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Article

Mutable Observation Used by Television Drone Pilots: Efficiency of Aerial Filming Regarding the Quality of Completed Shots

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Abstract: Drones, as mobile media of the present day, increase the operational and narrative capabilities of television and accelerate the logistics of shooting. Unmanned aerial vehicles with a camera properly steered by a pilot are able, to some extent, to replace a jimmy jib/crane and a dolly; basic technical devices, used in the studios, enabling the creation of narrative systems of pictures in film and television. Television is more and more often using drone footage to report events, broadcast live, as well as create coverage and television documentaries. In many productions the pilot of the drone simultaneously acts as the drone camera operator, which can improve the effectiveness of shooting, but also carries some risk related to flight safety. The article describes and presents in the form of processed footage the real conditional ties of a Visual Line of Sight (VLOS) flight faced by pilots filming with a drone. VLOS is a type of air operation, which requires maintaining eye contact with the drone. In many countries a drone visibility flight is legally sanctioned as VLOS Operation. An experiment was conducted to investigate the interactions between a human and a machine in airspace steered using a controller with a touchscreen. The drone pilot was considered an integral part of the drone's flight system control Experimental data was collected with the use of a mobile eye-tracker, video cameras, surveys and pilot declarations. During the experiment, eight television drone pilot operators recaptured a model shot under the regime of VLOS flight at low altitude. They all show that both advanced and beginner pilots did not look at the UAV for over half the time of shot execution. The experiment allowed establishing two coefficients related to the effectiveness of a VLOS flight aiming at filming from the drone. The results point to clear differences in screen perception styles used by drone television pilots.. The coefficients were described in the form of mathematical formulas and their limit values were determined. The research also determines the limits of pilots' perception, within which they are able to film with a drone. The outcomes may help to optimize the process of aerial filming with the use of a drone, carried out for television, film and other media, as well as in a simulation of such a flight for research and training. From the perspective of media science and social communication, the presented study included a technological component that can be accessed through information science, using statistical models and variable distributions. Media scholars can study the impact of the media without having to look into the metaphorical black box. Computer science opens up this possibility.

Keywords: aerial photography; television drone pilot; UAV; VLOS; perception of the drone pilot; VCEF; EHEF; empirical studies in interaction design; empirical studies in HCI

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1. Introduction

It is becoming more and more common to use drones in many fields of human activity. Ljungblat et al. [1] group domains, in which research on human – drone interaction is already carried out: such as sport, construction and rescue operations. The European Union Aviation Safety Agency (EASA) has published proposals to implement in Europe a special low-level altitude U-Space airspace available to unmanned aerial vehicles [2]. Drones have also become tools commonly used by television. It was already Levine [3] who had said that Unmanned Aerial Vehicles would bring about transformation in journalism and in the market of information transfer. In the media studies literature unmanned aerial vehicles have already started to be included in the group of mobile media. As an example, Hildebrand [4] describes drones in a variety of aspects as mobile media that allow not only to access physical, digital and social spaces, but also to shape them. Adams [5] presents ways in which drone pilots influence content-related shape and production of journalistic material. Therefore, technical aspects of applying new technology (among others, examining sight activity of drone pilots) related to operating an aerial vehicle are currently within the area of interest of researchers, also those dealing with media.

TV drone flights, during which the drone pilot or the observer maintains eye contact with an unmanned aerial vehicle, are permitted in many countries around the world after completing specific conditions. Visual Line of Sight (VLOS) flights are air operations in which the pilot maintains visual contact with the drone in order to ensure the safety of flight [6]. In Poland during a VLOS flight it is allowed to look away from the drone in order to control the drone flight parameters on the screen of the drone operator [7]. During television productions at low altitudes of flight, among many terrain obstacles, VLOS flight may prove more efficient and safer than BVLOS (Beyond Visual Line of Sight) flight. Using a drone in this manner opens up a possibility to capture significant shots, which open or close a given thread of news, coverage and documentary instead of using only descriptive shots from high altitudes.

The article analyses a special situation where the pilot is the drone camera operator at the same time. In such camera and film crews that require the team to be as compact and mobile as possible, television crews among others, the pilot of the drone is usually also the drone camera operator. In big, commercial news channels in Poland (such as TVN 24 – Discovery, POLSAT NEWS) ground camera operators, who obtained an adequate certificate of professional competence, use drones as pilots – cameramen, which speeds up the TV reactions to an event and extends the possibility of using drones in everyday information materials. For the sake of completeness it is worth adding that a flight with both a pilot and a drone camera operator is highly effective. The pilot is able to focus on observing the drone in airspace, while the drone camera operator is focusing on filming. Another situation is a flight with an observer, who informs the pilot of possible collision courses and the drone's position in relation to the pilot. Thanks to this the pilot is able to focus more on the images from the drone and can easily recover drone visibility after completing a shot. Flights of this type can be carried out as VLOS and BVLOS operations depending on legal considerations and qualifications of the pilot.

The authors of the article have narrowed down their research area to a VLOS operation carried out single-handedly by a television pilot (Fig. 1). The goal was to determine actual conditions of a VLOS drone flight while filming at low altitudes in a narrow maneuver corridor. A difficult flight – operator task carried out by pilots drone operators, which nearly ended in crashing the drone, allowed, among others, to isolate two VLOS flight coefficients.

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Figure 1. Research participant – Pilot P4 during shot execution. Photograph by Jarek Królikowski/JerryTheRabbit.com

2. Analysis of research status and the literature of the subject

Theoretical model of a drone pilot is an integral element of the system of unmanned vehicle flight control. In our model, the pilot – drone camera operator – processes information coming from the drone measuring instruments and the airspace, in which the unmanned vehicle is observed, whereby the drone pilot's contact with the aircraft may be of direct or indirect nature. We have paid attention to the significant role of the pilot's level of training in the techniques of television image execution. While analyzing the mutable observation of the drone by the television pilot, we have noticed that independent drone pilots have to combine two orders of observation: observing the drone in airspace and the image from the drone on the controller screen. Such perception actions require the skills of both piloting the drone, as well as cinematography. We have distinguished two types of vision that present the characteristics of image operator's perception (light and shade vision vs. contour vision). The query of research into pilots' visual activity and ergonomics of the equipment allowed noticing how the eye-tracker and other research tools to study drone pilots' perception had been used as well as what burden for the organ of sight can displaying information on the controller present. In relation to studies of manned aerial vehicles we assumed that the pilot – drone operator performs two complementary activities of filming and navigating the drone. We argue that using drones as mobile, interactive media requires developed skills of perception in the area of mutable observation.

