LOW-COST 3D-DISPLAY SYSTEM FOR LIGHT AIRCRAFT

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Abstract

A low-cost 3D-display system comprising Commercial-off-the-Shelf components is described, aimed at presenting guidance information in a 3-dimensional format. The 3D-display system is based on a guidance concept providing the pilot with command and status information not only of the current but also of future flight conditions. An outside world image and integrated guidance elements (command flight path and predictor indicating the future position of the aircraft) are displayed. An efficient computer software has been developed which is capable of generating the 3D-display imagery at a high update rate using low-cost PC based hardware. For adjusting the 3D-display imagery according to the actual flight condition, a low-cost navigation system is used.

1 Introduction

3D-displays providing the pilot with information in a 3-dimensional format offer an improvement in the guidance and control of aircraft, particularly for flight in poor visibility. They display status and command information not only of the current situation but also of the future. The guidance information is presented in a pictorial form, thus allowing an intuitive access by the pilot. As a result, the mental effort of the pilot for reconstructing the spatial and temporal situation may be reduced. Recent research on 3D-displays, including conceptual work and verifying experiments, shows promising results (Refs. 1-19).

Performance improvements in computer technology, especially in 3D graphics capabilities, allow the generation of 3-dimensional guidance information including an outside world scenery in real-time with a high update rate using PC hardware. Similarly, progress in navigation technology makes low-cost systems available. As a result, 3D-display and navigation systems are possible on a low-cost basis, using Commercial-off-the-Shelf components. Thus, they become affordable for light aircraft which, so far, have to rely on simpler instrumentation and navigation aids.

In this paper, a low-cost 3D-display system is described which presents an integrated imagery consisting of 3-dimensional guidance information and a realistic outside world image for application to light aircraft.

Experience of the Institute of Flight Mechanics and Flight Control of the Technische Universität München in the 3D-display field will be used to realize such a system as a project of the Bayerische Luftfahrtforschungs- und -technologieprogramm (Bavarian Aeronautics Research and Technology Program). The partners of this project are industry companies and a university institute:

- ESG Elektroniksystem- und Logistik-GmbH, München
- ETG Euro-Telematik AG, Ottobrunn
- Michael Stock Flight Systems, Berg/Farchach
- Reiser Systemtechnik GmbH, Berg/Höhenrain
- VIRES Simulationstechnologie GmbH, Rosenheim
- Institute of Flight Mechanics and Flight Control of the Technische Universität München

2 3D-Display

2.1 3D-Display Guidance Concept

The low-cost solution for the 3D-display system comprises the following main elements:

- Guidance concept featuring command and status information in 3-dimensional format
- Software with efficient data management for generating 3-dimensional guidance information at high update rate
- Low-cost PC based computer hardware
- Low-cost navigation system
- Air data system

The guidance concept is the basis for the low-cost 3D-display system, aiming at an improvement in the guidance and control of the aircraft by providing the pilot with command and status information in a 3-dimensional format. This is illustrated in Fig. 1 which shows a 3D-display presenting the command flight path and a predictor. With this type of display, command information and preview are available. With the use of preview, the pilot can structure a control feedforward, permitting him to anticipate the future flight path, as shown in Fig. 2. The predictor (Fig. 1) shows the position of the aircraft at a specified time ahead. It indicates, with reference to the command flight path, the future position deviation. The pilot can act in response to this deviation for minimizing system errors in the presence of command and/or disturbance inputs. From a control point of view, the prediction capability of a perspective flight path display is therefore an issue primarily related to compensatory control, Fig. 2.

