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An Application of Visual-Observation Unmanned Aerial Vehicles in Live Firing Range Tests

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Abstract. This paper describes a practical application of two visual observation VTOL UAVs (also "drones" further herein) in tests performed on a proving ground operated by the Military Institute of Armament Technology. One of the two drone's loads included a VIS light video camera, and the other one's load featured a thermal imaging (IR) video camera. As a part of the same application, both drones were used to visually monitor the flight path of an experimental short-range rocket missile, which featured an inertial guidance head with an onboard flight recorder. A live firing range test stand is described herein, including the positioning of both drones relative to the launcher of the experimental short-range rocket missile, and a target designed as a trap for the same missile. Two sequences of still frames are presented herein, selected from the video recordings captured by the drones' video cameras to record the flight path of the experimental rocket missile when it failed to hit the target.

The VIS video camera observation of the rocket missile's flight past the target, and especially in the end stage of flight facilitated an approximate determination of the missile's landing location; the IR camera observation of the same facilitated the precise location of the landed missile in the field. Hence, both drones proved to be tools capable in locating experimental rocket missiles which missed their target and landed in the field of the proving ground.

Keywords: external ballistics, drones, missile, firing range, observational cameras

1. BACKGROUND

In the winter of 2016, testing was carried out on experimental short-range rocket missiles, equipped with inertial guidance heads and onboard flight recorders, at the proving ground of the Military Institute of Armament Technology. Each experimental short-range rocket missile was 80 mm in calibre, 6 kg in start weight and had a launch velocity of approximately 200 m/s. The tests were designed so that the rocket missiles were to be captured by a target in the form of an aramid-fibre curtain suspended on a frame 18 m away from the launcher of the rocket missiles. The flight path of the rocket missiles during the burn stage was observed with ground-based slow-motion VIS light video cameras. During the tests, one of the experimental rocket missiles missed the target and left the field of view of the ground-based video cameras. Its flight path past the target remained unknown. Despite several days of search, the proving ground staff failed to recover the flight recorder of the rocket missile. In an attempt at avoiding such losses further, and inspired by the references [1, 2] concerning applications of UAVs for visual monitoring of hit and target sites as a part of artillery fire control systems, the authors hereof decided to use flying drones for further live firing range testing of the same experimental rocket missiles.

2. LIVE FIRING RANGE TESTS

In the spring of 2017, live firing range tests were continued with the application of two VTOL UAVs, or drones, for visual observation of the experimental short-range rocket missiles, especially in the case of the missiles missing their target. One drone was an DJI Inspire Pro (see Image 1), fitted out with a VIS light video camera with a resolution of 1920 × 1080 pixels and a recording frame rate of 120 fps. The other drone was a Bielik (see Image 2), with a Tamarisk 320 thermal imaging (IR) video camera, operating in the 8-14 μm spectrum. The image resolution of the IR video camera was 320 × 240 pixels with a recording frame rate of 60 fps.

The structure of the live firing range test stand (see Image 3) was the same as during the tests of winter 2016.

Image 1. DJI Inspire Pro visual observation drone with a VIS light video camera onboard

Image 2. Bielik visual observation drone with an IR video camera onboard

Image 3. Live firing range test stand during its setting up, comprising the launcher of the experimental short-range rocket missiles (see left), the target trap cantilever (see right) with the aramid-fibre curtain laid next to it and optionally backed with a stack of cardboard boxes, as recorded by the DJI Inspire Pro drone hovering overhead

Image 4. Experimental short-range rocket missile shown hitting the target's aramid-fibre curtain. Image captured by the VIS light video camera of the DJI Inspire Pro drone

The drones were positioned aft to the rocket launcher and hovering at 30 to 50 m above terrain level directly before each missile launch. The FOV of the drones included the launcher, the target, and the field past the trap, into the proving ground. Most of the rocket missiles hit the target (see Image 4).

Once decelerated by the aramid-fibre curtain, each rocket missile dropped to the ground several to ten-odd metres from the target.

