A DIRECTOR'S DASHBOARD FOR MULTIPLE DRONES LIVE PRODUCTION

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ABSTRACT

The usage of drones for media productions is by now commonplace. Many live media productions can benefit from the use of multiple drones to achieve multi-view video sequences. The main issue of such a system is its operational complexity, in particular with aspects related to planning, logistics, safety measures and supervisory procedures. This work presents the multi-drone director's dashboard, a tool for media production with autonomous drone fleets. This tool allows media people to focus on the artistic part of the job, rather than on the technical part. The dashboard was integrated into a full system and tested in actual experimental media productions in the context of the European Project MULTIDRONE. This paper overviews the tool developed for the media crew, i.e. the team in charge of the whole system from a production perspective, in order to interface with the robotic system and communicate general and concise cinematographic instructions. As a result of this Human-Computer Interaction (HCI), the system computes a shooting mission plan consisting of feasible flight trajectories that comply with any relevant artistic, logistic and legal restriction. Then, the mission plan is assigned to drones in order to autonomously fly and acquire the desired footage.

INTRODUCTION

Many media productions may benefit from the use of multiple drones to achieve multi-view video sequences. The main issue of such a system is its operational complexity, in particular for aspects related to planning, logistics, safety measures and supervisory procedures. The risk is that production people lose the focus on the creative part of their work, having to pay attention to the technical part too. To tackle this aspect, the MULTIDRONE project[1] developed an innovative and intelligent platform for multiple drone media production, mainly for outdoor event coverage. An overview of the state-of-the-art in this area, along with a brief review of current commercial Unmanned Aerial Vehicle (UAV) technologies and legal restrictions on their deployment is presented by Mademlis et al. (1).

This paper describes the director's dashboard, a Human-computer Interaction tool, developed for the media crew, i.e. the team in charge of the whole system from an editorial production perspective, in order to interface with the robotic system and to communicate it

[1] https://multidrone.eu/ (Last accessed April 2020).

general and concise cinematographic instructions. The result of the interaction with the tool is the computation of a shooting mission plan consisting of feasible flight trajectories that comply with any relevant artistic, logistic and legal restriction. Then, the mission plan is assigned for execution to drones, which (autonomously and harmoniously) fly and acquire the desired footage. The dashboard has been designed to be intuitive and simple. Among its functionalities, the dashboard allows media people to plan multi-drone shooting missions by using a simple Graphical User Interface (GUI), to describe shot geometry by clicking on aerial maps, and to validate and execute plans for the missions.

DASHBOARD TERMINOLOGY AND IMPLEMENTATION

The director's dashboard is a tool specifically designed to allow the media people to easily define, from their editorial perspective, shooting missions during the pre-production phase and to interact with the autonomous drone system during the mission execution. We designed this tool in three steps. After a detailed analysis of the requirements (2), we defined the high-level interactions between the dashboard and its users, resulting in an UML diagram depicting use cases. Then, we created a new XML-based formal language to describe the entities (information elements and relationships) involved in the use cases. Finally, we developed the dashboard back-end functionalities and front-end interfaces. The following subsections describe each of these steps in more detail.

Use Case Analysis

The use case analysis step led to identify the main entities and relations involved in the shooting mission production workflow. The analysis breakdown has been comprehensively described by Negro et al (3). Here are the most important concepts.

The roles involved in the process includes both humans and machine system components, as illustrated in Figure 1. Among them, the main entities are the director, the camera operator and the Mission Controller. The director is responsible of the definition, lead, and coordination of editorial shooting missions. The camera operator is the person in charge of checking and controlling the behaviour of the camera on board of each drone, thus replacing its autonomous operation when needed. The Mission Controller is the autonomous module in charge of managing the mission production from the robotics point of view. Mission Controller internals will not be covered here, but the interested reader can refer to Montes-Romero et al (4) for a full introduction.

The top-level process is the Event Management, i.e. the process by which information about a real world event to be produced and filmed (e.g. a cycling race) is created. It

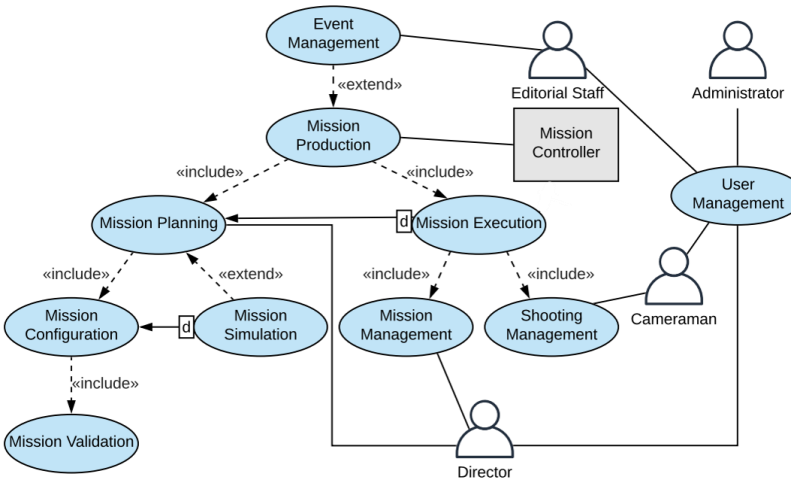

Figure 1 - Use case breakdown of the editorial shooting mission production process. Source (4)