2.1. Theoretical model of the pilot taking into account the VLOS flight filming process

Adamski [8] presents the general theoretical model of operating unmanned aerial vehicles w (UAV) in his book. "While carrying out tasks, a pilot-operator should be considered an integral element of the unmanned aerial vehicle flight steering system. We can distinguish two basic subsystems enabling cooperation between a human and an unmanned aerial vehicle (UAV). Information on the parameters of a UAV (such as flight parameters, navigation data, engine parameters) comes from measuring and processing collected data devices (treated as a subsystem 'input'). Pilot as the steering system operator passes back the adequately processed commands to executive systems" (see [8], p. 45).

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In this model the pilot, as an integral element of the steering system, processes input information coming from the measuring devices of the drone.

During VLOS flight filming, the pilot – operator has direct visual (and auditory up to a certain distance) contact with the aircraft in order to ensure safety of attempted maneuvers. At the moment of losing visual contact with the drone (while observing drone image on the display) "the contact of the pilot – operator with the aircraft is indirect and usually takes place through signals that are carriers of individual pieces of information. Those signals are considered actual features of the control object and constitute the basis for its decision making process. As a result, the decision taken, translated into controls movements, depends on the pilot's operating environment and environment in general." (see [8], p. 45). According to Adamski's typology, the factors influencing the pilot – operator while operating a UAV are, among others: training factors (methodology of training, training level, using the simulator), tactical factors (low altitude, collision hazard, high altitude, high speed, time deficit), technical factors (technological level of the construction, avionics equipment, equipment failure), biological and physical factors (oxygen deficiency, reduced threshold of color discrimination, fatigue), psychological factors (personal situation, professional situation, material situation, environmental situation) (see [8], p. 46). Additional training factors influencing the pilot – drone camera operator are the level of training in television and film making techniques and professional experience in this scope. Technical factors are, among others, sensors installed in drones, informing of obstacles (sensors operation is limited to specific, low cruising speeds and maneuver corridors with specific minimum width).

2.2. Mutable visual observation maintained by the drone pilot during VLOS flight

The authors of the article define the term 'observation' in relation to the concept of observation and observer created by Niklas Luhmann, the author of the Social Systems Theory. To this end they use the dictionary of terms developed by Krause [9]. "Also according to Luhmann – writes Krause – observing has something to do with seeing, watching the subject, following the events. The question is if at all and how can you see and what do you see, when you see" (see [9], p.71; translated from German by the author). The question about distinction that is at the base of observation arises from defining observation as "extracting distinction and naming the distinguished" (see [9], p.72; translated from German by the author). In this concept of observation the pilot consciously perceives the drone speedometer on the controller screen, if distinguishing the drone's speed is important to him at that moment. The observation includes the decision. "Anything that wasn't distinguished and named is excluded. The other side of distinction is not known, however, it contributes – as what has not been distinguished – to distinguished clarification" (see [9], p.72; translated from German by the author). An observer understood as a subject is replaced in the systems theory with an observer understood as a system. In this regard it is not the final instance of observation, but it is specified and distinguished by the observation of another observer or self-observation. Luhmann uses the term of first and second-order observers. "The first-order observer cannot see how he sees the object of his observation. The second-order observer can see that the first-order observer uses a distinction invisible to him and only thus can see his object. The distinction of the second-order observer is typical for him, not a type of a double distinction of the first-order observer. [...] There must be at least a minimal time difference [...] between the first and second-order observation" (see [9], p.78; translated from German by the author). The first-order observation is subject to the question (level) of 'what?', while second-order observation is subject to the question 'how?'. In this sense, observing the drone image on the controller screen is, to some degree, second-order observation, since the pilot who is filming with the drone should recognize the potential meaning contained in the shot. Such identification is possible thanks to, among others, bringing out distinctions that are at the core of observation of these shots by a potential spectator. Observing the drone in airspace also assumes a certain meta level. The aerial vehicle, maintaining the given altitude, moves away from the observer and can

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be perceived as descending. In order to control this illusion the pilot should be able to distinguish the real loss of height from the illusion caused by perspective. For this purpose, the pilot can distinguish the altimeter readings visible on the drone controller touchscreen, and so on.

Solo drone pilots must combine two types of visual surveillance: 1) observing the drone in the airspace is supposed to ensure flight safety and compliance with VLOS flight procedures, 2) observing the image from the drone on the controller screen is necessary for the execution of proper shots. The necessity to see light and shade as well as contours in the drone camera image competes with a different type of observation, which keeps the drone in real airspace and is focused on flight safety. This results in a specific visual perception, which in the first approximation we called a mutable observation of the drone pilot. In this way, the drone pilot carries out two complementary activities: filming and navigating the drone. An additional aspect is the pilot's situational awareness at the location from which he controls the unmanned aerial vehicle. In our study, the pilot did not have to move around. However, in many real-world situations, the space behind the pilot's back becomes important when, for example, the pilot follows the drone. Schmitz [10] conducted phenomenological deliberations on the perception of space behind human backs. In the conducted study, we tried to neutralize the impact of this space on pilots.

2.3. Contour and light and shade vision in the work of a cinematographer

The model of a drone pilot, (compared to Adamski data [8]) needs to be completed with forms of vision, i.e. strategies of observation significant during execution of television and film shots in general (not only with the use of a drone). Creating the composition of a frame by adequately locating the camera requires the ability of contour vision from image operators. Such vision is facilitated by black and white viewfinders frequently used in professional television cameras. Strzemiński [11] with regard to the art of indigenous peoples, introduces the term of contour vision as the earliest type of visual awareness. In Strzemiński's theory of vision [11], contour vision "used as a tool for battle for survival, rejects all unnecessary, complicating visual sensations and stops at those that allow to confirm the existence or non-existence of an object – on the contour drawn around the object" (see [11], p. 23). Contour vision allows the image operators to reduce the information content of a frame to its composition potential.

Framing space by image operators to a high degree consists of observing the edges of a frame. Looking into the frame in order to assess image quality is a different kind of look – light and shade vision, which allows image operators to notice, among others, the exposure level of a shot (black noise, white balance, etc.). In relation to baroque paintings, Strzemiński [11] explains the new visual awareness of light and shade vision: "Light and shade visual awareness blurred the contours of images, introduced the color of shade (from the background), shattered the existing local unity of color. Individuality of the object, individuality of its character as a sample of a product, had to give way to seeing the whole – for the benefit of the process of seeing" (see [11], p.125). According to the researcher, the light and shade visual awareness causes "the line of contour to disappear not only in the shade. It also disappears in passages from shadow to light, becomes torn in several places. The object ceases to possess one continuous contour line" (see [11], p. 117). Light and shade vision is characteristic in film productions, but it constitutes additional difficulty for safe navigation of the drone by a pilot, who is simultaneously a camera operator, like in our experiment.

