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Mobile complex augmented reality to control the aircraft

The article describes a stereoscopic version of "tunnel-in-the-sky" visual interface, that has no direct analogues and is implemented as an autonomous pocket-size augmented reality system, made of inexpensive components and free from flaws inherent to existing computer and enhanced vision systems.

Keywords: augmented reality, computer vision system, enhanced vision system, aircraft control.

Introduction

A pilot visual interface termed "tunnel-in-the-sky" (TS) has been known for nearly 20 years. As early as the 1990s, prototypes of aircraft (AC) control systems with TS were successfully tested at real airplanes (e.g. a system developed in the Stanford University [1]). In spite of their advantages, Synthetic Vision Systems (SVS) with TS (Fig.1) [3] up till now have not found wide use in practice, though they remain within researchers' view [2] and are available for pilots through the use of today's head-up displays (HUD).

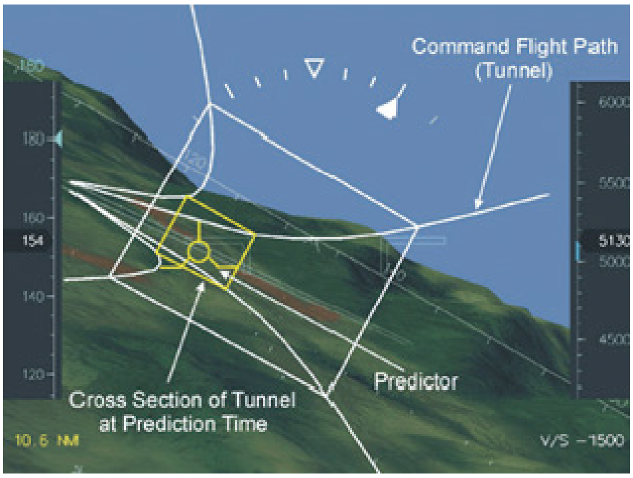

Fig. 1. *SVS* display with HT

The current situation around the TS concept seems to have two main reasons: 1) progress in automatic flight control technique reduced the importance of TS for large commercial airliners and existing developments are not compact and cost-efficient enough for general-purpose aircraft; 2) current display of 3*D* TS structures on standard flat screens of *SVS* and *HUD* gives no considerable gain versus traditional Primary-Flight-Displays (PFD) [4].

This article describes a prototype with a TS stereoscopic version made as an Augmented Reality Mobile System (ARMS) free from above-mentioned flaws because: 1) it employs inexpensive components such as light-weight (less than 150 g), transparent AR glasses with built-in tracking, and a mobile device that works as a controller, which makes the system self-powered and literally pocket-size; 2) it implements a stereoscopic TS representation in the form of three-dimensional frames, i.e. in 3*D*-AR stereo mode.

In 3*D*-AR stereo mode, with the minimum added digital indication and visual structure remarkably simple and natural for human perception, makes TS an alternative for any *PFD* navigation indicators. 3*D*-AR stereo mode offers the following important advantages over *PFD* markings on *HUD* and TS imaging on a separate flat screen:

use of transparent AR-glasses excludes excess mental loading, since, unlike *SVS*, they do not require correlation between sectors of vision and image scale of the real world and the display picture [4];

TS-forming frames are three-dimensional and oriented along the horizon line (Fig. 2). In stereo perception, it allows for highly accurate visual estimate of aircraft yaw, bank and pitch angles in a manner familiar for a human being, thus skipping a mental conversion of symbolic information and estimation of these angles as is done in case of *PFD* use [5].

stereo 3*D*-AR eliminates the problem of attention distraction characteristic of *HUD* [6],