includes the time and location of the event, as well as references to any child events, i.e. specific actions of interest within the event timeline, such as the start of the race, the climb of a mountain or the last kilometer. Events are organised hierarchically, and they are associated to shooting missions productions that will be produced when they occur.
The Mission Production process is composed of two distinct sub-processes, namely Mission Planning and Mission Execution. Mission Planning is the process in which all aspects related to a shooting mission are configured. Among them, there are shot types and shooting targets (e.g. the race leader or any point of interest within the race route). A fundamental sub-process of Mission Planning is Mission Validation, i.e., the process by which the flight plan originated by a shooting mission is checked and validated in terms of feasibility, safety and security. Mission Validation is based on both automatic and human-in-loop decision systems, as overviewed in (3) and (5). Optionally, a mission can be simulated, in order to test the behavior of drones within a 3D virtual environment.[2] Mission Execution is the process that governs the actual running of a shooting mission. Mission Execution cannot take place if Mission Planning is not complete. It is made of two sub-processes, namely Mission Management and Shooting Management. Mission Management is the process by which the director finally takes decisions about which among the several alternative missions associated with an event will be actually executed. Shooting Management is the process that allows the dashboard user to adopt some fault tolerance mechanisms in case of unexpected failure or malfunction, such as abort of the mission or manual adjustment of drone camera parameters.

Data Model for Shooting Mission Description

Our data model uses an XML representation to specify entities, relationships and attributes of events and shooting missions. In our knowledge, this is the first study to propose a general framework to specify complete multi-drone missions for autonomous cinematography. Figure 2 shows the data model structured in a relational database.
As previously described, the central point of the system is the concept of event. An event may contain an arbitrary number of shooting missions describing the aerial shots designed by the director for the event they refer to. Any mission is characterised by a specific role. This is because the director might design different missions for the same event, depending on contextual conditions. For example, they might plan two mutually exclusive missions, in case of sunny or cloudy weather, respectively.
A mission consists of one or more shooting action sequences, which can also have different roles. Thus, the director may plan different actions within the mission depending on contextual circumstances. For example, if the selected event is the crossing of the King of the Mountains line during a cycling race, they might decide to have two possible shooting action sequences, one in case of arrival in the sprint, the other in case of a solo attack. All shooting action sequences with the same role within a mission are assumed to happen concurrently as the associated event occurs.
A shooting action sequence is made up of a time-wise ordered sequence of shooting actions, which run sequentially. A shooting action represents an aerial visual shot to be filmed with one or more drones. A shooting action has a reference target that is tracked to move the

[2] A video of a drone simulation done in the MULTIDRONE project can be found at the following link: https://youtu.be/qRPXTid9dFI (last accessed April 2020).