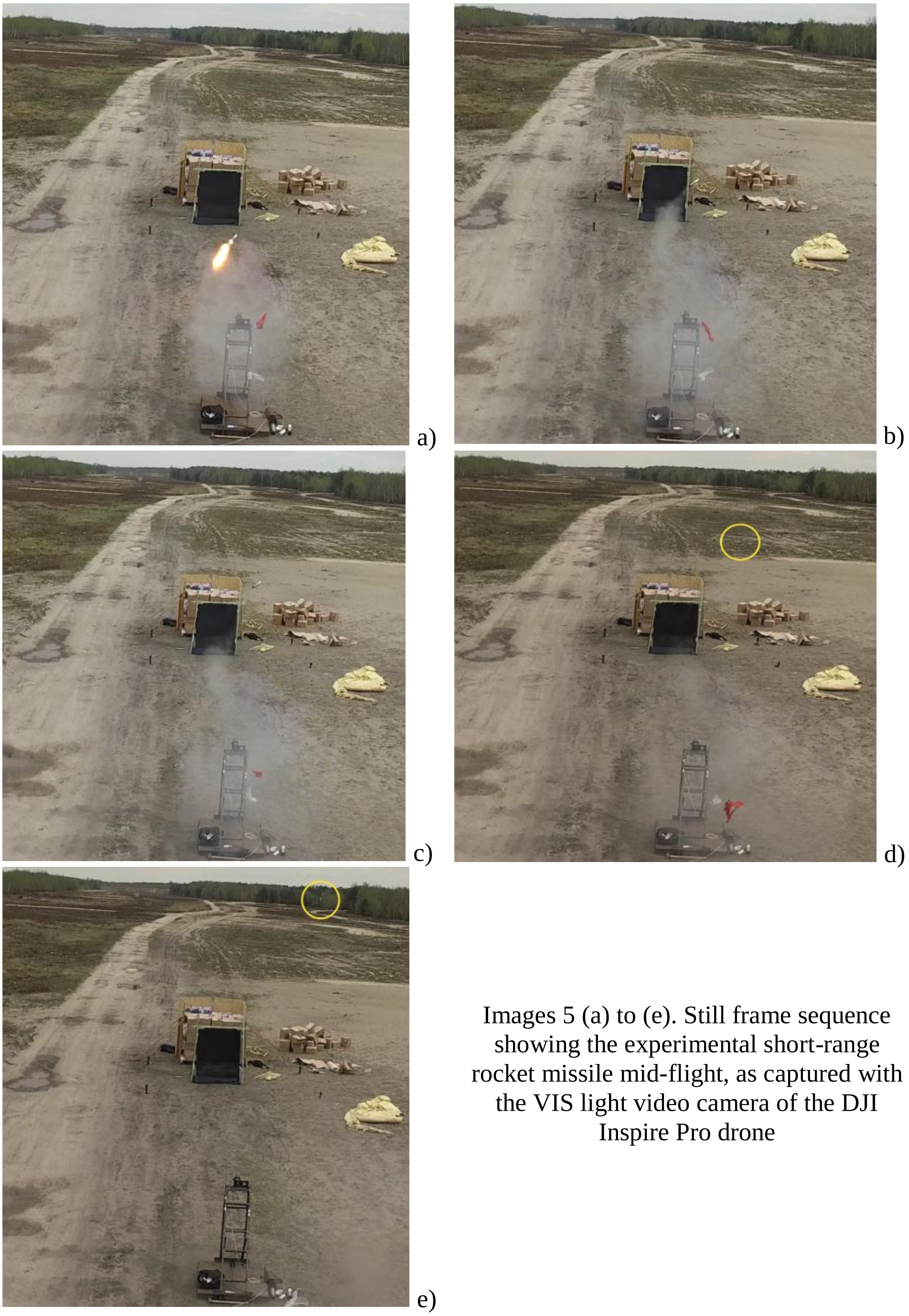
If a rocket missile missed the target, its flight path past the target was monitored with the video cameras of the drones. See below for sequences of selected still frames from the VIS light video camera (Images 5 (a) to (e)) and the IR video camera (Images 6 (a) to (d)) which recorded further flight stages of the same rocket missile. Images 5(d), 5(e), 6(a) and 6(d) show the rocket missile circled for easier identification.