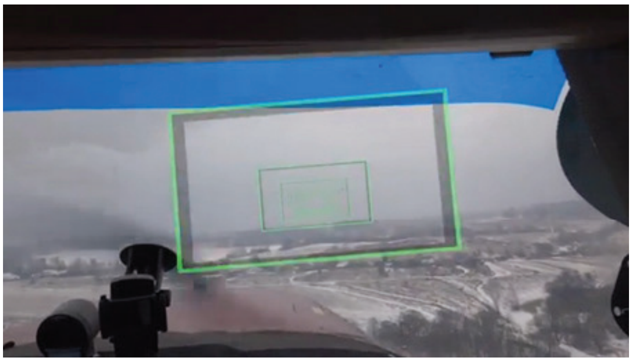

Fig. 2. A combined reality image generated by ARMS in flight. View through the cockpit windshield

because TS frames act as navigation indicators and become a part of the real world picture.

The nearest analogues to the solution offered are *Enhanced Vision Systems, EVS,* consisting of an infrared camera on the nose of the aircraft and an *HUD*, that are used in the latest-generation aircraft (of *Boeing* 787 type). Unlike TS implemented in *EVS*, the developed engineering solution is mobile (i.e. requires no special installation works, as almost all its components are of pocket size) and less expensive (tens of times); it allows for better spatial orientation thanks to stereo-imaging of virtual markers placed in the real world, and reduces workload on pilot, as switching of pilot's attention and mental conversion of navigation information are not needed.

Fig. 3 shows technical facilities that formed the ARMS prototype. Linear coordinates for the experimenter's head were obtained with the help of a certified aviation *GPS*-receiver and a *GPS*-receiver of the mobile device. Under experiment conditions, the *GPS*-receiver of the mobile device gives more exact *GPS*-coordinates through the use of smoothing algorithms. The ARMS was powered by a compact car battery.

Angular coordinates for the head of the experimenter sitting next to the pilot were obtained from micromechanical gyroscopes and accelerometers integrated into the augmented reality glasses, and an infra-red tracker whose camera was placed above the instrument panel.

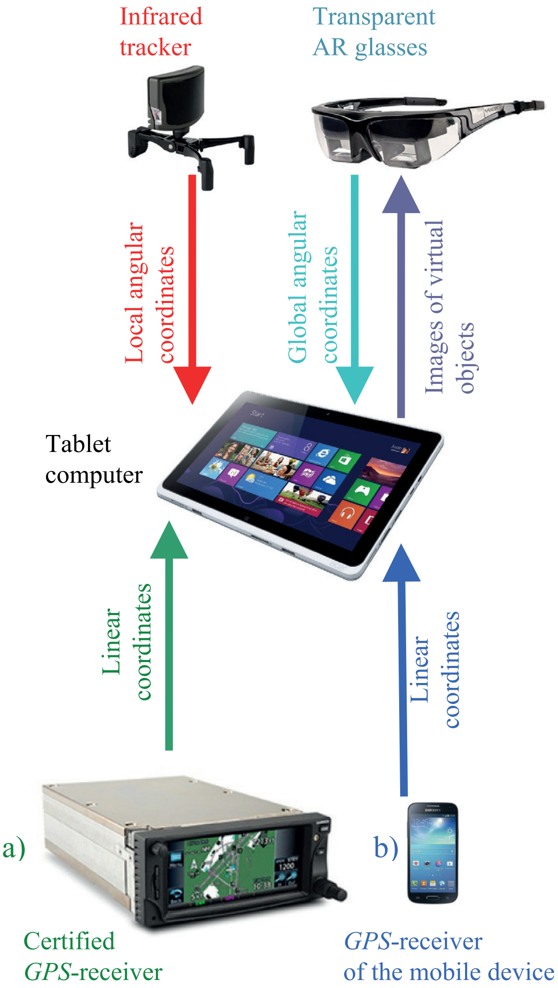

Fig. 3. ARMS hardware (converters, controllers, and adapters that connect the components are omitted in the picture):
a) an option with a certified *GPS*-receiver;
b) an option with a *GPS*-receiver of the mobile device

In addition to the equipment mentioned, a monitoring camera was fixed on the experimenter's head and recorded real world picture during the experiments (Fig. 4).