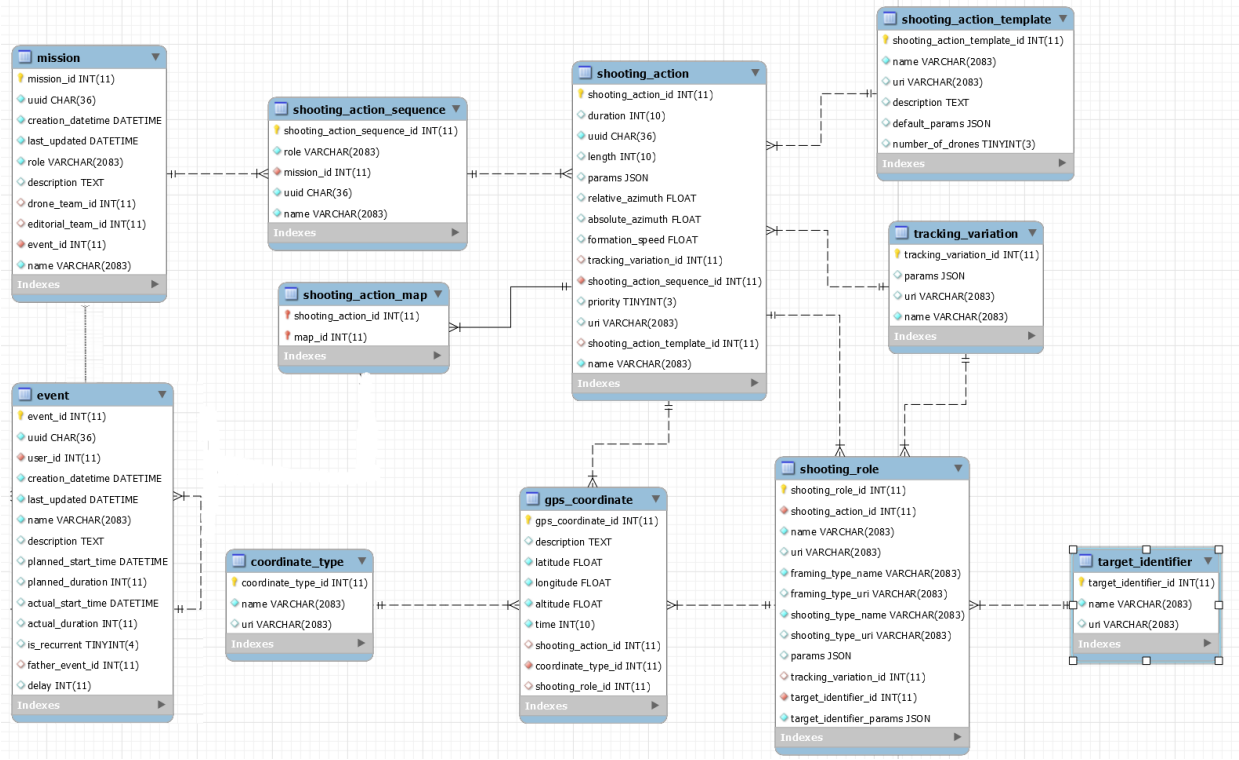

Figure 2 – ER database schema representing the shooting mission data model

drone formation alongside. Any information related to the movement of the formation, e.g. origin coordinates, trajectory and speed, is encoded within the shooting action properties.
A shooting action includes one or several shooting roles, one per drone involved. This is helpful to indicate the role of each drone in shots with multiple drones. Each shooting role has a shooting type defining the type of movement of the camera, e.g., static, lateral, orbit, etc., plus some shooting parameters, defining the geometry of the flying formation. These parameters vary depending on the specific type of shot, for instance, to indicate the lateral distance of the drone in a lateral shot or the radius and angle rate in an orbit shot.

Functionality of the Software Stack

The dashboard software architecture is a 3-tier Java EE application, as shown in Figure 3. At the bottom, there is the data access layer, which communicates with a MySQL database, translating data from/to database format to/from domain format. In the middle, there is the business logic layer, which manages user authentication/authorization, and performs actions based on user inputs and expected outputs. It provides a set of RESTful HTTP endpoints used to drive most of the functionality of the dashboard, including administration facilities, as well as CRUD (create, read, update, and delete) operations on the database data. Finally, at the top, there is the presentation layer, which handles user requests and displays information to users.
During its lifecycle, a mission can assume one of the following status:

1. *Planned*, in which the mission has not been sent to the Mission Controller yet;
2. E*nrolled*, in which the mission has been sent to the Mission Controller, but no validation request has been done yet;

3. *Pending*, in which the mission is under validation by both automatic (mission plan feasibility) or human (mission plan safety and security) supervision;
4. *Validated / Rejected*, in which mission validation succeeded / failed;
5. *Ready*, in which the director selected and notified the Mission Controller to execute one particular combination of missions – shooting action sequences among those validated;
6. *Running*, in which the mission has started and it is in progress;
7. *Aborted* / Ended, in which the mission was manually stopped before end, or concluded as planned.

Information about the status of each mission as output of the Mission Controller is always sent back to the dashboard, in order to constantly update the director. The general architecture of this information flow is shown in Figure 4.

Once a mission has been set (i.e. the mission is in the planned status), the corresponding XML description file is created and sent to the Mission Controller for data validation and flight plan creation (i.e. the mission is in the enrolled status). The dashboard and the Mission Controller communicate to each other through the ROStful framework[3] that translates ROS messages from the MULTIDRONE robotic system to RESTful web services consumed by the dashboard.

Once mission plans are computed and validated (i.e. the mission is in the validated status), the director can select any valid combination of mission and shooting action sequence roles to run (i.e. the mission status changes from validated to ready). During execution (i.e. the mission is in the running status), the mission timeline is shown, so that the director is able to monitor in real time its progress.

Dashboard GUI

The dashboard front-end is based on HTML5 and state-of-the-art UI development tools. It allows the user to easily and intuitively accomplish any task of the mission production