The still frames recorded with the VIS light video camera (Images 5 (a) to (d)) and the IR video camera (Images 6 (a) to (c)) allowed a good determination of the rocket missile's position in its initial flight stage, i.e. between the launcher and the target; the IR still frames helped locate the rocket missile quite easily in its initial flight stage by a well-defined thermal signature of the combustion products exiting the jet of the rocket motor combustion chamber. The combustion products were identifiable for a longer time in IR imaging than in VIS light imaging. During the further flight stage, which was several dozen and several hundred meters past the target, the rocket missile was observed with the VIS light video camera only (see Image 5(e)).

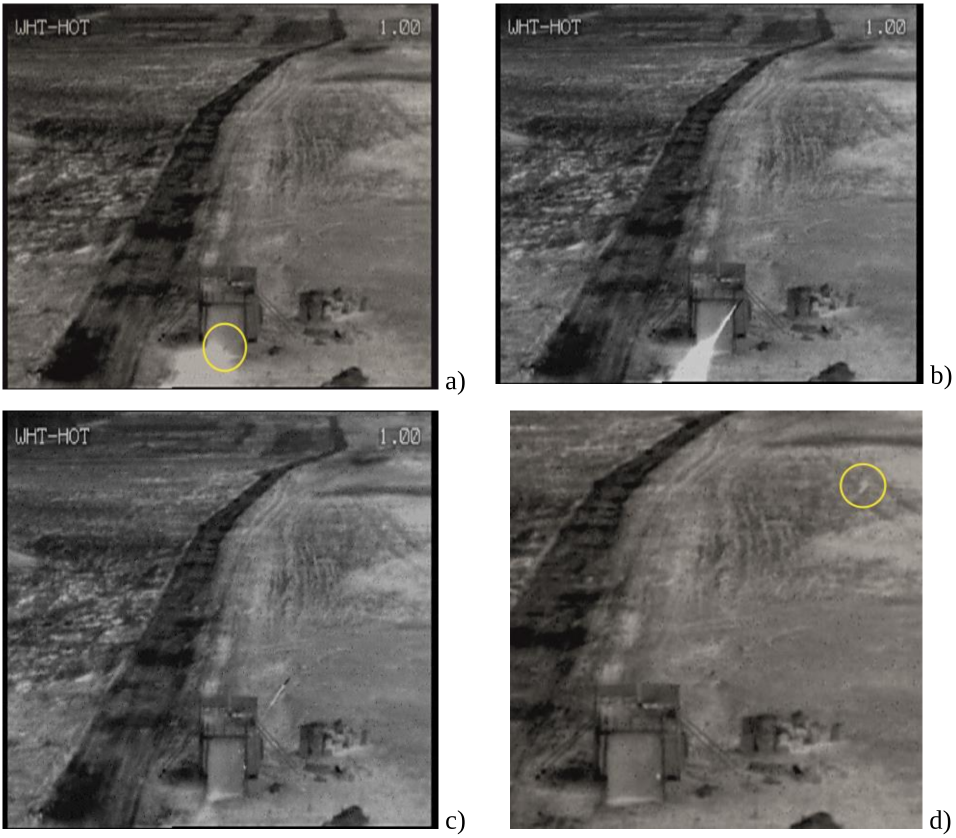
Once the location of the rocket missile's landing site was roughly estimated from the final still frames of the VIS light video camera recording (from the DJI Inspire Pro drone), the Bielik drone (with the IR video camera) and the proving ground staff were dispatched to find the rocket missile.

With the Bielik's IR video camera, the rocket missile was located resting on the ground approximately 300 m from the target and with a readily distinguishable thermal signature against the background of the soil, and remained distinguishable as such for more than 15 minutes from firing (see Image 7).

Once the rocket missile was found, its inertial guidance head and flight recorder assembly, shown in Image 8, were separated from the propulsion stage.