2.4. Examining sight activity of drone pilots and equipment ergonomics

Hoepf et al. [12] described data related to eye movements of a drone pilot (eye blinking rate, blink duration, pupil diameter size) and pointed out to severe eyestrain during piloting. High eye workload resulted in lower eye blinking rate, shorter blink duration and dilated pupils. According to the researchers, it would be a good idea to introduce an automated system of monitoring physiological changes (eye movements and heart rate) with the potential to detect an upcoming decrease in labor efficiency of a drone pilot in high eye workload conditions.

On the other hand McKinley et al. [13] used the time of complete eye closure to detect the presence of fatigue during simulated use of a drone. The authors did not find any fatigue effects during simulated use of a drone after a period of sleep deprivation. However, they did notice fatigue effects after carrying out tasks in a traditional flight simulator in the case of two specific tasks of a drone flight (defining objectives and psychomotor vigilance task). According to the authors, those two tasks proved to be more complex and difficult for drone pilots in comparison to other tasks and, as a result, led to the so-called optimal excitement, which, in turn, led to overall better performance of drone pilots.

Moreover, McIntire et al. [14] demonstrated that eye-tracking tests might be used to monitor changes in drone pilots' vigilance levels. Increased and longer blinking and longer eye closure reflected weak focus of attention during drone pilots' vigilance task. The researchers additionally noted that until then no scientific papers had been published, that would compare eye scanning strategy between drone pilots and manned aircrafts pilots.

While steering and flying a drone it is also important to visually control its display. Tvaryanas [15] conducted research on how drone pilots visually scanned data from the RQ1 Predator drone flight controller. Focusing sight by the drone pilot was, according to Tvaryanas [15], a heavy strain on the pilot's eyes due to the method of information presentation on the RQ1 Predator controller. The author stated, for example, that the information was displayed in frames that kept moving up and down the screen linearly. Tvaryanas [15] concluded that such method of data display on the drone flight controller proved inefficient due to wrong design, which was not taking into consideration the limitations of human perception.

Jin et al. [16] also analyzed the efficiency of display/controller, however, of the Mission Planner. They conducted an experiment where the drone flight controller usability was compared with the use of altered original interface version of the device. According to the researchers, the main problems with controller usability concerned, among others, the flexibility of the system, user activity and minimum load of the memory. A result analysis of a few factors such as: task execution time, clicks of the mouse and fixation points showed that according to respondents the reprogrammed system interface worked more efficiently.

Researchers Kumar et. al. [17] proposed an innovative camera system Gazeguide, which offers possibility to control movements of a drone-mounted camera through sight of a remote user. A video recorded by the drone camera is sent to eye-tracking glasses with the display function located on the user's head. The test involved filming both static and mobile elements in 3D space. According to the test's authors, comparing Gazeguide system with a system using a classic flight controller shows better results of Gazeguide.

One of the latest physical examinations conducted by Wang et al. [18] showed that researchers see the necessity of changing the philosophy of designing drone pilots equipment. The research was aimed at assessing the flight controller/display ergonomics, using eye-tracking exams. The researchers also pointed to the necessity of connecting methods that scan the drone pilot's sight. Apart from the method of measuring sight activity with the use of eye tracking, the test on 12 pilots also used the method of expert evaluation.

2.5. Studying pilots' complementary activities during a complicated flight situation

The experiment conducted by the authors of the article involved modeling a complicated flight situation and studying complementary activities during drone filming, which allowed tying flight safety directly to effective filming. The aerial-film task was highly difficult because it was assumed that in complicated flight conditions the drone pilots would be forced to use their entire potential to execute it. A complicated drone maneuver they had to carry out in order to capture the model shot should reveal any shortcomings of the eye-head system[1] activity, flight strategy and interface ergonomics.

In research regarding psychology, physiology and safety of flights of Łomow and Płatonow [20], it is possible to distinguish two most typical and universal models of complicated experimental flight situations. The first is modeling the conditions of complementary activities, where attention is divided between two essential tasks requiring active perception and operation. "Such is the situation of a low altitude flight in the regime of searching for ground-based orientation points, where it is necessary to join piloting with activities related to solving emergency situation or controlling and assessing the state of aircraft systems (...). The second model consists of modeling emergency situations evoked by technical elements refusing to work or receiving incomplete or imprecise information. In this case, it is essential to maintain the confidentiality of the experiments goal. This model should be aimed at determining the reliability of the cooperation between the pilot and the devices in a technical failure situation (...)" (see [20], p. 348).

Researchers of aviation psychology Łomow and Płatonow [20] point out that "in simple flight conditions the pilot manages inactivated reserves, which allows to compensate for some equipment shortcomings (...). Examining the influence of a complicated situation on the pilot provides knowledge of performance properties of the pilot in an emergency situation, on changing the structure of activities, characteristics of intellectual and perceptive process, allows to determine what is the critical component of activity, what especially disrupts the cooperation of the pilot and the aircraft, which activity component needs to be trained in the training process or support it with technical measures (...)" (see [20], p. 348–349). It is worth noting here that, as van Dijk [21] writes: "Taking full advantage of the opportunities offered by the new media requires well-developed visual, auditory, verbal, logical and analytical skills" (see [21], p. 298).

3. Hypothesis, research method and description of carrying out the experiment, including data collection

Safe and effective drone visibility flight, during which the pilot is also the operator of the camera mounted on the unmanned aerial vehicle, can be a heavy burden for the pilot's perception. At higher altitudes (within 100 meters), if the drone pilots find that there are no obstacles in the vicinity of the unmanned aerial vehicle, they usually focus on the image from the drone displayed on the controller screen. However, in this case, the pilot should (simultaneously) observe the drone in the airspace to ensure separation from other aircrafts, birds or objects that may unexpectedly appear[2]. Filming with a drone at low altitudes is more associated with the risk of collision with terrain obstacles, but at the same time it extends the possibilities of narration with the image. With appropriate lighting and spatial conditions, the image quality from a small drone may not differ noticeably from the image from professional ground cameras. It encourages TV and film producers to include pictures from drones in their productions. Small and foldable drones providing good quality recordings, easy to transport and use, are most often piloted by independent pilots.

To sum up: the basic research problem can be formulated in the form of a question about the impact of mutable observation of the drone and the controller screen (during the VLOS flight) on the efficiency, quality and safety of aerial photography. The research

[1] Gregory [19] describes the operation of two movement perception systems, which he calls "image-retina system and eye-head system." "(...) The image-retina system: when eyes are immobile, the image of a mobile object is running on the retina, which creates movement information as a consequence of another receptor discharge on the route of a moving image. (...) In the eye-head system, when eyes are following a moving object, the image does not move on the retina, yet we see movement. Both systems may sometimes produce non-compliant information, which is the source of peculiar illusions." (see [19], p.106).

[2] To decrease the risk related to drones moving in the controlled airspace, The Polish Air Navigation Services Agency is developing an innovative system UTM PANSA to manage, control and integrate unmanned air traffic with controlled air traffic (see [22]).

