Vehicles (UAVs, or “drones”) have made their way in the media and entertainment industry**:
  - Movies
  - TV: sports, newsgathering, documentaries
  - Advertising.
- **Drones allow filmmakers to capture shots that were impossible, extremely difficult or costly to capture so far**:
  - Wide shots of remote or hard-to-reach landscapes
  - Follow-along close up views of sports or other action
  - Impressive fly-throughs, fly-bys and fly-overs.
- **Essentially drones provide a level of camera motion freedom that was so far available only in animation.**

Drone Cinematography

Drone Cinematography

- Value of current business services and labor that will be replaced in the near future by drone-based solutions, in the media & entertainment sector: $8.8 Billion (Source: PricewaterhouseCoopers).

Drone Cinematography in Sports Coverage

Major channels (Fox Sports, BBC, NBC) use drones to cover outdoor sports events: Golf, auto-racing, skiing, rowing (2016 Olympics).

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Drone Cinematography in News

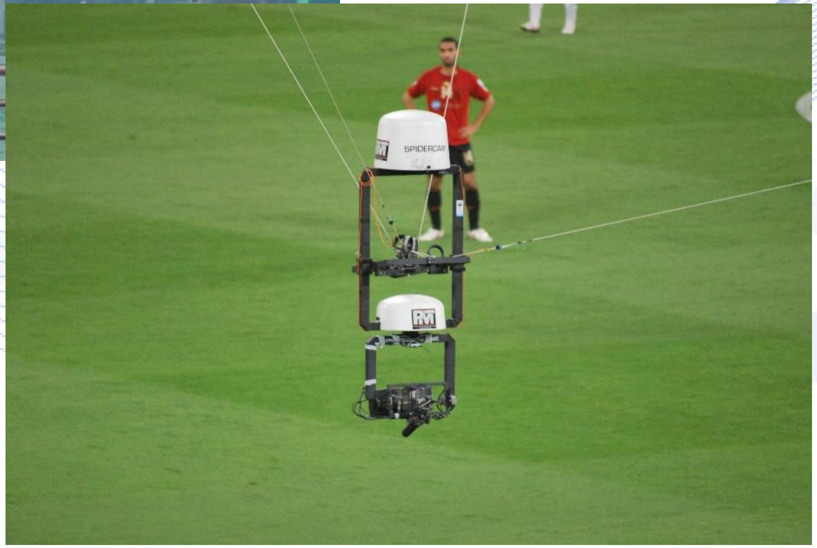
- TV channels are using **drones** to cover **large-scale events** (e.g., demonstrations), or capture videos from **war** zones, **natural disasters** etc.

War-torn Aleppo, Syria (AMC).

Moscow protest.

Drone Cinematography

- Drones can **replace** spidercams, camera dollies, cranes and helicopters.

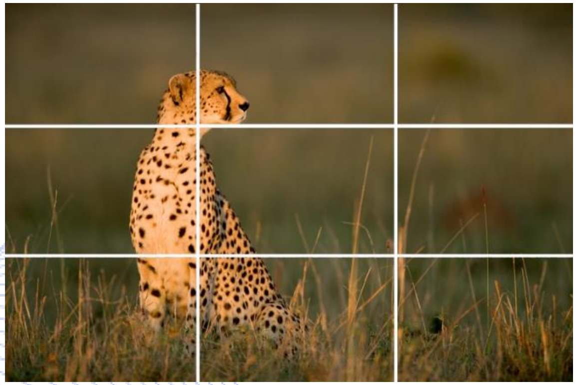


Drone Cinematography

- The media and entertainment industry has already **praised** the **contribution of UAVs in modern cinematography**:
  - Drone companies (DJI, PictorVision, Aerial MOB, Flying Cam, etc) won a **2017 Emmy Award for Technology and Engineering** for Low Latency Remote Controlled Airborne Video Platforms for TV.
  - G. Hooper, P. George (HoverCam) were awarded a **2013 Academy of Motion Picture Arts and Sciences (AMPAS) Technical Achievement Award** for Helicam miniature helicopter camera system.
  - E. Prévinaire, J. Sperling, E. Brandt and T. Postiau were awarded a **2013 AMPAS Scientific and Engineering Award** for the Flying-Cam SARAH 3.0 system.

Drone Cinematography

- Composition principles:
  - Central Composition.
  - Rule of Thirds.
- Illumination rules.
- Depth-of-Field / Focus settings.
- Need to define a standardized ***drone shot type taxonomy***.



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Drone Cinematography

- Actual drone footage and related articles / guidelines were used to this end [1] (2019):
  - A total of **8 framing (static) shot types** and **26 drone / camera motion types** suitable for drone media production have been identified.
  - Camera motion types were clustered into groups according to their characteristics.
  - Visually pleasing combinations of framing shot types and camera motion types were identified.

Mathematical Drone Shot Type Modeling

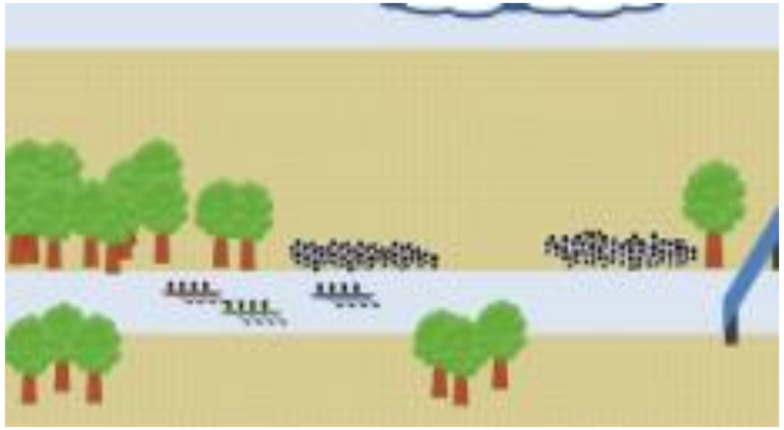
- The identified drone / camera motion types have been modelled mathematically, using two coordinate systems:
  - A global World Coordinate System (WCS)
  - A Target Coordinate System (TCS), attached to the target.
- This analysis can prove useful for several tasks.
  - Example: analytically determine maximum allowable camera focal length when the drone orbits a moving target, so that 2D visual tracking does not fail.
- The mathematical descriptions have been used to generate realistic simulation of the drone / camera motion types in Unreal Engine 4 and AirSim.