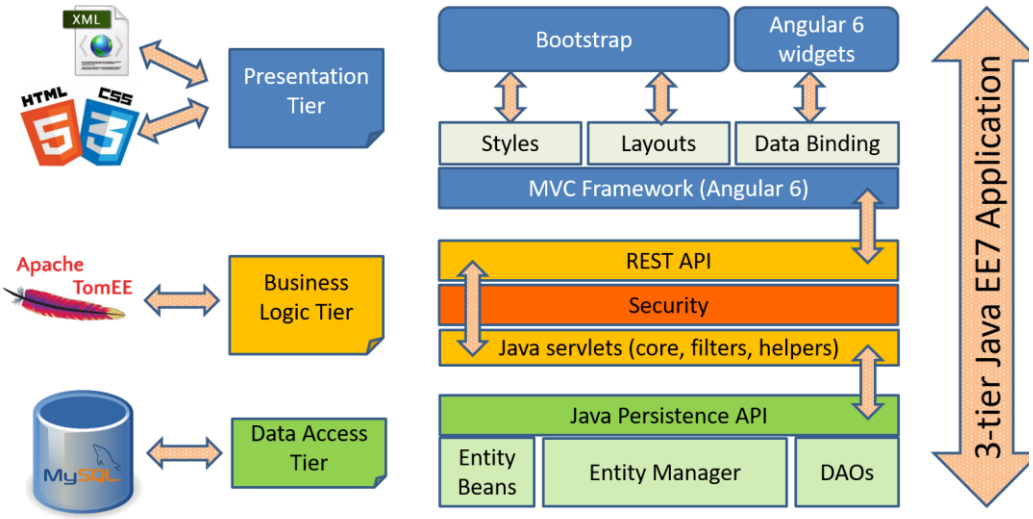

Figure 3 – Dashboard software stack

[3] https://github.com/pyros-dev/rostful (last accessed April 2020).

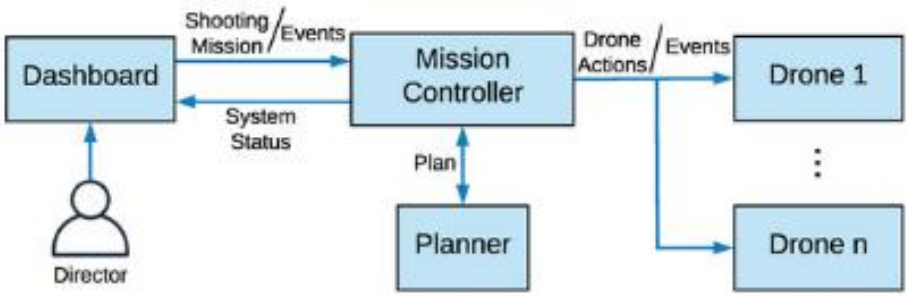

Figure 4 – Information exchange between the media director and the MULTIDRONE robotic system. The director uploads mission and event information to the Mission Controller. The Mission Controller receives a flight plan based on the mission XML, and sends this plan to the drones. Polling the Mission Controller, the director knows at any time the status of all missions. Source (4)

workflow. Simple web pages allow the user to interact with the underlying database, in order to set up new missions or update existing ones in a friendly way. The Dashboard GUI is accessible through a login page, which requests for user credentials and role (e.g. administrator, director, cameraman). Once logged in, different home page layouts based on the selected role are displayed.

Administration home page

The administrator home page shows three tabs to manage users, permissions and shooting action templates. The user screen lists all users that have been set up. New users can be created by setting personal information (i.e. first name, last name, organisation and email), as well as one or more roles the user can have. The permission screen shows the list of permissions (e.g. CREATE_MISSIONS) for each user role. New permissions can be created by selecting the role and switching on / off the corresponding resource. As an example, directors would be allowed to perform any action to a mission, i.e. creation, visualisation, modification and deletion. On the contrary, camera operators would be limited to only visualise it. The shooting action template screen shows the list of available shooting action templates, including a brief description and the number of involved drones. New templates can be created by filling out a form with the following information: name, XML schema reference uri, description, parameters (in JSON format) and shooting roles. Each shooting role will correspond to a specific action done by a drone of the formation. As an example, Figure 5 shows a shooting action template with no parameters and three drones, doing a lateral, a chase and an elevator shot, respectively.