The compensatory control issues are addressed in Fig. 3 which shows a block diagram for the predictor (lateral dynamics). A predictor control law which is based on pilot-centered requirements for achieving best control performance of the pilot-predictor-aircraft system and on geometric-kinematic properties for realistically describing the continuation of the flight path reads

$$Y_{PR} = K_{PR}\, g \frac{(T_{PR}^2/2)s^2 + T_{PR}s + 1}{s^2} \tag{1}$$

With the aircraft dynamics model valid for the frequency region of concern

$$Y_C = \frac{L_{\delta_a}}{s(s+1/T_R)} \tag{2}$$

the transfer function of the open-loop predictor-aircraft system can be expressed as

$$Y_{PR}Y_C = K_{PR}\, g L_{\delta_a} \frac{T_{PR}^2}{2} \frac{s^2 + (2/T_{PR})s + 2/T_{PR}^2}{s^3(s+1/T_R)} \tag{3}$$

With regard to this system, the pilot operates on visually sensed inputs (deviation of predictor position indicated in 3D-display) and exerts manual control outputs. Proper design of the predictor control law yields best control performance of the pilot-predictor-aircraft system.

2.2 3D-Display System Software

An efficient software has been developed for real-time generation of the 3-dimensional guidance information at a high update rate, using low-cost computer hardware. This is considered an essential constituent of the 3D-display system. Main elements are

- Hierarchical adaptive triangulation technique for terrain data management
- Level-of-detail control
- Data organization for reducing required computer memory
- Reloading capability during runtime

The data management scheme is illustrated in Fig. 4. Position and attitude data are available from a navigation module, using the CAN Aerospace Interface. The navigation data is transferred to a shared memory segment at a rate of 50 Hz. The synthetic vision module uses navigation data for generating a terrain image in a 3-dimensional format. The tunnel manager is concerned with the command flight path which is displayed in the form of a tunnel. A moving map module is available for generating an overview of the terrain.

There are three objectives for an efficient data management concerning the guidance application in mind: high degree of data compression, level-of-detail control and reloading capability of memory segments at runtime. For achieving these objectives, a hierarchical interpolation method similar to the system proposed in Ref. 20 is used.

For hierarchical terrain elevation data interpolation, rectangular areas are used to which hierarchical levels are assigned (Fig. 5). Each elevation value is related to its hierarchical predecessors. The difference between interpolated and actual values, the hierarchical surplus of the underlying branch, is stored in each node. Every node is separately allocated in memory and connected with pointers in the tree.

A level-of-detail function is introduced, providing control over the resolution with regard to the displayed terrain imagery. Objects farther away from the observer are presented with a lower resolution than those which are nearer. Thus, a smaller number of triangles is needed to generate the mesh. The level-of-detail function used for this process checks with the hierarchical surplus stored in every node as to what resolution the mesh parts are generated.

The developed software has a reloading capability for terrain elevation and feature data at runtime. Such a feature is required for flights over large terrain areas the data of which cannot be completely stored in the main memory. Basically the software structure shows two processes (Fig. 6). One process is concerned with constantly updating the graphics display. The other process launches a reloading event if the aircraft approaches a border of the area the data of which are stored in memory.

The software has a performance of generating the 3-dimensional guidance imagery with an update rate of 25-30 Hz, using low-cost PC based hardware described in the following section.

2.3 Hardware

For generating the 3-dimensional guidance information, a slot-card personal computer (800 MHz, Pentium, OS Linux, 256 MB) with a 3D-accelerated graphic-card (NVidia GeForce 2) is used (Fig. 7). The CAN bus is a two-wire multi-transmitter serial data bus for real-time data transmission.

The navigation system comprises an attitude and heading reference unit, an integrated Air Data measurement unit, an externally mounted magnetic heading fluxgate sensor and a DGPS receiver (Fig. 8). The attitude and heading reference unit includes a rotating inertial sensing platform containing the following elements:

– Three orthogonally mounted angular-rate Coriolis force vibrating gyroscopes
– Three capacitive accelerometers aligned with the axes of the gyroscopes
– A stepper motor with associated gear driving mechanisms
– A pre-programmed microcontroller with associated electronics
– Mechanical components

The attitude and heading reference unit which operates at a refresh-rate of 50 Hz shows the following data:

Angular rate:	+/- 75° pitch/roll
	+/- 68° yaw
Normal acceleration:	+/- 12 g
Accuracy:	+/- 0.5° pitch/roll
Power supply:	9 - 18 VDC / 1 A
Operation:	-20° C to +85° C
Size:	145 × 145 × 130 mm
Weight:	2.0 kg

Furthermore, the aerodynamic control surface deflections (elevator, aileron, rudder) and the position of the power lever are measured and recorded. For this purpose, an analog/digital converter is used which receives the signals from control position transducers. These data are then transferred to the 3D-display computer via CAN bus.