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problem posed has led to the distinction of two VLOS flight coefficients that affect the course of the flight and the quality of the shots taken.

Research hypothesis: During a solo VLOS flight, the more experienced pilots gaze towards the unmanned aerial vehicle (UAV) more rarely and for shorter periods of time and focus more on observing the screen content of the controller than the less advanced pilots.

The test of drones pilots was conducted under the regime of a VLOS flight at low altitudes among obstacles such as: buildings, TV antennas and trees. The research material was recorded on 8 and 9 June 2019 in Warsaw and the experiment was conducted with the use of: Tobii Pro Glasses 2 mobile eye-tracker, Sony X70 camera, DJI Mavic Pro drone, Blackmagic VideoAssist recording monitor and DJI Crystal Sky 5,5″ touchscreen. Eight television pilots – drone operators were qualified for the test and divided into two categories: advanced and beginners, based on the declared number of hours spent piloting drones.

While making the decision on the choice of location for the experiment, an important factor turned out to be the degree of shading of the drones' takeoff site. In order to maintain and control the lighting conditions, the subjects were divided into two subgroups of 4 persons. Both groups had been subjected to an identical test on two consecutive days, in the same time frames. The local weather and lighting conditions were very similar. At the start of the test, a participant was shown the model shot[3] and asked to re-capture it at least three times duplicate within a specified time frame.

The shot lasted 50 seconds. The model, complicated shot was at first executed at an altitude of 3 meters, which grew to 22 meters. It required implementing many techniques of executing aerial imagery by a drone. Therefore, various aspects of its completion are representative for many types of shots used in television and film. Repeating the shot seen earlier creates more problems for the pilot than executing his own shot. This made the task more difficult and required the pilots to use most of their perceptual reserves. Therefore, we did not study the creativity of the pilots as image operators, but the limits of their technical and perceptual abilities when executing the shots. Apart from navigational difficulties, such as maneuvering in a narrow air corridor, an additional difficulty for the tested pilots was the necessity to repeat the model shot. In the experiment, researchers designed a complex flight and filming situation to study the perception of pilots in extreme VLOS flight conditions, which may happen in various other situations of aerial photography from a drone. According to the assumptions of aviation psychology according to Łomow and Płatonow [20], described in detail in subsection 2.5, it was assumed that in the complicated flight conditions the drone pilots would be forced to use their full potential to perform the task. During the experiment, the conditions of complementary activities were modeled (in the case of the presented study, it was piloting and filming a drone). The aim of the study was to assess the effectiveness of human-machine cooperation, i.e. the cooperation of drone pilots (beginners and advanced) with the classic controller system with a touchscreen for shot execution in the VLOS flight mode.

The eye-tracking analysis was carried out on seven shots included in the research based on the choice made by reviewers6. In case of each of the seven shots, the reviewers chose one best shot (the most similar shot to the presented model – with similar time and visual course). The same criteria were used to choose two best shots in the entire group. Additionally, the third shot of pilot P6, which showed a collision of the drone with a treetop, was included in the analysis.

The eye-tracking analysis was carried out on 7 shots included in the study, based on a selection made by peer reviewers[4]. In the analyzed research material, none of the shots

[3] The model shot was executed by the co-author of the article S. Strzelecki, who, in addition to scientific work, is a professional drone operator and pilot cooperating with the most important Polish TV broadcasters: TVP and TVN – Discovery.

[4] Peer review method – method of objectification of assessments collected during quantitative research, when a group of people, with similar competencies in a given field, analyses and assesses the research material (see [23]). Three peer reviewers took part in the analysis of the collected research material. The competencies

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taken by the pilot 8 were taken into account, because no shot was completed and their visual course significantly differed from the model shot[5]. In the case of each of the seven subjects included in the sample, the peer reviewers indicated one best shot (the closest to the model shot – a similar time and visual course of this shot). According to the same criteria, peer reviewers selected the two best shots in the whole group. Additionally, the analysis included the third shot of the P6 pilot, during which there was a collision with the tree crown.

In order for peer reviewers to be able to select the shot most similar to the model shot and to conduct eye-tracking analysis using the Imotions7 software, the researchers developed a proprietary method of video imaging techniques. For this purpose, the researchers combined on a computer screen the footage recorded by the eye tracker with two videos recorded by the drone and with a shot taken by the Sony X70 camera archiving the operator's behavior (see Fig. 2). The method of image production techniques consisted in combining four time-synchronized video recordings on one screen. The researchers determined the beginning and end of each shot by entering a number in the center of the screen (see Fig. 2).

Figure 2. Research footage of the authors – screenshot. The upper left window contains the image from the eye tracker camera with fixations; the upper right window contains the image from the drone's camera along with the graphical user interface (GUI); the lower left image shows the pilot and additional information: pilot number, number of flying hours, shot date and time code of the entire flight; the image in the lower right window appears when the pilot starts recording – this image contains additional information about the drone's position along with the camera parameters; Source: own study

The survey for each of the respondents was carried out immediately after completing the flight with the drone of each of the surveyed pilots. A detailed methodological description of the entire experiment can be found in the text Każdoń-Dębecka and Strzelecki [24][6], where the authors focused primarily on the research methodology.

of reviewers were due to their employment in the Laboratory of Television and Film Studies at the Faculty of Journalism and Book Studies at the University of Warsaw.

5 The model shot in the form of a video file is available on request.

6 Paper accessible in English and Polish.

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4. Findings

4.1. Results of surveys

An analysis of surveys made it possible not only to group drone pilots' opinions and proposals as well as their preferred methods of operation regarding the VLOS flight, but also their previous experiences and new technological solutions for the drone interface, proposed by the subjects. Table 1 presents only those answers of the pilots that occurred with at least two pilots – respondents.

Table 1. Comparison of results of a survey carried out among television drone pilot (Markings: P[X] – pilot no. X, B – beginner, A – advanced), Source: own study

Issues raised in the survey	Opinions collected on the basis of the survey
Biggest difficulties	* zoom filming [P1(A), P8(B)] * limited maneuver space [P3(B), P4(B), P8(B)] * own, limited competences [P7(B), P8(B)]
Helpful features of the drone and filming methods	* drone position maintenance system (GPS) [P1(A), P5(A)] * drone camera Auto Focus [P7(B), P8(B)]
Control rod grip	* thumb only [P1(A), P3(B), P2(A), P7(B), P8(B), P4(B), P6(A)] * between thumb and index finger [P8(B), P4(B), P5(A)]
Significant interface signals in and emergency situation	* flight duration on battery [P1(A), P3(B), P6(A), P7(B)] * distance from the takeoff site [P3(B), P6(A)]
Used modes of intelligent flight outside the experiment	* Tripod [P1(A), P8(B)] * Terrain follow [P4(B), P6(A)] * Point of interest [P6(A), P7(B)] * "I don't use any of them" [P3(B), P6(A)]
Proposed improvements	* programmable automatic flight [P1(A), P5(A), P2(A), P8(B)] * better sensors [P2(A), P3(B)]
One pilot's complementary statement	* the drone blending in with its surroundings [P2(A)]