Object testing

A visual check of flying along a virtual trajectory in real space and reconstruction, in the testing process, of the augmented reality picture observed, through the use of video reconstruction that combined a video record from the monitoring camera and a virtual trajectory built on linear and angular coordinates of the experimenter's head recorded in the course of testing, were performed during a flight test for visual inspection of the ARMS interface and its positioning capacity.

Fig. 3. An infrared camera and a monitoring camera

The tests were performed with a light airplane under the following flight plan: procedure – two 180° turns; after take-off – 2 minutes of straight ascent flight followed by a left turn ascending to 200 m; passing the beam while turning on base leg, left turn to landing heading; distance 1 km from the runway threshold.

A “tunnel-in the-sky” virtual trajectory made up of several green frames, with dimensions WHD 40x20x10 m and wall thickness of 1 m, spaced at intervals of 200 m, was plotted according to the flight plan.

The testing took place in a layer of clouds, at altitude of 1,000 m and visibility of more than 2,000 m. The sequence of four flights was performed, two of them carrying a GPS-receiver of the mobile device and two of them carrying a certified GPS-receiver. The first flight with a GPS-receiver of the mobile device offered good conditions for observation of navigation satellites (not less than five), that assured correct positioning of the virtual trajectory. In three other flights, an unstable number of the navigation satellites observed, that dropped down to 1, allowed for correct positioning of the virtual trajectory for several flight legs only. The number of navigation satellites observed was controlled with the on-board *GPS*-receiver.

The following intermediate conclusions stem from the test results:

1. Stable operation of satellite navigation provides for reliable space positioning of the virtual trajectory.

2. Because of flares that appear when sunlight reflects from side and rear glasses in the cockpit, the infrared tracker that corrects drift in micromechanical sensors producing a yaw angle works steady in dull weather and unsteady in sunny weather, even in the absence of direct sun outage.

The problem was solved by placing a metallized semi-transparent film in front of the infrared camera with light-emitting diodes used as active targets of the tracker. This solution cannot be called an optimum one, as tracker targets should be put on the glasses (that makes their use less convenient) and the infrared camera wired to the processor, on the windscreen (that clutters workspace in the cockpit). In the future, it should be a good practice to abandon the infrared tracker in favour of experimenter’s head positioning in yaw angle with the help of computer vision methods and use of a video camera integrated in the augmented reality glasses.

3. The glasses used for testing cannot give sufficiently bright image of virtual objects to observe them at daytime against the sky even in dull weather. In the future, glasses with virtual objects brightness of not less than 5,000 Nits (kd/m^2) should be used.

Bench testing with cockpit simulator

Pilot’s visual interface simulator includes two tablet computers connected via a wireless channel (through a *Wi-Fi* router) that makes it flexible enough to be placed in different simulators of cockpits. The first tablet manages the simulation

Table 1

Description of Experiments

Independent variable (type of visual interface)	Dependent variable	Task	Technical environment of testing	Description of test
Experiment 1. Comparing the visual interfaces efficiency in minimum time for capturing of planned trajectory				
a) three-dimensional “tunnel-in-the-sky”: three-dimensional frames in stereo mode; b) flat ’tunnel-in-the-sky’; flat frames in mono mode	Time for capturing of planned trajectory	Capture the planned trajectory as soon as possible. Capture criterion: deviation from trajectory makes less than 10 m in 5 minutes	1. Full-flight simulator *Airbus A320 Touch Screen Trainer*. The simulator creates effect of presence in a cockpit of a real aircraft. 2. ARMS for aircraft control. The visualization is implemented through the use of combined reality glasses, the virtual aircraft is controlled with a joystick. Visualization coordinates a demonstrated image of 3D-objects and motions of experimenter’s head. Joystick slider simulates the control of aircraft control rod	1. Imitation of a night flight with zero visibility through the cockpit windows: the room is darkened. 2. The subject’s glasses receive a stereo image of visual interface of a) and b) types. 3. Starting point is 300 m horizontally and 100 m vertically from the planned trajectory, the aircraft controlled with zero pitch is directed perpendicular to the planned trajectory. 4. The subject controls the moving virtual aircraft with the joystick of the ARMS simulator to bring the virtual aircraft to the trajectory set by virtual markers
Experiment 2. Comparing the visual interfaces efficiency in minimum deviation during flight along desired trajectory				
Same as in experiment 1	Average deviation from the desired trajectory	Keep the airplane on the planned trajectory as precisely as possible	Same as in experiment 1	1–2– same as in experiment 1. 3. The subject controls the moving virtual aircraft with the joystick of the ARMS simulator to keep the virtual aircraft on the trajectory set by virtual markers