Images 5 (a) to (e). Still frame sequence showing the experimental short-range rocket missile mid-flight, as captured with the VIS light video camera of the DJI Inspire Pro drone



a) b) c) d)

Images 6 (a) to (d). Still frame sequence showing the experimental short-range rocket missile mid-flight, as captured with the IR video camera of the Bielik drone

Image 7. Proving ground workers seen finding (as guided by the Bielik drone operator) the experimental short-range rocket missile (shown as the thermal hot spot in the lower part of the picture)

Image 8. Inertial guidance head, containing the flight recorder, traced by the Bielik drone operator (note the slight damage to the head's casing)

3. CONCLUSIONS

VTOL UAVs, one with a VIS light video camera and another with a thermal imaging (IR) video camera, proved to be capable in locating experimental rocket missiles, which moved at approximately 200 m/s in mid-flight and missed their target. The VIS video camera observation of the rocket missile's flight past the target, in the end stage of flight, facilitated an approximate determination of the missile's landing location; the IR camera observation of the same facilitated a precise location of the landed missile in the field, especially when overgrown with vegetation (which was predominantly grass, shrubs, and isolated trees).

If attempted with a thermal imaging camera, the location of a rocket missile on the ground should be ascertained as soon as possible after its landing, and while the outer surface of the rocket missile is still hot (mainly due to the fuel combustion products), being a well-defined hot spot against the much colder background of the soil.

A more precise observation of rocket missiles in mid-flight at a velocity of approx. 200 m/s with a thermal imaging video camera would require an IR camera with performance at least equivalent to that of the VIS light video camera used in the application presented herein, i.e. an IR CCD with a minimum resolution of 1920 × 1080 pixels and a recording frame rate of at least 100 fps.

This would enable loading out a single drone with a VIS light video camera and the specified IR video camera. However, a single UAV platform would require a common stabiliser for both cameras. The optical axes of both cameras placed on a common stabiliser should be parallel, and the FOVs of both cameras should be approximately equal.

Directly before launching an experimental rocket missile, the lenses of the visual observation drone cameras should monitor the landing site (projected in different scenarios).

The authors recommend the installation of a device capable of outputting the geographic coordinates of the rocket missile's landing site, e.g. a GPS receiver, onboard the UAV.

REFERENCES

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ZASTOSOWANIE OBSERWACYJNYCH, BEZZAŁOGOWYCH STATKÓW POWIETRZNYCH DO BADAŃ POLIGONOWYCH

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Streszczenie. W artykule przedstawiono zastosowanie dwóch obserwacyjnych dronów powietrznych pionowego startu i lądowania do badań prowadzonych na poligonie Wojskowego Instytutu Technicznego Uzbrojenia. Jeden z dronów wyposażony był w kamerę wizyjną, zaś drugi – w termowizyjną. Z obu dronów jednocześnie rejestrowano obraz lotu eksperymentalnego pocisku rakietowego krótkiego zasięgu, wyposażonego w głowicę inercyjną zawierającą pokładowy rejestrator. Opisano stanowisko badawcze do badań poligonowych, w tym usytuowanie dronów względem wyrzutni rakietowej i tarczy do wychwytywania pocisków rakietowych. Zaprezentowano także dwie sekwencje wybranych zdjęć z filmów uzyskanych za pomocą kamer zainstalowanych na dronach, rejestrujących lot pocisku w przypadku nie trafienia w tarczę. Obserwacja pocisku po minięciu tarczy, zwłaszcza w końcowej fazie jego lotu za pomocą kamery wizyjnej, umożliwiła określenie w przybliżeniu miejsca upadku pocisku, zaś dzięki zastosowaniu kamery termowizyjnej możliwa była precyzyjna lokalizacja pocisku w terenie. Oba drony okazały się zatem przydatne do odnajdywania na terenie poligonu eksperymentalnych pocisków rakietowych, w sytuacji gdy te nie trafiały w tarczę.

Słowa kluczowe: balistyka zewnętrzna, drony, pocisk rakietowy, poligon, kamery obserwacyjne