Concluding opinions, experiences and findings of the pilots, it is worth reminding that the aerial-film task prepared for the pilots had a high level of difficulty from the start. Therefore, the maneuver space in the air corridor was limited and the camera was set to double zoom before the flight. These elements made it hard for pilots to maneuver the drone on the basis of camera playback and enforced observation of the drone in airspace. In their surveys, the pilots admitted that zoom filming and limited maneuver space together with their own limited competences caused the greatest difficulties. One operator also mentioned drone visibility problem since it was blending in with its surroundings. The pilots mentioned stability of the drone as its advantage. They mainly used thumb grip for control rods steering. Thumb and index finger grip, which, in the authors' opinion, provides more control, for control rods steering was less popular among pilots – operators. Modes of intelligent flight used (outside the experiment) by some professional pilots – operators are *Tripod*, in which the drone reacts calmly to steer movements, *Terrain follow*, in which the drone is able to automatically react to land elevations and depressions, and *Point of interest*, in which the drone is able to circle a designated point. Some pilots noted it should have been possible to turn off displaying some flight parameters on the controller screen. In emergency situation flight duration on battery and distance from takeoff site were the most significant for the pilots. The pilots also noticed the need for better distance sensors, since currently the sensors can only stop the drone in front of an obstacle at a limited speed of the UAV.

4.2. VLOS flight factors. Eye-tracking and video-analytical tests

Two VLOS flight factors influencing drone maneuver safety and efficiency of operation of the drone pilot's eye-head system during a VLOS flight were distinguished based on the

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analysis of variables: visual contact efficiency factor (VCEF) and eye-head system efficiency factor (EHEF).

The efficiency factor of visual contact with the drone while filming during a VLOS flight (Visual Contact Efficiency Factor – VCEF) determines the ratio of the number of eye contacts with the drone to the sum of: the number of eye contacts with the drone, the number of full gazes on the drone controller display and the number of gazes outside of the drone – controller display layout during the shot execution. Based on the hypothesis, it can be assumed that the efficiency of eye contact with the drone increases the closer the VCEF factor value is to the maximum. The maximum and minimum critical values of the VCEF depend on the size of maneuver corridor in a given airspace and the perceptual-motor possibilities of the drone pilot.

$$VCEF = \frac{\text{number of eye contacts with the drone}}{\substack{\text{number of full gazes on}\\ \text{the drone controller display}} + \substack{\text{number of eye contacts}\\ \text{with the drone}} + \substack{\text{number of gazes}\\ \text{outside the layout}}} \times 100\% \quad (1)$$

Gazes within the drone-controller layout include: (1) drone vision (central or peripheral) within the scope of possibility to assess the drone's position in relation to terrain obstacles and (2) drone controller display vision (central or peripheral) within the scope that enables navigation on the basis of the drone camera feed.

In the analyzed cases of the experiment the number of detected gazes outside the layout visible in the denominator amounted to 0. We assume that in a real-life situation it may be necessary to gaze outside of the drone-controller display layout in order to, for instance, observe other flying or ground objects or in case there is need to change the position or location of the operator. In such a situation, while the number of gazes outside the layout increases, the efficiency of visual contact with the drone decreases.

The eye-head efficiency factor (EHEF) while filming during a VLOS flight (EHEF) determines the ratio of the total time spent on full gazes on the drone controller display to the time of flight with no drone visibility. Based on the hypothesis, it can be assumed that the efficiency of the eye-head system increases the closer the EHEF factor value is to maximum. The maximum and minimum critical values of the EHEF factor depend on the size of maneuver corridor in a given airspace and the perceptual-motor skills of the drone pilot.

$$EHEF = \frac{\text{total time spent on full gazes on the drone controller display}}{\text{time of flight with no drone visibility}} \times 100\% \quad (2)$$

Table 2 presents the values of the VCEF and EHEF coefficients calculated for the best shots (in the assessment of peer reviewers) made by individual pilots. The criteria for assessing the shots by the judges assumed a similar time and visual course compared to the model shot. Columns P1 and P4 (data for pilots P1 and P4 – marked in green) show the results obtained on the basis of the analysis of the two best shots in the entire study group. The last column contains the VLOS flight data of the P6 pilot, where during the third attempt to take the shot, the drone collided with the tree's crown after 35 seconds of flight (after the collision, the drone remained in the air). The analysis of the eye-tracking record applied to the video image showed that some of the eyesight clusters of pilots P1 and P5 exceeded the selected area of the controller's screen (AOI). This situation is marked with an exclamation mark in the table (!). Therefore, the values of the eye-head system efficiency (EHEF) and eye contact efficiency (VCEF) for these pilots may differ from the actual effectiveness of their perceptual systems as part of their screen observation methods (cf. 4.3 Anomalies in eye-tracking results).

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Table 2. Results of eye-tracking and video-analytical research, Source: own study

(B)eginner / (A)dvanced	P1 A	P2 A	P3 B	P4 B	P5 A	P6 A	P7 B	P6* A
Total no. of flying (H)ours: TVN Discovery + other [h]	140 + 20	50 + 20	20 + 60	6.5 + 6.5	90 + 800	50 + 120	4 + 0	50 + 120
(AS) Index of the analyzed shot in accordance with the order of flights	2**	4	3	4**	4	4	2	3
Number of shots (R)ecorded	6	6	4	8	4	5	6	5
(T)ime of selected shot [s]	57	56	91	53	52	60	60	35
Number of full gazes on the controller touchscreen (FGC)	28	12	17	18	13	38	18	21
Number of eye contact with the drone (ECD)	9	11	12	15 ***	10 ***	8	11	3
Visual Contact Efficiency Factor (VCEF) [%]	24.3% !	47.8%	41.4%	45.5%	43.5% !	17.4%	37.9%	12.5%
BVLOS [s (%)]	48 (84.2%)	38 (67.9%)	53 (58.2%)	41 (77.4%)	36 (69.2%)	53 (88.3%)	40 (66.7%)	33 (94.3%)
FPV [s (%)]	4 (7.0%)	30 (53.6%)	11 (12.1%)	21 (39.6%)	2 (3.8%)	24 (40.0%)	22 (36.7%)	18 (51.4%)
Eye-head efficiency factor (EHEF) [%]	8.3% !	78.9%	20.8%	51.2%	5.5% !	45.3%	55.0%	54.5%

* P6 pilot collision flight
** best shot according to competent judges (similar timing and visuals (BS))
***low amplitude of up-down head movements (LA)
(!) pilots exceeded the marked area of the controller display (AOI)