Framing Shot Types

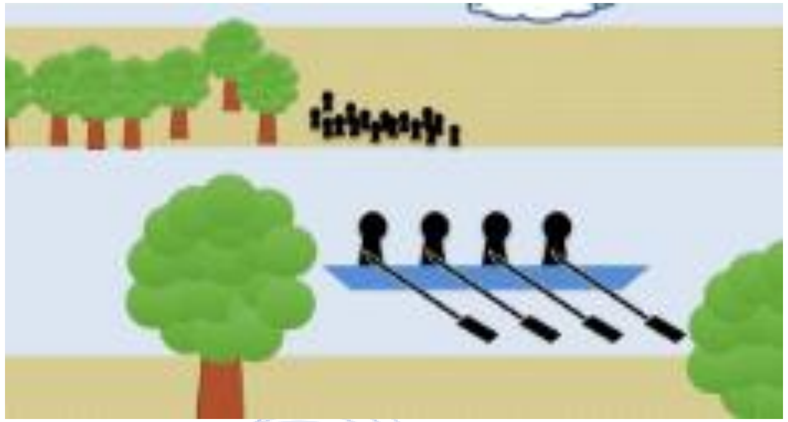
- **Framing Shot Types** are more or less those of traditional cinematography.
- Most are defined based on the **percentage** of the **video frame** width / height **covered by the single target** / subject.

FRAMING SHOT TYPE	Percentage of frame width/height covered by target
Extreme Long Shot (ELS)	<5%
Very Long Shot (VLS)	5-20%
Long Shot (LS)	20-40%
Medium Shot (MS)	40-60%
Medium Close Up (MCU)	60-75%
Close Up (CU)	>75%

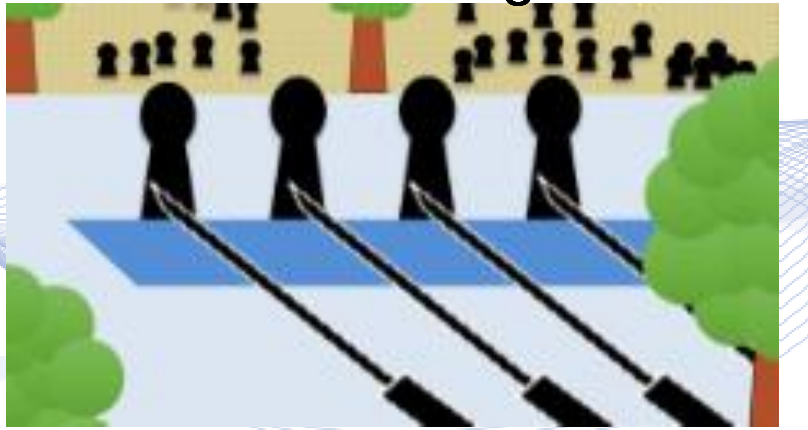
Framing Shot Types



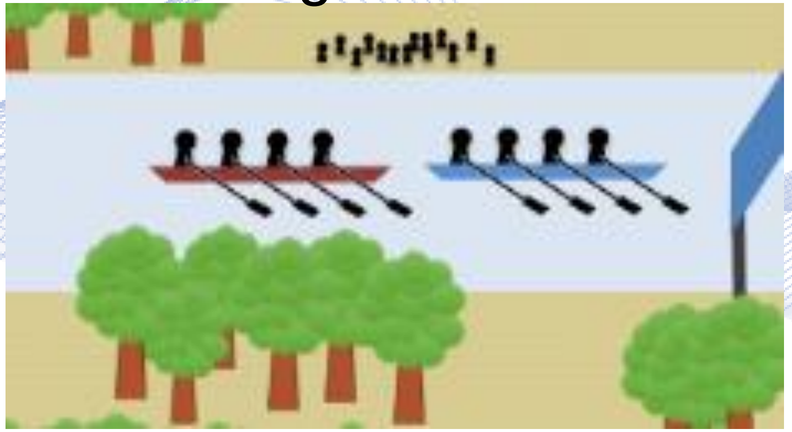
Extreme Long Shot.



Long Shot.



Medium Close Up.

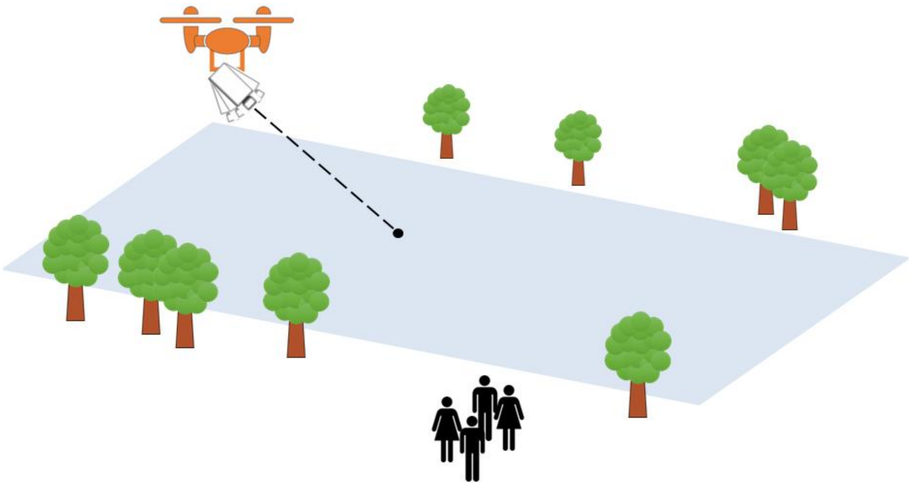


Two Shot.

Drone / Camera Motion Types

- Drone / camera motion types can be considered as either "**scene-oriented**" or "**target-oriented**".
- Four groups of drone / camera motion types were defined.
  - ***Static shots*** **(6). No drone motion, target may or may not be present:**
    - Static Shot (SS)
    - Static Shot of Still Target (SSST)
    - Static Shot of Moving Target (SSMT)
    - Static Aerial Pan (SAP)
    - Static Aerial Tilt (SAT).