A LCD display at which the 3-dimensional guidance imagery is presented to the pilot is installed in the research aircraft of the Institute of Flight Mechanics and Flight Control of the Technische Universität München. It is positioned at the right side of the instrumentation panel (Fig. 9), for the test pilot. There are conventional instruments at the left side for the safety pilot. The LCD display has a screen size of 10.4", providing a resolution of 640 × 480 pixels at a minimum refresh rate of 60 Hz and a brightness of 1600 cd/m^2.

Conclusions

A low-cost 3D-display system which presents guidance information in a 3-dimensional format to the pilot has been developed for use with light aircraft. The 3D-display system is based on a guidance concept providing the pilot with command and status information not only of the current but also of future flight conditions. The 3-dimensional visual information comprises an image of the terrain (elevation and features) and integrated guidance elements including a tunnel for showing the command trajectory and a predictor indicating the future position of the aircraft at a specified time ahead. An efficient computer software has been developed, capable of generating the 3D-display imagery at a high update rate using low-cost PC based hardware. For adjusting the 3D-display imagery according to the actual flight condition, a GPS and attitude reference navigation system is used.

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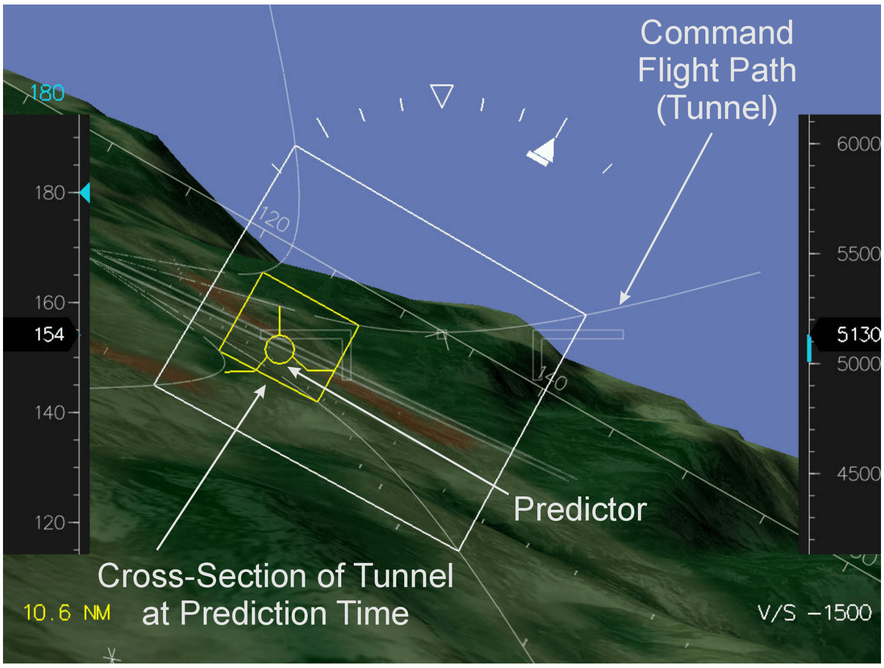

Fig. 1 Display presenting command trajectory and predictor in 3-dimensional format