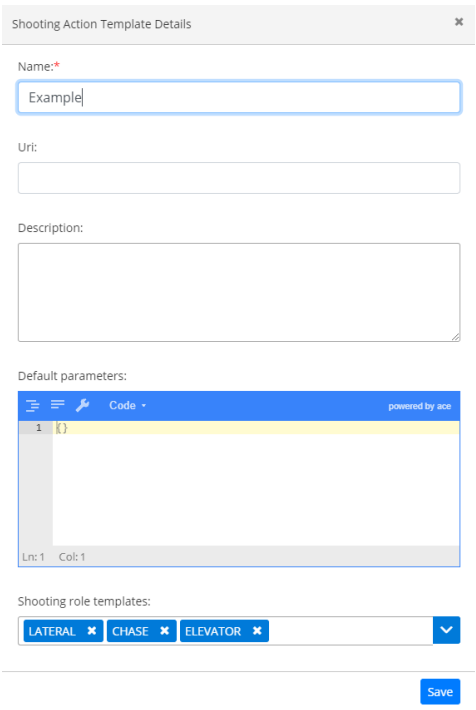

Figure 5 – Example of creation of a Shooting Action Template

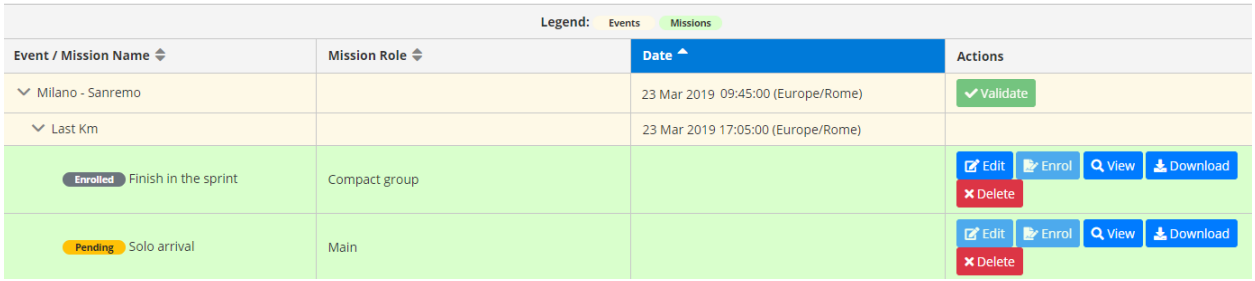

Figure 6 – Director home page

Mission planning pages

The director home page lists a hierarchy of events and missions in which he / she is involved. Events are created by the event configuration page, where a form containing information about the new event can be filled and then saved on the database. For each event, the user could create new sub events or new missions if the event "father" of the mission does not have sub events itself. At the same time, the user cannot link sub events to an event that already has a mission attached (i.e. it is a leaf event). Only leaf events can have missions attached. Figure 6 shows an example. The main event is the “Milano - Sanremo” cycling race. The goal, i.e. the leaf event, is the shooting of the last kilometre. Two missions have been planned. The former (i.e. “*Finish in the sprint*”) is going to run if the cyclists approach the race finish in a compact sprint. On the other hand, the latter is in case of solo arrival. During the race, the director may decide to run the most appropriate mission according to the actual race conditions, provided that I was correctly validated. The GUI shows the status of each mission, so that the director may know for every mission what are the next steps of the planning or execution workflows that can be taken. For example, if a mission is "*Pending*", it means that the director requested to validate the mission, and the Mission Controller is performing the necessary feasibility, safety and security checks. Several actions can be performed from this page, as editing or deleting a mission. Deletion would remove of all the stuff contained into the mission itself (i.e. any related shooting action sequence and shooting actions). New missions are created through a web form, requiring inputs such as name, role, involved people, and target. For example, the page for the creation of the “*Finish in the sprint*” mission would look like in Figure 7. The crew enrolled in the mission includes four people (i.e. one director, two camera operators and one production technician). The main shooting target is a cyclist. The mission configuration page also shows, if present, a

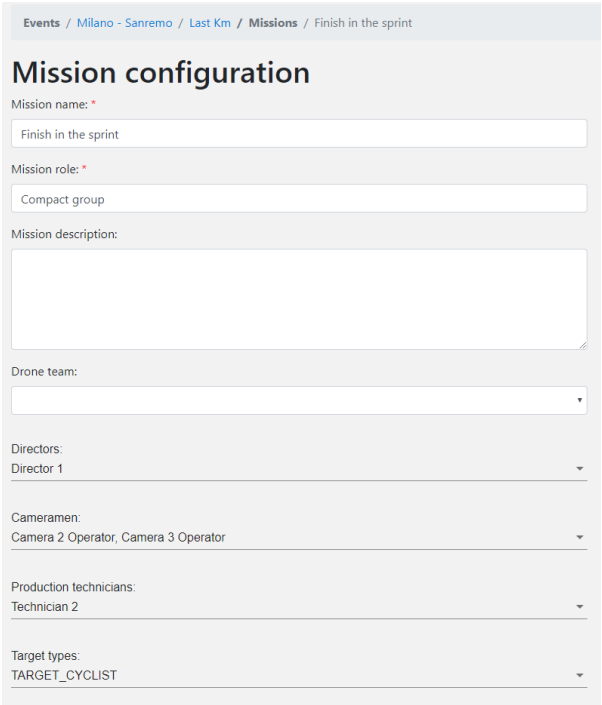

Figure 7 – Mission creation web form

list of shooting action sequences related to the mission. The director can either add new shooting action sequences, choosing among the available templates, or update existing ones. For each shooting action sequence, the director can add one or more shooting actions, detailing through appropriate web forms what the drone formation will do during the live event and what each single drone will do as well. Three tabs compose the shooting action configuration page. The first tab is about the choice of the shooting action to be performed by the drone's formation (see Figure 8). The second tab allows the director to fill information about the reference target and the drone's formation. This include, for example, the speed of the formation and its reference trajectory on a map (see Figure 9). The third tab carries specific parameters about each single drone role in the drone's formation, such as drones' displacements, frame types (e.g. long shot, medium shot, close-up shot, etc.), camera shot