Drone / Camera Motion Types

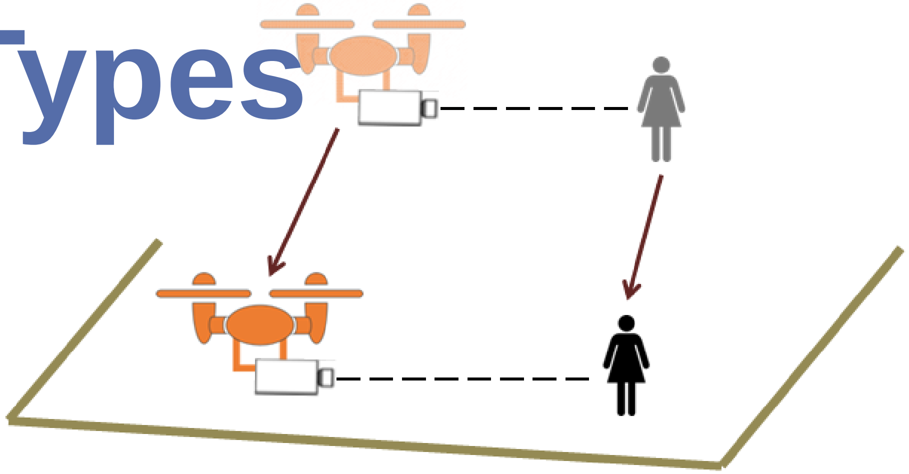


Static Aerial Tilt (***SAT***):

- Drone hovers.
- Camera gimbal rotates slowly around the pitch axis in order to capture the scene context.

Source: Youtube: "5 Drone Moves Every Flier Should Know", https://www.youtube.com/watch?v=1hz-lkx4o6c

Drone / Camera Motion Types

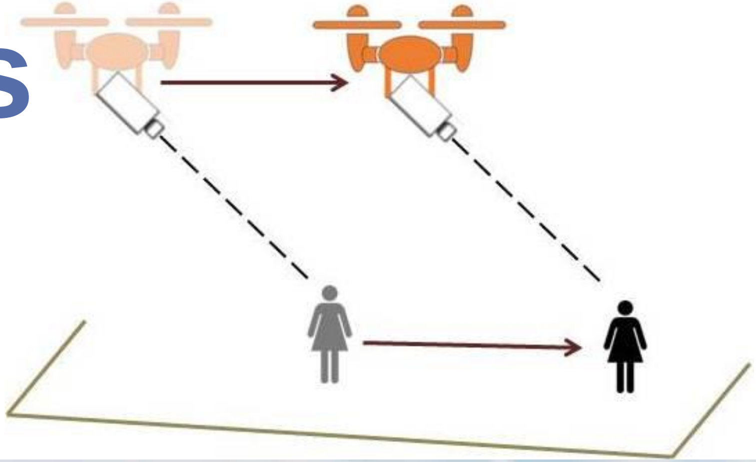


Lateral Tracking Shot (***LTS***):

- Camera stays focused on the moving target.
- Drone flies sideways / in parallel to the target, matching its speed.

Source: Youtube: "5 Drone Moves Every Flier Should Know", https://www.youtube.com/watch?v=1hz-lkx4o6c

Drone / Camera Motion Types



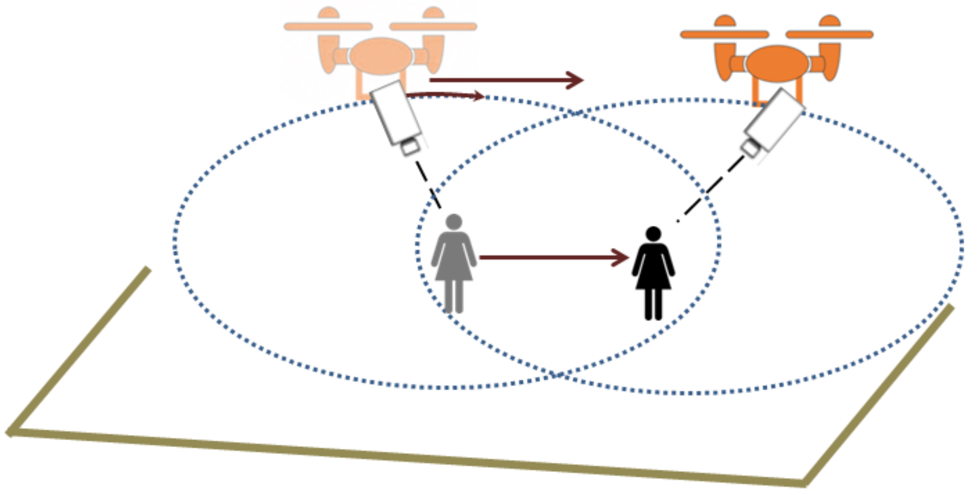
Chase/Follow (***CHASE***):

- Camera stays focused on the moving target.
- Drone follows / leads the target

from behind / from the front, matching its speed.

Source: Youtube: "Drone footage of Cycle-Racing", https://www.youtube.com/watch?v=vQ94R4LC9ig

Drone / Camera Motion Types



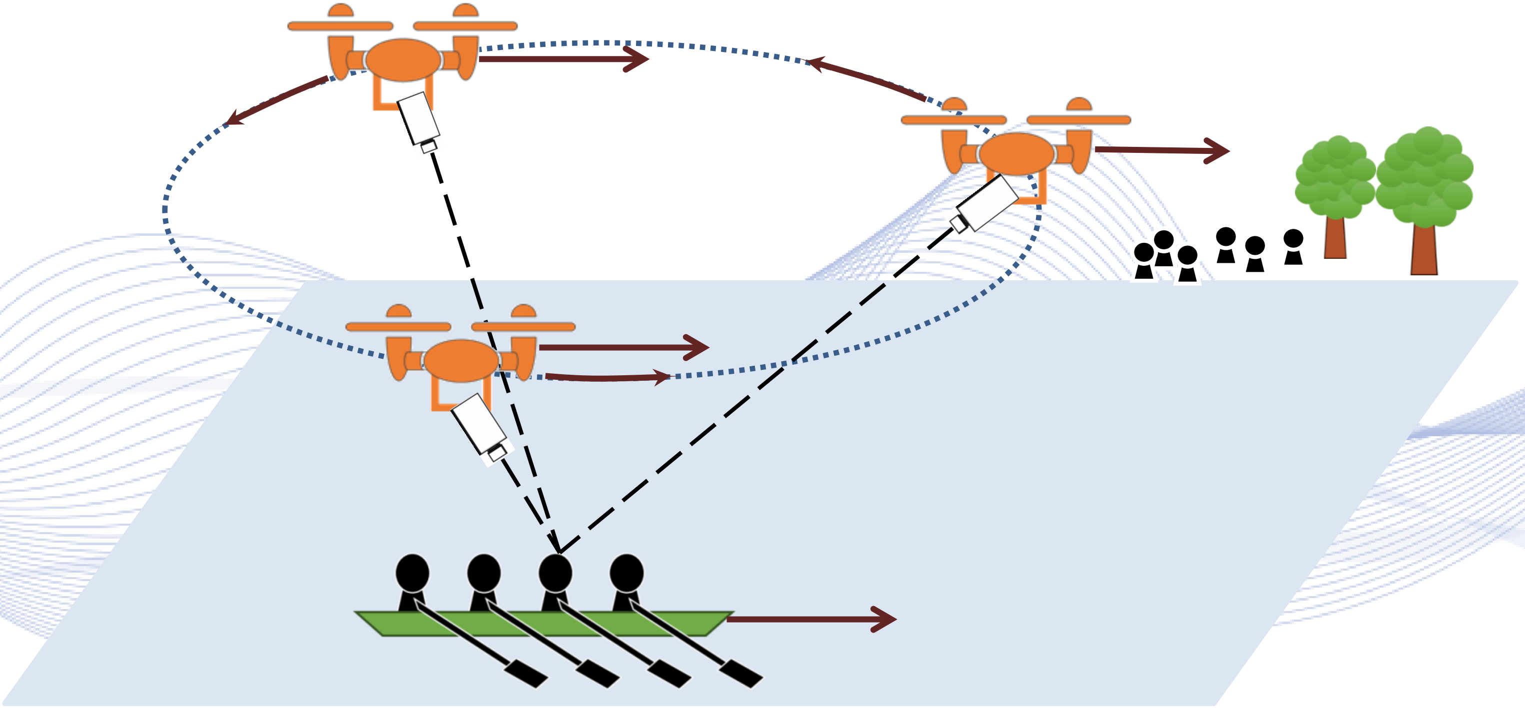
Orbit (***ORBIT***):