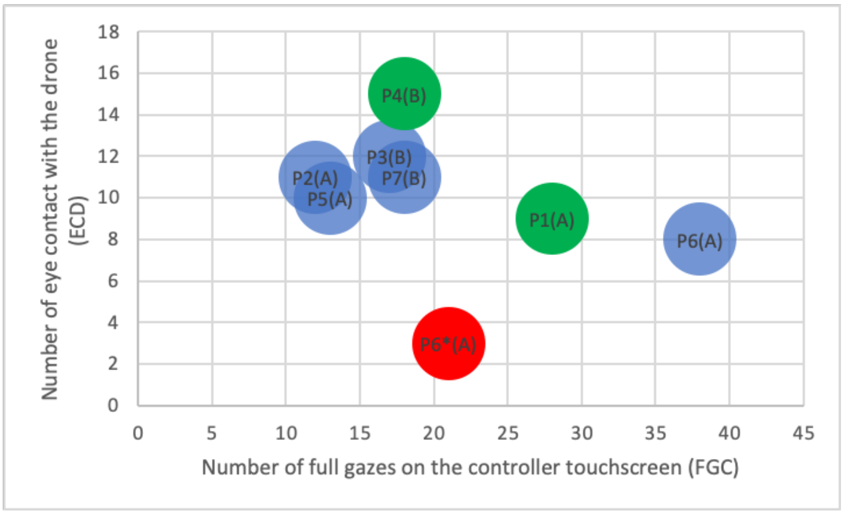

Figure 3. Diagram of the relationship between the number of full gazes at the controller and the number of eye contacts with the drone. In the diagram, the best shots in the assessment of peer reviewers are marked in green, and a collision flight is marked in red, Source: own study

The blue bubbles describe the pilot's best shots selected for analysis. The diagram (Fig. 3) shows that the best shots from the entire study group (green) were taken by the novice pilot P4 (B), who had the most visual contacts with the drone using the intra-screen observation of the controller (IS), and the pilot advanced P1 (A), who had about half as much eye contact with the drone using the peri-screen observation of the controller (PS). It can be seen that, depending on the flight technique, the photos may be at the same level of implementation, but in the case of the advanced pilot P1 (A), the flight was more burdensome for him. This is evident in the video material attached to the article and it is also probably due to the pilot's use of the peri-sceen observation (PS). The diagram shows that in the case of professional drone pilots, in most cases, the number of eye contacts with the controller screen exceeded the number of eye contacts with the drone, however,

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with too few eye contacts with the drone, the drone collided with the crown of the tree (red bubble P6*(A)). All the shots made by the pilot P1 (B) – green bubble, P4 (B) and P6 (A) – red bubble, were included in the video material in three separate files. The number appearing in the center of the screen indicates the start and end of the shot and its number.

Based on the results of the analysis of the best shots from Tab. 2, it was calculated that the average shot time, in BVLOS, for advanced pilots was 77.4% of the shot time, and 67.4% for beginner pilots. It follows that both beginner and advanced pilots did not look at the drone for more than half of the flight time (BVLOS flight time in relation to the shooting time is greater than 50%). The minimum flight time with no drone visibility for advanced pilots is 67.9%, and for beginner pilots 58.2% of the shooting time. The maximum flight time with no drone visibility is 88.3% for advanced pilots and 77.4% for beginners. The results show that despite the rather narrow air corridor in which the drone could safely maneuver during the VLOS flight, the pilots spent more time observing the image from the drone than the aircraft itself.

The authors of the article noted that the total flight time with no drone visibility differs from the total time spent looking at the drone controller screen. It takes time to change the view angle from the drone to the controller. The smaller the difference between these times, the greater the efficiency of the eye-head system. It is worth noting that one of the best shots in the entire group was taken by the P4 pilot, for whom the efficiency of the eye-head system (EHEF) was 51.2%. Pilot P2 with an efficiency factor (EHEF) of 78.9% had problems reproducing the model shot during his flight. The skill of the pilot as a camera operator is not directly correlated with the EHEF factor. Perhaps there is a limit value for the work of the eye-head system, beyond which the work of the system becomes over-effective and overburdens the pilot's perception. The maximum critical value of this factor should be determined in separate research.

It is worth paying attention to the differences in the way the controller is operated by individual pilots. The advanced P5 pilot and the beginner P4 pilot held the controller high compared to other pilots. Observation of the image on the controller held high made it possible to reduce the amplitude of head movements (up and down). It can be assumed that thanks to this, the pilots consciously used peripheral vision[7] to observe the direction of the drone's movement.

The results of the video image analysis confirm the research hypothesis, while both advanced and beginner pilots did not look at the drone for more than half of the shooting time during the VLOS flight.

4.3. Anomalies in eye-tracking results

Pilot P1 had 28 revisits/full gazes/fixations in the AOI tested area (FGC) in 4 seconds (per 57 seconds of the shot duration). 84.2% of the shot execution time (BVLOS flight) he was not looking at the drone. He spent only 7% of that time (FPV Time) actively focusing on the interface display (highlighted area of AOI). The analysis of eye-tracking recording of the applied on the video showed that some of the sight fixations of this pilot went beyond the highlighted area of AOI. Analysis of all fixations of the pilot shows that in some of them, the pilot was visually scanning the upper screen frame, focusing his sight slightly above it.

The advanced P5 pilot also looked beyond the screen while focusing on the drone controller. Such perceptive effects caused pilots 1 and 5 to have very short total times of full gazes calculated by the eye-tracker (FPV Time) in comparison to the time of BVLOS flight. Hence, the values of eye-head system efficiency factors (EHEF) for advanced pilots 1

[7] Gregory [19] points out that the perimeter of the retina allows the perception of movement and its direction, but the viewer is not able to determine the type of object. On the other hand, when the movement stops the object becomes invisible. According to the researcher this experience is closest to the most primal forms of perception. "The periphery of the retina is therefore an early warning device that rotates the eyes so that the object-recognizing part of the system is aimed at objects that may turn out to be friendly or hostile, at least not indifferent" (see [19], p.106).

and 5 may diverge from the real efficiency of their perception systems within the executed methods of screen perception. The research results only initially point to possible relations between the visual contact efficiency and the eye-head efficiency and the quality and safety of executed shots. Precisely determining these relations requires further research of greater accuracy and larger number of test subjects. Therefore, the results presented in this article are of heuristic nature.