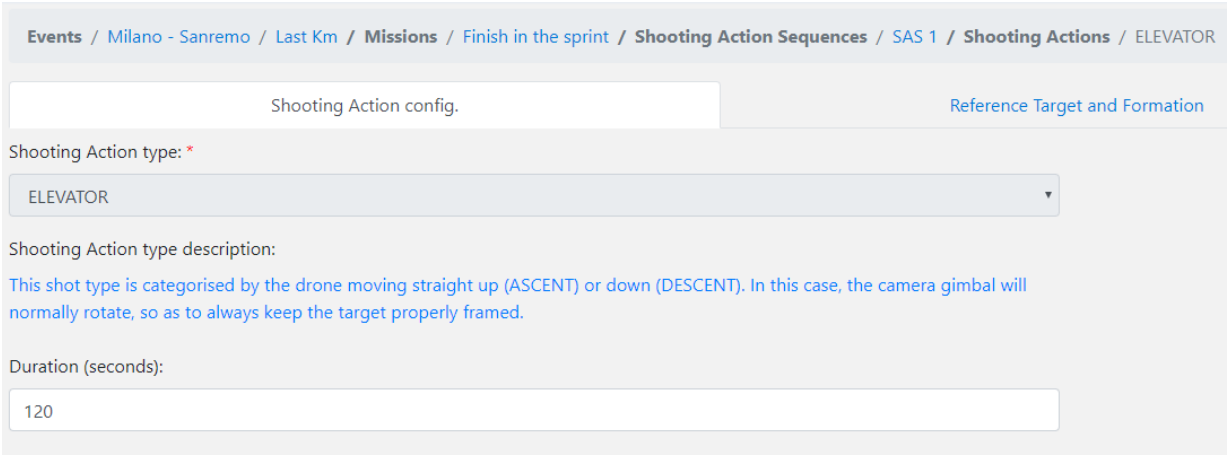

Figure 8 – Shooting action creation: configuration tab

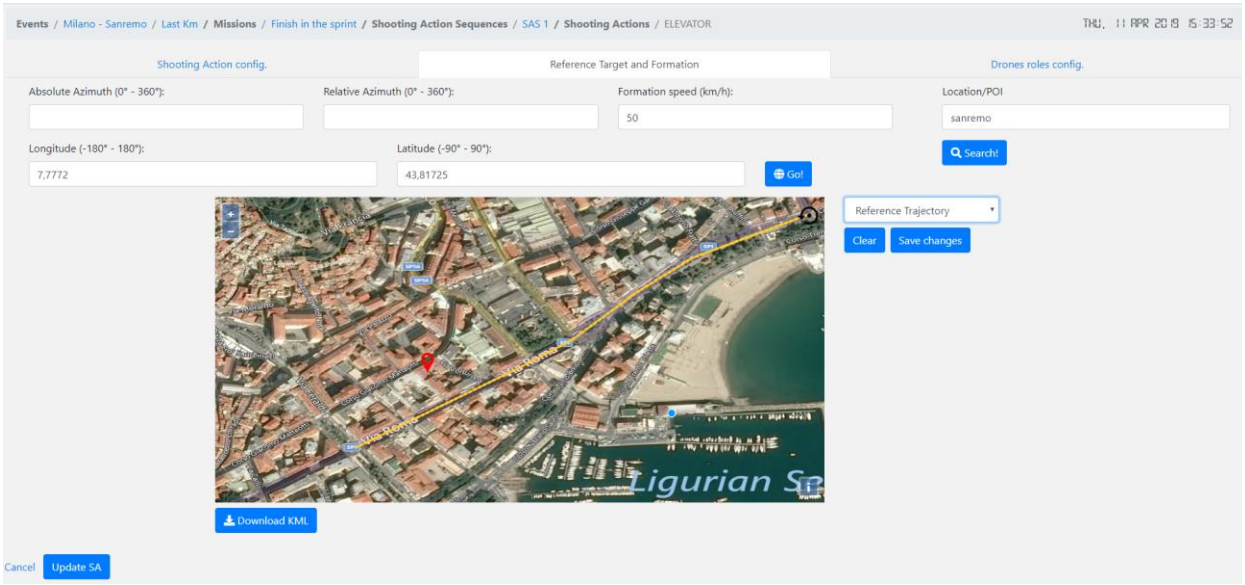

Figure 9 – Shooting action creation: reference target (yellow dashed line) and origin of the drone formation (black circle)