- Camera gimbal is slowly rotating, so as to keep the still or moving target properly framed.
- Drone circles around the target while following its trajectory (if any).

Source: Youtube: "Drone Chasing Horses", https://www.youtube.com/watch?v=O0uw8py9qmw

Multiple Drone Motion Types

- Motion types involving 2 or more drones in orchestrated motion can be also considered.



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Drone Motion Type Modeling

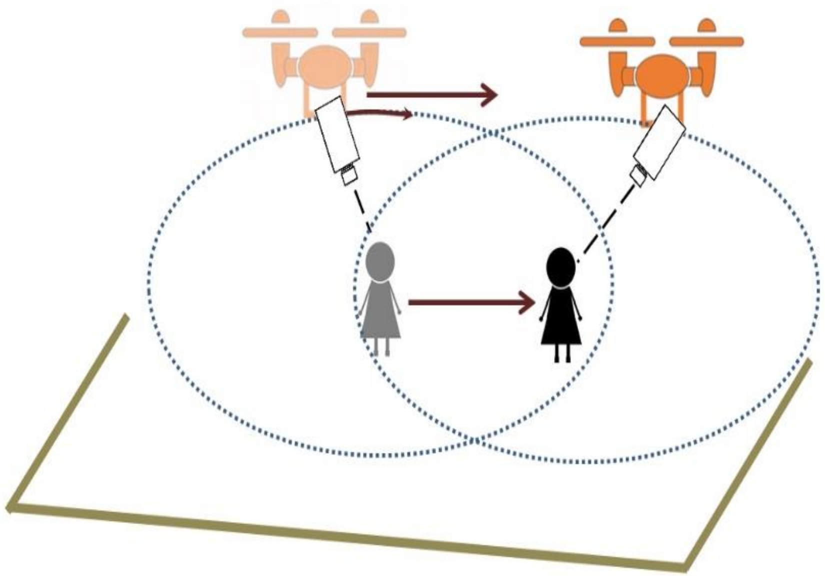
Example: ORBIT.

- The camera always looks at the target while the drone moves on a circle in the TCS:

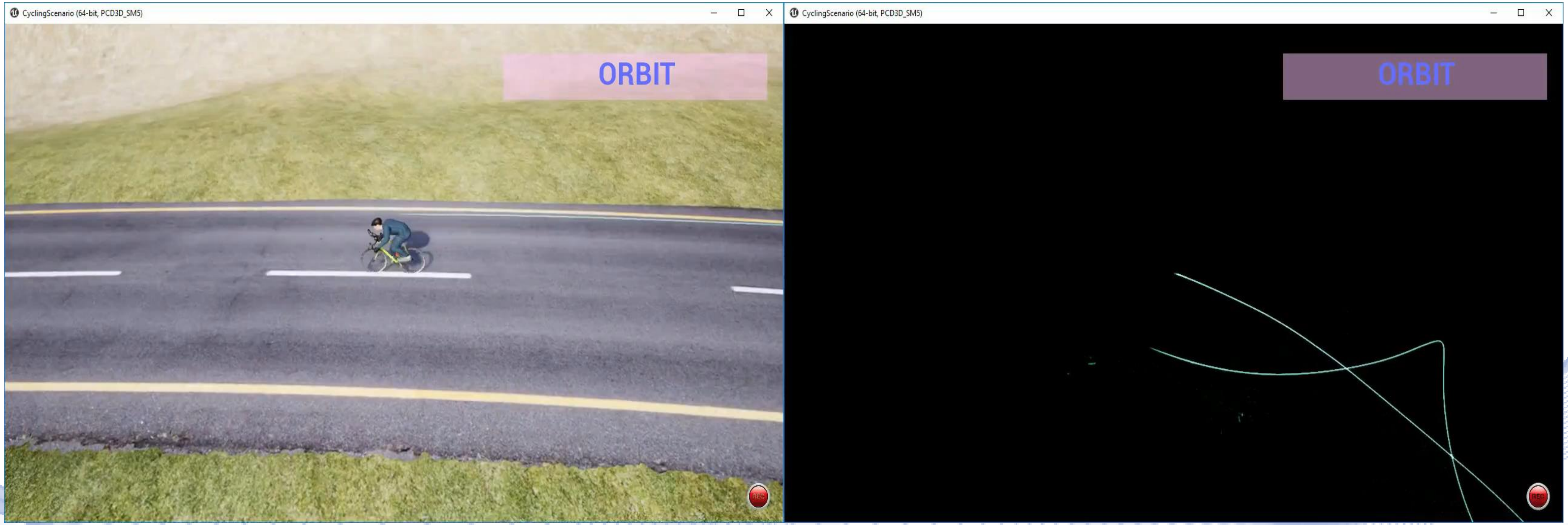
$$\mathbf{X}_t = \left[\lambda \cos\left(t\frac{\omega}{T} + \theta_0\right), \lambda \sin\left(t\frac{\omega}{T} + \theta_0\right), x_{t3}\right]^T$$

$$\mathbf{L}_t = \mathbf{P}_t.$$

- $\mathbf{P}_t = [p_{t1}, p_{t2}, p_{t3}]^T$: Target position in WCS.
- $\mathbf{X}_t = [x_{t1}, x_{t2}, x_{t3}]^T$: Drone position in TCS.
- $\mathbf{L}_t$: Camera Look-At Point in WCS.