4.4. Pilot perception techniques

Comparison of shots captured by individual operators (carried out by peer review) allowed distinguishing shots taken by two pilots, advanced pilot P1 and beginner pilot P4 as the best and most closely resembling the model shot (similar timing and visual course of the shot). The first advanced pilot P1 with many flight hours (around 160h), was not looking at the drone for 84.2% of the shot execution time, and during the shot had 9 eye contacts with the drone and executed 29 full gazes on the drone controller display. Hence, his visual contact efficiency factor was low (VCEF=24.3%). The fourth beginner pilot P4 with very few flight hours (13h), was not looking at the drone for 77.4% of the shot execution time. This pilot had 15 eye contacts with the drone and executed 18 full gazes in the AOI tested area (FGC). Hence, his visual contact efficiency factor was quite high (VCEF=45.5%). P4 pilot, despite lack of experience in filming from an unmanned aerial vehicle, captured, similarly to the advanced P1 pilot, one of the best shots in the entire tested group[8]. What aided him was most probably his experience in using a video game console, similar to some degree to a drone controller used in the experiment. (Pilot P4 also mentioned using video game console in the talks after the experiment). There were also significant differences between P1 pilot and P4 pilot in techniques of image perception on the drone controller display. The beginner pilot P4 focused his vision in the middle of the controller display, which allowed him to see the whole frame, including perimeters, on the 5.5" screen. Saccades (rapid, involuntary movements of the eyes between fixation points) appeared mainly in the vertical axis. The advanced pilot P1 quickly sand frequently canned the upper frame of the screen focusing his vision slightly above the frame. Many horizontal saccades appeared. In both cases, the pilots were probably effectively using their peripheral and contour vision, described in the theoretical part of the study, but fixated their sights in different spots.

The beginner P4 pilot focused his vision more or less in the center of the screen taking in the entire frame using perception of perimeter. Both pilots probably used perimeter vision to observe the frames of the shot, but started off at different points of fixation, different techniques of eye tracking. The perception technique of the beginner pilot P4 may be called intra-screen observation (IS), the technique of the advanced pilot P1 – peri-sceen observation (PS). The intra-screen observation (IS) was also observed in the advanced pilot P2 and the beginner pilot P7. Compared to the rest of the group, the flight efficiency factors were high in P2 pilot's performance (EHEF = 78.9%, VCEF = 47.8%). However, according to peer reviewers, shots executed by these pilots were not the best.

The intra-screen observation of the fourth pilot P4 allows to simultaneously join the contour vision with the light and shade vision (discussed in subsection 2.3) more effectively than the scanning perception of the first pilot, since fixation points fall on a limited area of the screen. Such intra-screen observation (IS) is probably a smaller burden for the pilot's perception systems than the peri-sceen observation (PS). The advanced P1 pilot informed of problems with shot execution, his facial expressions showed signs of perception difficulties. It is worth to remind that the shots of both pilots P1 and P4 were assessed as the closest to the model shot. It should also be mentioned that the control rod thumb only grip signalized in surveys as preferred by the P1 pilot was different from the one preferred by the beginner P4 pilot gripping the rod between the thumb and index finger.

[8] The P4 beginner pilot did not press 'record', hence the shot was not recorded. It was, however, analyzed by peer review, since an image along with the interface transmitted from the drone controller directly to an independent video recording monitor was recorded.

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4.5. Risky drone filming during VLOS flight of the pilot P6 (EHEF = 94.3%; VCEF = 12.5%)

If a BVLOS flight time (BVLOS Time) was longer than 90%, then collision situations appeared. During his second attempt, the advanced P6 pilot (170 flying hours) did not look at the drone at all throughout the entire time of the execution of the shot. It led to a highly dangerous situation in the 35th second of the shot execution (18th minute of the flight). Too wide left arc almost caused the drone to collide with a building, which had suddenly appeared on the controller display in the distance of around 2 meters from the drone. The pilot managed bring the aircraft under control, however, it came really close to a collision. During the following, third attempt (analyzed shot AS3, last column of Table 2), the pilot P6 gazed at the drone three times (ECD=3). This meant he was not observing the drone for 94% of the shot execution time (EHEF=94.3%, VCEF=12.5%). In the 30th second of the third attempt (AS3), the drone got caught in some tree leaves as a result of performing too wide left arc, similar to the one in the second attempt. The drone flew through the leaves and remained airborne. In the fourth attempt (AS4), the pilot safely executed a shot, which turned out to be the most similar to the model shot. Time of BVLOS flight (BVLOS Time) shrunk from 94.3% to 88.3%, the pilot also increased the number eye contacts with the drone (ECD) from three to eight. The analysis of P6 pilot's best shot (AS4) showed the visual contact efficiency factor VCEF was as low as 17.4%. During the execution of the shot (AS4) the P6 pilot had 8 eye contacts with the drone and made 38 full gazes on the drone controller display. It shows that the pilot preferred to navigate the drone on the interface and limited the looking at the drone in airspace. Compared to other pilots, P6 pilot compensated the limited number of eye contacts with the drone with an accurate analysis of the drone video. However, three eye contacts with the drone in the first thirty seconds of the third shot AS3 execution were not enough to safely navigate the drone among the buildings.

5. Discussion

Our study may prove the plausibility of monitoring flight coefficients dependent on the pilot's perception in order to keep him informed on the limits of his perceptive capabilities. At the beginning we referred to research by Hoepf et.al [12] suggesting the introduction of an automated system to monitor physiological changes for drone pilots. Whereby, such a system in the case of described coefficients should monitor pilot's eye and head movements. At the same time, monitoring eye movement enables eye control. Kumar et al. [17], point to high efficiency of drone camera control by means of sight and with the use of opaque virtual reality goggles, which enforce a BVLOS flight[9]. Eye control in virtual reality should concern, first of all, such camera parameters as focus, aperture, shutter, white balance, zoom. Eye control of other functions of the drone should concern only those parameters that do not have a direct and immediate impact on the flight trajectory of the drone. It is easy to imagine a situation, where an operator is executing a shot with the drone positioned with the sun behind it, which causes the operator to be momentarily blinded. For that reason, the controller interface with built-in control rods should be retained and could, optionally, accommodate the sticks' response to the drone overburdening and also transfer the drone engine sound in order to provide the pilot with the information of the unmanned aerial vehicle flight dynamics. The bigger the focal length of the drone camera (bigger zoom), the gentler the sticks' performance characteristics should be.

Another researcher Tvaryanas [15], who analyzed the graphic interface operations of a reconnaissance version of Predator military drone drew attention to burdening a pilot's perception as a result of graphic layout of information displayed on the screen. Imperfections of this type are also visible in a popular drone flight application (DJI GO). For instance, observing the drone's speed indicator during a solo VLOS flight poses additional difficulty for an independent pilot, since he needs to simultaneously observe images

[9] Flight with VR goggles, during which the pilot does not see the drone, may be considered a VLOS flight, if there is an observer present, who informs the pilot of possible collision courses and other threats.

from the drone and the aircraft itself. On one hand, it is fairly easy to imagine better graphic solutions (i.e. user modifiable ones); on the other hand, many operators have got accustomed to the present solutions in the user interface. New technology, which can improve drone-filming possibilities, is in our opinion an adequately designed augmented reality system, taking into account verbal communication, engine noise and visualization of the interface elements in the operator's line of sight.