process (start/stop, various modes of debugging, etc.) and, at the same time, enables visual monitoring of the picture the user receives via augmented reality glasses. The glasses and joystick used by the user to control the virtual aircraft are connected with the second tablet via USB interfaces (glasses sensors, joystick) and *HDMI*.

Experiments with ARMS simulator

Experiments (Table 1) involved two groups of subjects, each consisting of 12 students of MGTU GA who had gaming experience with aircraft flight computer simulators. The tests were performed in the presence of an instructor-researcher. The subjects in the first group performed experiments 1a and 2a, in the second group – experiments 1b and 2b (the figure stands for the experiment number, the letter means a type of an independent variable from Table 1).

Preliminary procedures. Each subject received a short briefing (5 minutes) and a training session (5 minutes) for gaining skills of virtual aircraft control thought the use of a joystick.

Post-testing procedures. Each subject passed *NASA-TLX* [7], a test developed in the 1980s in *NASA Ames* research center for a comparative analysis of loads on the aviation personnel (pilots, technicians, controllers, etc.). The test was being developed for 3 years and involved more than 40 research groups. Now it has found wide use in aerospace industry as well as in other industries.

NASA-TLX, a multivariate rating procedure, is a weighted average based on 6 evaluative factors:

1 – Mental Demand;
2 – Physical Demand;
3 – Temporal Demand;
4 – Performance;
5 – Effort;
6 – Frustration.

During deriving of a final grade, the weight of each factor is obtained from the answers the subjects give when offered to compare pairs of factors. Values of grades in each factor are found from 10-step scales used after completion of each test task. Sensitivity of the test is assured by variation of the factors' weights.

NASA-TLX is a two-step procedure that includes assessment of weights and factors.

In the first step, the subjects are to assign weights to factors in accordance with individual evaluation of their contribution to the final demand. This information is then used for revealing of distinctions in expert approaches and dissimilarities in criteria importance for accomplishing of various tasks.

In the second step, the subjects are to assess the factors, through the use of 20-sectioned scale, each scale weighing 5 with 0 as a minimum value and 100 as a maximum value. The scales are supplied with opposite descriptors of weak/strong type. The assessment results are given in Table 2.

Conclusion

The results of ARMS bench testing have supported the hypothesis that pilot's visual interface of "stereoscopic three-dimensional virtual tunnel" type has greater efficiency. The results of the flight experiments have proved the system capacity for correct positioning of the virtual tunnel.

ARMS may be positioned as a back-up device for commercial airliners, applicable in emergency situations when standard equipment develops troubles, especially during landing under reduced visibility. In the future, ARMS may become the main navigation instrument for general-purpose aircraft, as it is low-cost, mobile and simple in use.

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Table 2

Bench testing results

"Tunnel-in-the-sky" type	Average values		
	time of planned trajectory capture, sec	deviations from desired trajectory, m	NASA-TLX load assessment
a) Three-dimensional "tunnel-in-the-sky": three-dimensional frames in stereo mode	27.1	33.41	42.92
b) Flat "tunnel-in-the-sky"; flat frames in mono mode	28.2	65.93	48.42

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