Drone Motion Type Modeling



ORBIT.

AV Shot types

AV Shot types

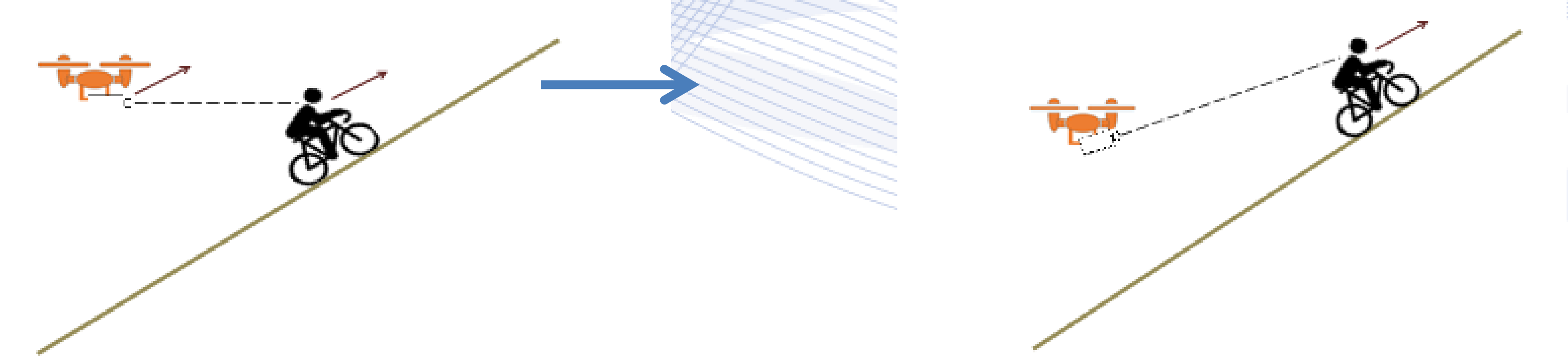
Drone Cinematography Issues

- A drone cinematographer has the following means for achieving a certain framing shot type or UAV/camera motion type or for transitioning between types:
  - **Drone location** and **orientation**.
  - **Camera orientation** through gimbal control (usually 3 degrees of freedom: roll, pitch, yaw).
  - **Camera focal length.**

Drone Cinematography Issues

Example: **CHASE** (follow) from behind a target moving uphill.

- Due to **energy consumption** considerations, the same shot can be approximately materialized by:
  - Having the **drone** stop following the target and start **hovering.**
  - Continuously **changing** the camera **zoom** and camera **gimbal orientation** so as to always have the target in the frame center and with the same size.



Drone Cinematography Issues

Camera Motion	Framing	Energy	Technology
SS	ELS, VLS	medium	minimum
SSST	All	medium	vision
SAP	ELS, VLS	medium	minimum
SAT	ELS, VLS	medium	minimum
SSMT	All	medium	vision
MAP	ELS, VLS	any *	vision+3D
MAT	ELS, VLS	any *	vision+3D
PS	ELS, VLS	$\downarrow$ or $\uparrow$	minimum
BIRD	None	$\downarrow$ or $\uparrow$	minimum
MOVBIRD	ELS, VLS	any *	vision+3D
SURVEY	ELS, VLS	any *	vision+3D
FLYTHROUGH	ELS, VLS	any *	vision+3D

Drone Cinematography Issues

Camera Motion	Framing	Energy	Technology
MAPMT	LS, MS, MCU, OTS, 2S/3S	any *	vision+3D
MATMT	LS, MS, OTS, 2S/3S	any *	vision+3D
LTS	VLS, LS, MS, MCU, OTS, 2S/3S	any **	vision
VTS	VLS, LS, MS, MCU, 2S/3S	any **	vision
ORBIT	LS, MS, MCU, CU, 2S/3S	any **	vision
FLYOVER	LS, MS, MCU, CU, 2S/3S	any **	vision+3D
FLYBY	LS, MS, MCU, CU, 2S/3S	any **	vision+3D
DESCENT	LS, MS, MCU, CU, 2S/3S	low	vision+3D
DESCENTOVER	LS, MS, MCU, CU, 2S/3S	low	vision+3D
ASCENT	LS, MS, MCU, 2S/3S	high	vision+3D
CHASE	VLS, LS, MS, OTS, 2S/3S	any **	vision
CONLTS	LS, MS, MCU, OTS, 2S/3S	any **	vision
PST	LS, MS, 2S/3S	$\downarrow$ or $\uparrow$	vision
RS	LS, MS, 2S/3S	any *	vision+3D

Drone Cinematography Issues

Drone mission feasibility [3]:

- Drone missions with arbitrary mission parameters are not always feasible.
- Example:
  - Maximum allowable camera focal length f_{max} can be analytically determined, when the drone orbits a moving target, so that 2D visual tracking does not fail (e.g., target ROI does not go out of frame boundaries across consecutive video frames).
  - f_{max} is a function of the current drone position relatively to the target and the current deviation of the target velocity from the expected one.

Drone Motion Type Modeling

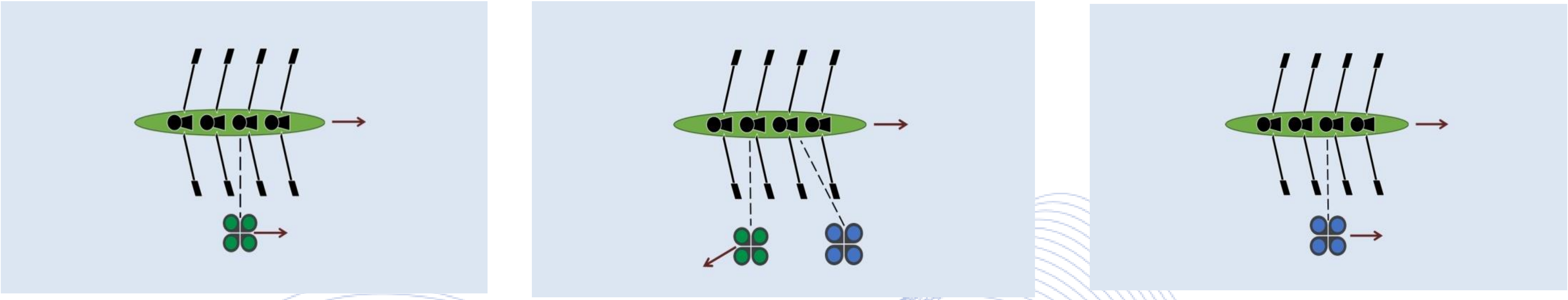
Maximal focal length f_{max}, so that 2D visual tracking does not fail:

$$f_{max} = \frac{2R_{max}s_x s_y|-Tw + q_{t1}\lambda\cos(\phi) + q_{t2}\lambda\sin(\phi)|}{\lambda\sqrt{\frac{2\left(s_x^2 z^2 - s_y^2 w\right)E + 2(q_{t1}^2 + q_t^2)\left(s_x^2 z^2 + s_y^2 w\right)}{w}}},$$

$$\phi = \frac{\omega}{T} + \theta_0, \quad w = x_{t3}^2 + \lambda^2,$$

$$E = 2q_{t1}q_{t2}\sin(2\phi) + (q_{t1} - q_{t2})(q_{t1} + q_{t2})\cos(2\phi).$$