6. Conclusions

Professional television drone pilots are able to independently execute complicated outdoor day shots in a narrow maneuver corridor during a VLOS flight. This is difficult, as the flight is partially carried out among terrain obstacles. Throughout the entire flight trajectory, the pilots are not able to gaze at the drone even for the majority of the shot execution time. The experiment proved that if a pilot, focused on the drone controller display, does not look at the aircraft for over 90% of the shot execution time; it may lead to a collision of the unmanned aerial vehicle with terrain obstacles and increases the risk of an accident. The best shots (BS – closest to the model shot) were executed when the pilots made on average over a dozen eye contacts with the drone and were not observing the aircraft for close to 80% of the time of shot execution focusing their attention on the drone controller display. The biggest difficulties related to the execution of the task, reported in the surveys, concerned the necessity to film with a double zoom and limited maneuver space.

Determining the maximum and minimum critical values of a VLOS flight factors (VCEF and EHEF) requires a separate study. The results of pilots P2 and P7 show, that a high level of VLOS flight factors does not always go hand in hand with the quality of the executed shot, as assessed by peer reviewers.

Within the conducted experiment, the best compromise for the visual contact efficiency, eye-head system efficiency and filming effectiveness is shown by the data collected during P4 pilot flight: eye-head efficiency factor (EHEF=51.2%), visual contact efficiency factor (VCEF=45.5%), low amplitude of up-down head movements as well as effective intra-screen observation (IS) allowing to join the contour vision with the light and shade vision in a single perception act. The beginner P4 pilot, despite the lack of experience in flying a drone, executed (as assessed by peer reviewers) one of the best shots in the entire tested group (timing and visual course closest to the model shot). The advanced P1 pilot executed another of the best shots in the entire group, however, his low visual contact with the drone efficiency factor (VCEF=24.3%) introduced additional flight risk in a narrow maneuver corridor, which was related to the peri-screen observation (PS) used by this pilot.

Filming in VLOS flight by one person requires a lot of commitment. In this type of situation, the pilot paradoxically loses the drone's line of sight many times to control the drone's controller screen. In the light of the conducted research, devoting half of the shooting time to drone observation seems to be a good compromise between the safety of shooting and the quality of shots taken at low altitudes among many terrain obstacles. More advanced pilots are able to spend less time observing the drone, but the time when pilots lose sight of the drone, even with very advanced pilots, should not exceed 80% of the shooting time.

The results can help, for example in improving the efficiency of aerial photography from a drone taken for television, film and other media or for training purposes (for example, in simulating such a flight). Due to the difficulties and danger of shooting at low altitude under the VLOS flight regime, it seems justified to simulate the conditions of this flight in the safe space of augmented reality. In such a simulator, the detected real-time monitored flight coefficients can determine a critical moment in the pilot's perception. The system can react by immobilizing the drone or informing the pilot on the basis of a control lamp that it has reached its limits of stimulus integration.

Further research would require the creation of appropriate virtual drone flight spaces representative of many real movie sets. When designing the spaces assuming the achievement of specific values of the coefficients for the operators taking the intakes, the degree of difficulty of the intakes can be related to the VLOS flight coefficients described in the article. VLOS flight factors can therefore help design suitable spaces for a VLOS flight simulator in virtual reality.

Another conclusion concerns the drone's flight assist function. The current assisted flight functions often do not support low-altitude television shots. The functions of assisted flight in the popular DJI GO 4 application used by more experienced drone operators in news television are, above all, Point of Interest, Active Track, Follow Me Mode, Course Lock. Neither of these assisted flight modes allowed for the footage taken during the experiment, as it was necessary to change the flight path in the horizontal/vertical plane with the simultaneous rotation of the drone. These are maneuvers that can be successfully creatively carried out by properly trained television and film drone pilots.

7. Summary

Drones allow us to create shots that are more and more important in the narrative of the image, but using the full potential of aerial photography requires pilots to be highly competent in controlling the drone and executing shots. Media is a challenge to the abilities of their users, as van Dijk [21] aptly noted when defining media in the spirit of McLuhan: "Media and computers can be treated as extensions or even substitutes of human perception, cognition and communication. They extend in time and space and reduce the consequences of limitations imposed on us by the body and mind" (see [21], p. 301). Drones used for filming, as mobile media of the present day, require pilots to combine two orders of observation: pragmatic vision focused on the assessment of distance and risk related to flight, and film vision aimed at recognizing the meanings in the image from the drone that are important in a TV or film narrative.

In our article, we have indicated the risks associated with VLOS flight filming, which result from the pilot's need for mutable supervision on two levels: film and air. The results of the research presented in the article may help, among others in improving the effectiveness of aerial photos taken from a drone for television, film and other media as well as in flight simulation, for training and research purposes. The factors described by us primarily affect the efficiency of drone filming and flight safety. Monitoring these factors can be important when building a VLOS augmented reality (VR) flight simulator model. A simulator based on VR goggles would be able to reliably reproduce VLOS flight conditions and monitor specific flight coefficients. Designing virtual spaces in such a simulator should take into account the potential values of flight coefficients for specific drone maneuvers. At the training level, monitoring of the relevant flight coefficients can signal to the pilot that he has reached the limits of his own stimulus integration capacity and should modify his flight method. On the research level, the simulator will enable the optimization of the process of alternating observation during filming in flight with drone visibility.

Society is on the threshold of a new era in which machines will no longer be separate, lifeless mechanisms but will be extensions of the human body. Drones equipped with appropriate control controllers expand human observation capabilities, but at the same time require the use of many perceptual reserves. The alternating enforced observation by the medium of the drone allows humans to see from an avian perspective, but inadequate surveillance of the aircraft carries the risk of crashing it.

Supplementary Materials: The model shot in the form of a video file is available on request.

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Abbreviations

The following abbreviations are used in this manuscript:

BVLOS (Beyond Visual Time of Sight) – time of flight with no drone visibility, during which the pilot was focusing attention on the drone controller display
FPV (First Person View) – total time spent on full gazes on the drone controller display
EHEF – eye-head efficiency factor while filming during a VLOS flight
$\text{EHEF} = \frac{\text{FPV}}{\text{BVLOS}} \times 100\%$
FGC – Number of full gazes/fixations in the AOI tested area (gazes on the controller touchscreen)
ECD – number of eye contacts with the drone
VCEF – efficiency factor of visual contact with the drone while during VLOS flight filming
Out – Gaze outside the layout (drone, operator, controller)
$\text{VCEF} = \frac{\text{ECD}}{(\text{FGC}+\text{ECD}+\text{Out})} \times 100\%$

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