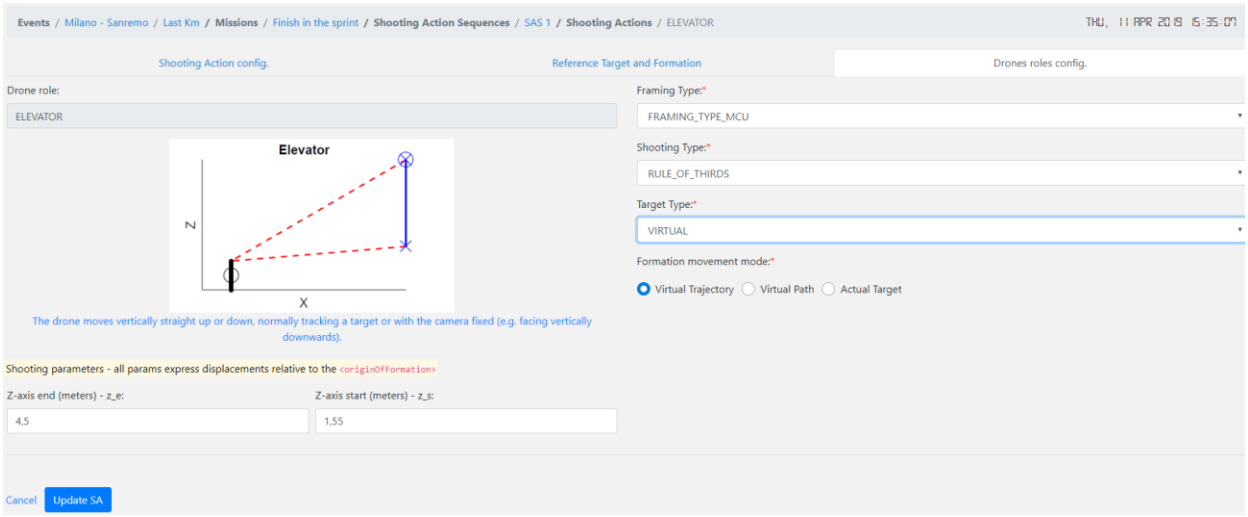

Figure 10 – Shooting action creation: drone's role configuration tab

types (e.g. rule of thirds) and shooting target tracking modalities, i.e. based on GPS localization, or AI visual object recognition (see Figure 10).
Once all the parameters of a mission have been set, validation can start. This is done by clicking the "Validate" button in the director home page (see Figure 6). This notifies the Mission Controller to start the validation of the selected mission(s), by sending to it the corresponding XML description.

EXPERIMENTAL MEDIA PRODUCTION

This section presents some of the results of proof-of-concept testing and validation of the dashboard and the MULTIDRONE system, in the context of the experimental media productions (both mock-ups and real scenarios) that took place in Hof Siek and Berlin (Germany, 09/2019) and in Seville (Spain, 11/2019). A complete report of the full findings of those experiments is presented by Heise et al (6, 7).

Experimental Campaign Set-up and Running

The experimental media production campaign was performed in three phases. In the first phase, three mock-up scenarios, namely cycling, rowing and parkouring, were used to assess the system's ability to achieve its main objectives and to test them in terms of technical components and functionalities developed within the project. These included end-to-end integration of the software stack, ground-to-air LTE-based communications and execution of simple shooting missions involving at least two concurrent drones. In the second phase, we organised a media production targeting a real event. For this purpose, the 'Rund um Wannsee' (Around Wannsee) international rowing regatta[4] was selected to film some of the race moments with the MULTIDRONE system. In the third phase, a location in Spain was set to test advanced system functionalities, including collision avoidance in case of smooth trajectories, transparent drone replacement in case of e.g. battery consumption, trajectory adjustment based on crowd detection. Shooting missions involving

[4] https://www.berliner-ruder-club.de/rund-um-wannsee/ruw-2019.html (last accessed April 2020).

at least three drones and reproducing a cycling scenario were performed. Figure 11 shows an example for a mission executed in the Wannsee Regatta scenario run in Germany. For the sake of simplicity, only the main elements of the XML are included. The main target of the mission is a boat. There are two shooting action sequences with the same role, thus planned to run in parallel. The first shooting action sequence has one shooting action with one role (i.e. one drone) performing a static shooting, i.e. the drone remains stationary, with the camera being stationary or moving. The duration of this shooting action is 180 seconds. The shot type is an extreme long shot (ELS) conforming to the rule of thirds. The second shooting action sequence has two shooting actions. First, the drone performs a fly-by shooting (i.e. the drone flies past the reference target in a straight line, constantly rotating

```
<mission eventRef="719aac48-b474-42c2-97df-bc5d4af8bb4b">
  <name>Rowing experiment with 2 SAS in parallel</name>
  <role>Two parallel SAS</role>
  <description>Drone 1 does a flyby and a fly through. Drone 2 does a static.</description>
  <creationDatetime>2019-09-20T09:02:28Z</creationDatetime>
  <targetTypes>
    <targetType><name>TARGET_BOAT</name> </targetType>
   <shootingActionSequences>
     <shootingActionSequence>
       <role>Flyby + Fly through. Static.</role>
         <shootingActions>
           <shootingAction shootingActionTemplateRef="STATIC">
             <duration>180</duration>
             <formationSpeed>1.0</formationSpeed>
             <shootingRoles>
               <shootingRole>
                 <name>STATIC</name>
                 <framingTypeName>FRAMING_TYPE_ELS</framingTypeName>
                 <shootingTypeName>RULE_OF_THIRDS</shootingTypeName>
    <shootingActionSequence>
       <role>Flyby + Fly through. Static.</role>
         <shootingActions>
           <shootingAction shootingActionTemplateRef="FLYBY">
             <duration>80</duration>
             <shootingRoles>
               <shootingRole>
                 <name>FLYBY</name>
                 <framingTypeName>FRAMING_TYPE_VLS</framingTypeName>
                 <shootingTypeName>RULE_OF_THIRDS</shootingTypeName>
                 <params>…</params>
           <shootingAction shootingActionTemplateRef="FLY_THROUGH">
             <duration>80</duration>
             <shootingRoles>
               <shootingRole>
                 <name>FLY_THROUGH </name>
                 <framingTypeName>FRAMING_TYPE_LS</framingTypeName>
                 <shootingTypeName>RULE_OF_THIRDS</shootingTypeName>
```