Current State of the Art

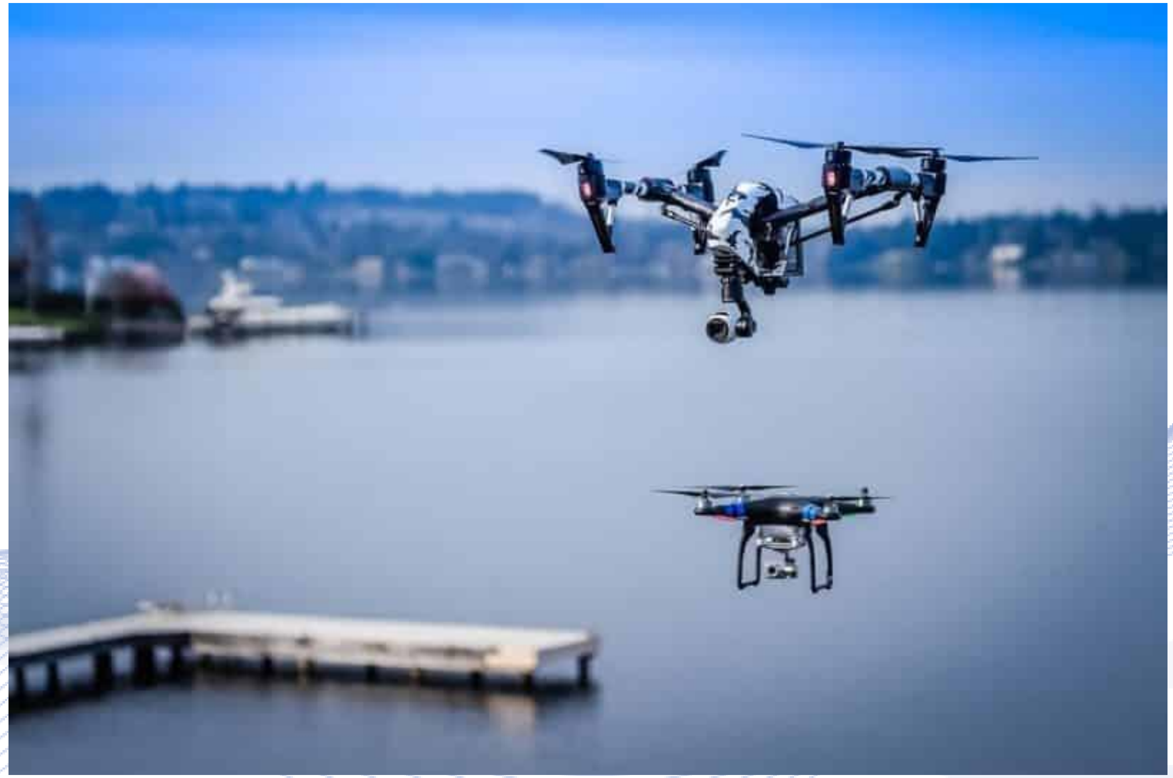


- Example: a drone following a target is soon expected to enter a low-battery mode and land.
- Another drone can take off and continue the task.

Current State of the Art

Multiple drone shooting **challenges**:

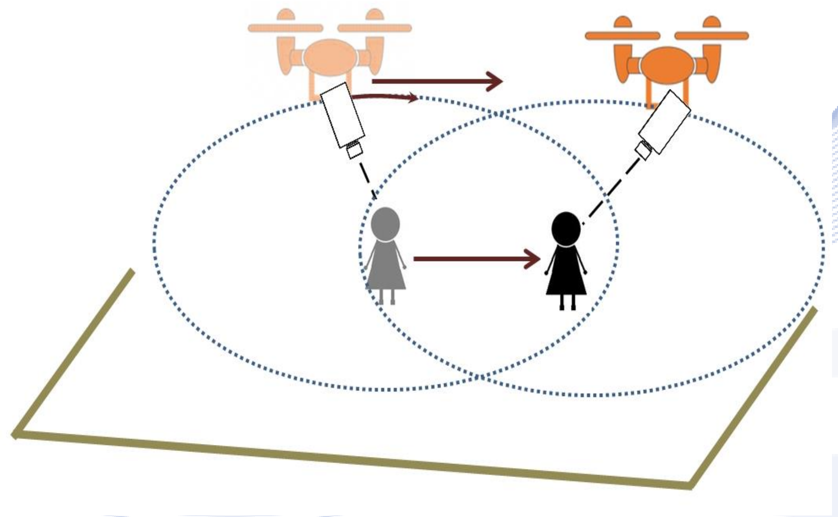
- Drone to drone **collision avoidance.**
- Avoid having one drone entering the **field of view** of another drone.
- **Coordination.**
- **Crew size** may increase.



Current State of the Art

Manual control limitations:

- **Difficult** to achieve **complex drone motions** especially when combined with **coordinated camera** gimbal **movement**.
  - Orbit around a static target, camera alw
    pointing to the target.
- Additional difficulties when the **target** is **moving** :
  - Orbit around a moving target.
  - Follow a fast/unpredictably moving targ
    physically or with the camera.

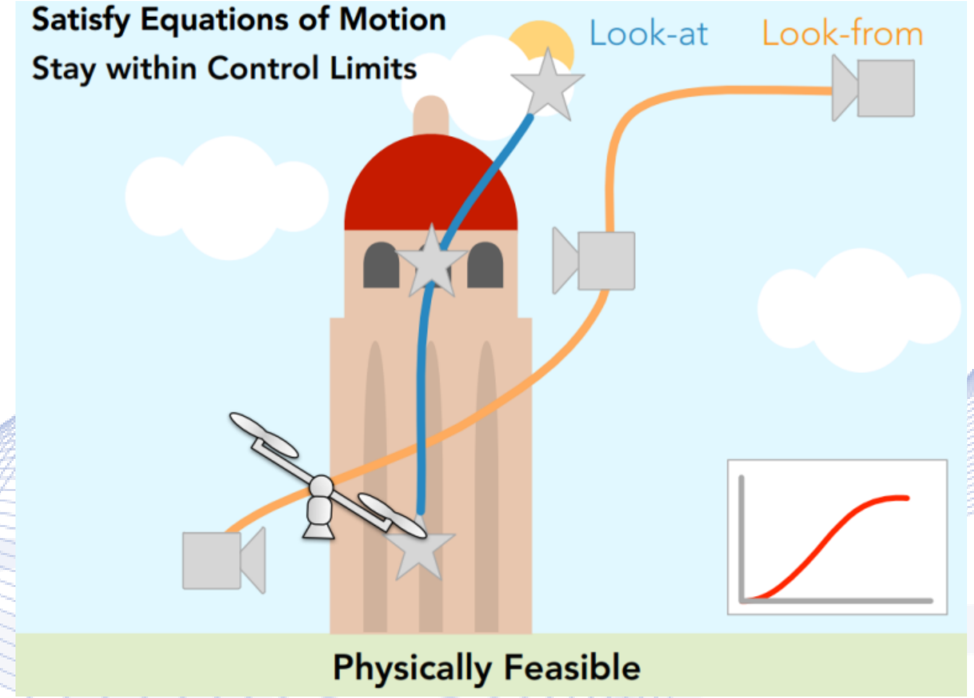


Research and Products

In [11] (2015) a tool is presented to support drone video capture of static scenes.

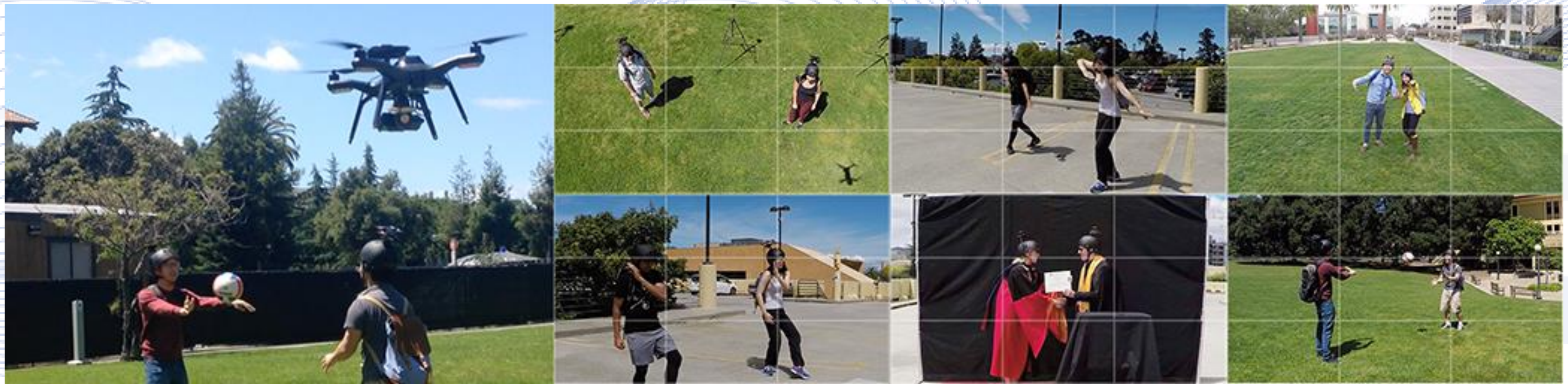
It enables users to:

- Specify shots visually, using **keyframes** for the drone camera location and the camera look-at point.
- The system then generates drone trajectories that satisfy motion equations.



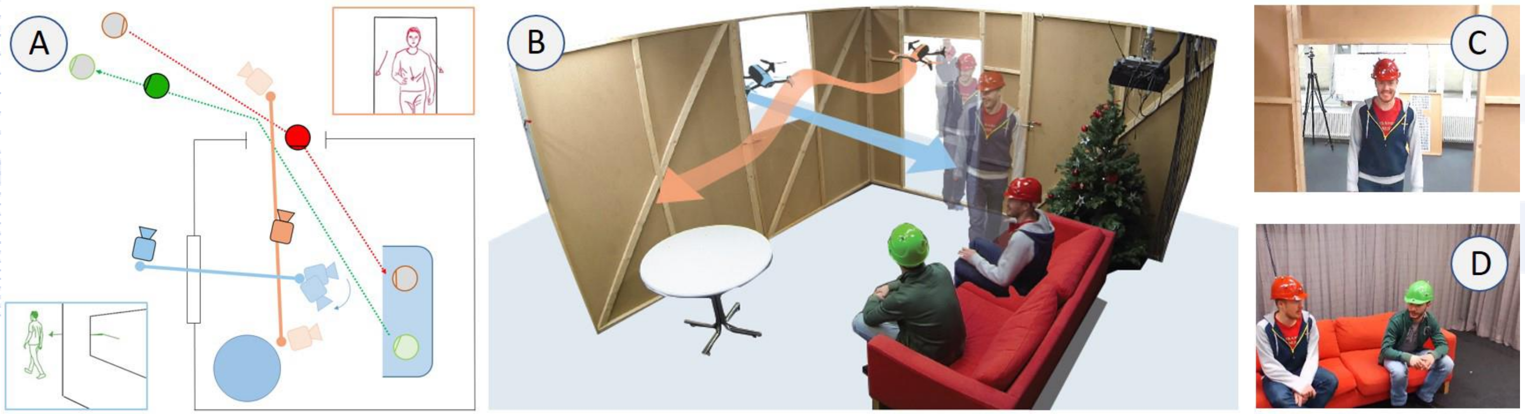
Research and Products

- In [10] (2016) a system is presented to capture drone video footage of human subjects performing rather limited movements:
  - Subjects are **tracked** using **RTK GPS** and **IMU** sensors.
  - The system **automatically captures static (framing) shots** that respect visual composition principles (rule of 3rds).