Figure 11 – Excerpt from a shooting mission XML example

the camera gimbal to keep the target object in frame) with a duration of 80 seconds. The shot type is a very long shot (VLS). Then, it moves to a new position and it changes to a fly-through shooting (i.e. the drone flies through the scene with a constant speed following a pre-programmed path with different camera movement), performing a long shot (LS) until the end of the mission. Once a mission plan has been, the director may execute any of its combination of shooting action sequence / shooting actions. This is done by triggering two commands in sequence. First, the "*Roll Camera*" command notifies the Mission Controller to order the drones to take-off and reach the starting position defined in the map. Then, the "*Action*" command notifies the drones to start the shooting. During execution, a mission can be monitored in real time through a dedicated page, which shows mission metadata and shooting action sequences, plus corresponding shooting action timeline and video streams coming from drones' camera. Figure 12 shows a picture taken during the Wannsee Regatta. The foreground shows the dashboard. The background shows one drone ready to take off.

Figure 12 – Ready to run mission

The cameraman page shows mission information plus a console to manually adjust drone camera parameters (i.e. orientation, gimbal, focus) in case of automatic calibration failure.

Qualitative Platform Testing and Validation

The mission workflow was tested several times during the three media production experimentation periods. A questionnaire was given to 11 evaluators who took part to the German production campaign. Figure 13 shows the questions about the dashboard. From left to right, Q1 was about the possibility to set up a flight plan without extensive refinement or simulation; Q2 was about the reliability of the process used to transfer a mission XML from the dashboard to the MULTIDRONE robotic system; Q3 was about the usability and perceived usefulness. Overall, the dashboard did not show any particular criticality, highlighting consistency and integrity of data, good stability and usability of the tool.

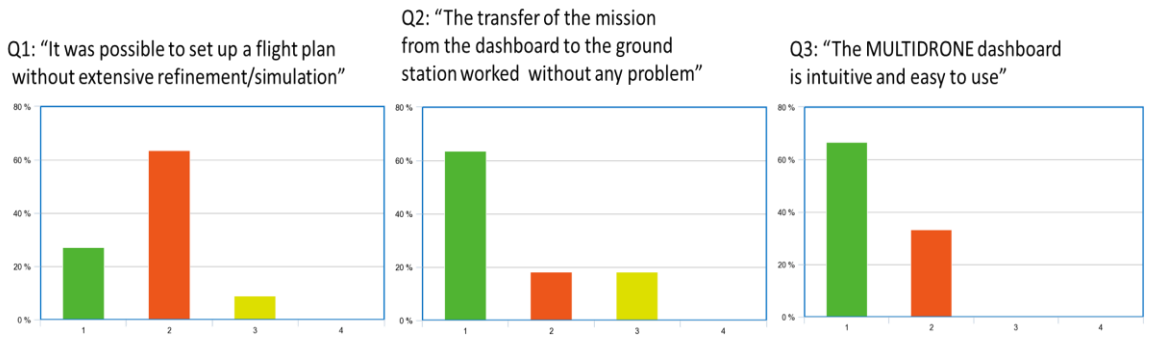

Figure 13 - Dashboard evaluation. Green, red and amber bars mean fully agree, agree, and disagree, respectively. Source (7)

CONCLUSIONS

This paper presented the director's dashboard, i.e. the tool used by media teams to manage the editorial aspects of multi-drone media production with an autonomous robotics system. The dashboard is intuitive and simple. Among its functionalities, it innovates in at least three ways. First, it allows media people to define complex shooting missions by navigating through a few configuration pages. Second, it provides a functionality for describing shot geometry by clicking on aerial maps. Finally, it enables a standard methodology to describe, validate and execute plans for the missions. Thanks to its generality, the dashboard can be integrated with alternative (multi) drone mission planning systems, other than that developed within the MULTIDRONE project.

ACKNOWLEDGEMENTS

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