Research and Products

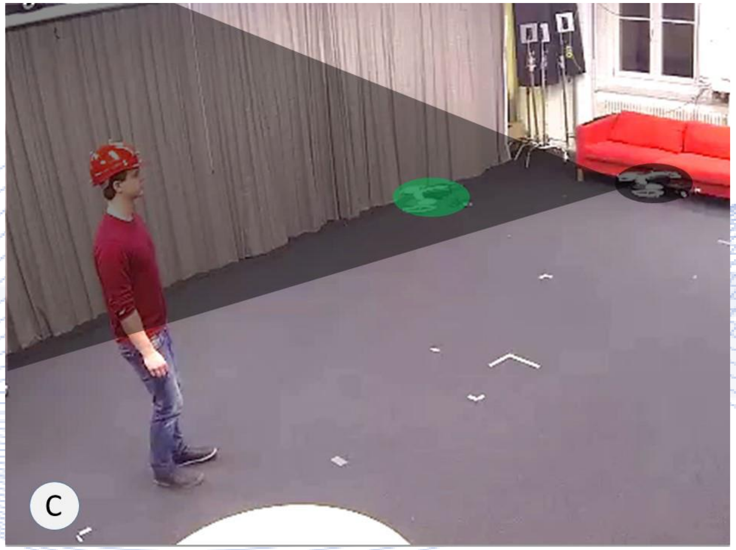
- In [7] [8] (2017) a method for aerial videography planning in cluttered and dynamic environments is proposed.
- The method takes as input user specified, **high-level plans** (paths) and **framing objectives** (position and size of filmed person in the frame).
- The algorithm **adapts** the high-level plans in **real-time** to produce feasible drones trajectories, while also taking the **motion of the subjects** into account, e.g., to avoid collisions.



Research and Products

The algorithm can also handle **multiple drones:**

- Drone to drone **collision avoidance**.
- Drone path modification to prevent a drone from entering the field of view of other drones.



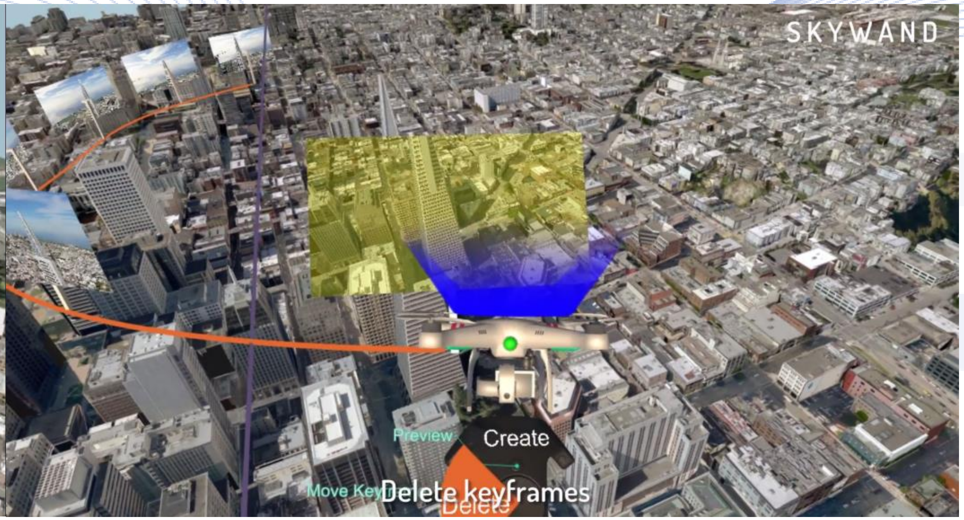
Research and Products

Skywand:

- A **VR system** allowing the user to explore a 3D model of the scene and place desired, example key-frames in the environment.
- The system computes **drone trajectory** and **camera motion** sequence, so as to capture **smooth footage** and key-frames.
- Previsualization of the trajectory and the video is available.

Freeskies CoPilot:

- Similar functionality with a 3D map instead of VR.



Tools and Research Needed

- R&D in **computer vision** and **machine learning.**
- Intuitive and informative **graphical user interfaces for planning** the drone and camera / gimbal movements.
- Tools (simulators) for the **pre-visualization** of the drones trajectories and the videos acquired by the cameras.

Example: drone shooting mission description

- Tree-like structure of events
- Missions assigned to leaf events
- Concurrent SA Sequences
- Sequence has ordered SA
- Several SR for multi-view shots

```
<event> Main event: e.g., race to film
    <event> Leaf event 1: e.g., race start
        <mission>
            <shootingActionSequence>
                <shootingAction>
                    <shootingRole>
    <event> Leaf event 2: e.g., race finish line
        <mission>
            <shootingActionSequence>
                <shootingAction>
                    <shootingRole>
```

[AS2020]

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Example: drone shooting mission description

XML Shooting mission
- Defined by the Dashboard

List of shooting actions
- With triggering events

High level Tasks
- With start location, start time and duration

Leaf event: *START_RACE*

Mission: *M1*

SA Sequence: SA1 (lateral) + SA2 (still)

SA Sequence: SA3 (orbit with 2 drones)

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```
SA1:
    start_event: START_RACE
    mission_ID: M1
    action_ID: A1
    precedence: -
    shoot_type: SHOOT_TYPE_LATERAL
    planned_start_time: 0
    duration: 10
    length: 0
    shooting_roles:
        SR1:
            framing_type: FRAMING_TYPE_MS
            shooting_parameters: {"y":-7,"z":8}
```

```
SA2:
    mission_ID: M1
    action_ID: A2
    precedence: [A1]
    shoot_type: SHOOT_TYPE_STILL
    planned_start_time: 10
    duration: 10
    length: 0
    shooting_roles:
        SR1:
            framing_type: FRAMING_TYPE_CU
            shooting_parameters: {"x":90,"y":-7,"z":15}
```

```
SA3:
    mission_ID: M1
    action_ID: A3
    precedence: -
    shoot_type: SHOOT_TYPE_ORBIT
    planned_start_time: 0
    duration: 20
    length: 0
    shooting_roles:
        SR1:
            framing_type: FRAMING_TYPE_MS
            shooting_parameters: {"r":10,"initial_azimuth":0,"z":10}
        SR2:
            framing_type: FRAMING_TYPE_LS
            shooting_parameters: {"r":10,"initial_azimuth":180,"z":10}
```

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[1] I. Mademlis, N. Nikolaidis, A. Tefas, I. Pitas, T. Wagner and A. Messina, "*Autonomous drone Cinematography: A Tutorial and a Formalized Shot-Type Taxonomy*", *ACM Computing Surveys*, vol. 52, issue 5, pp. 105:1-105:33, 2019.

[2] I. Mademlis, V. Mygdalis, N.Nikolaidis, M. Montagnuolo, F. Negro, A. Messina and I.Pitas, "*High-Level Multiple-UAV Cinematography Tools for Covering Outdoor Events*", IEEE Transactions on Broadcasting, vol. 65, no. 3, pp. 627-635, 2019.

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[11] N. Joubert, M. Roberts, A. Truong, F. Berthouzoz, and P. Hanrahan, "An interactive tool for designing quadrotor camera shots", ACM Transactions on Graphics, (TOG), vol. 34, no. 6, pp. 238, 2015.

Q & A

Thank you very much for your attention!

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