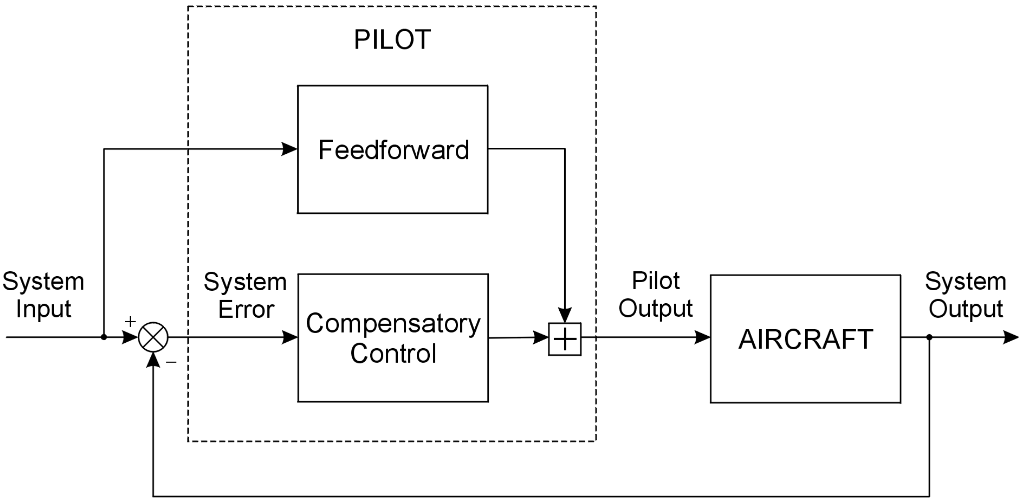

Fig. 2 Model for aircraft control with feedforward and compensatory control

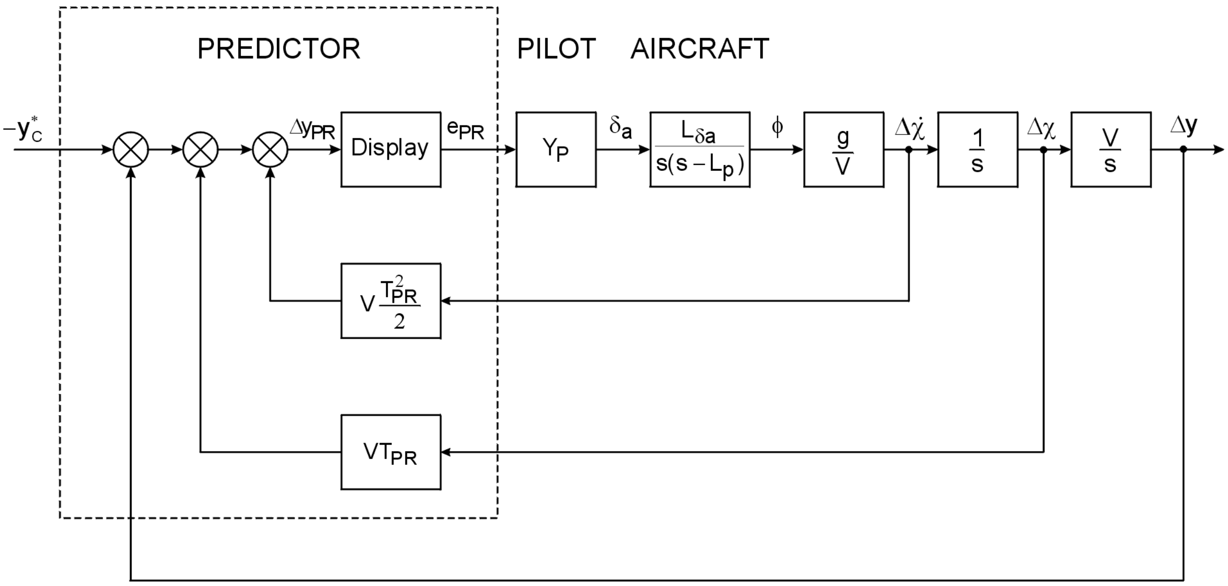

Fig. 3 Block diagram for predictor (lateral dynamics)

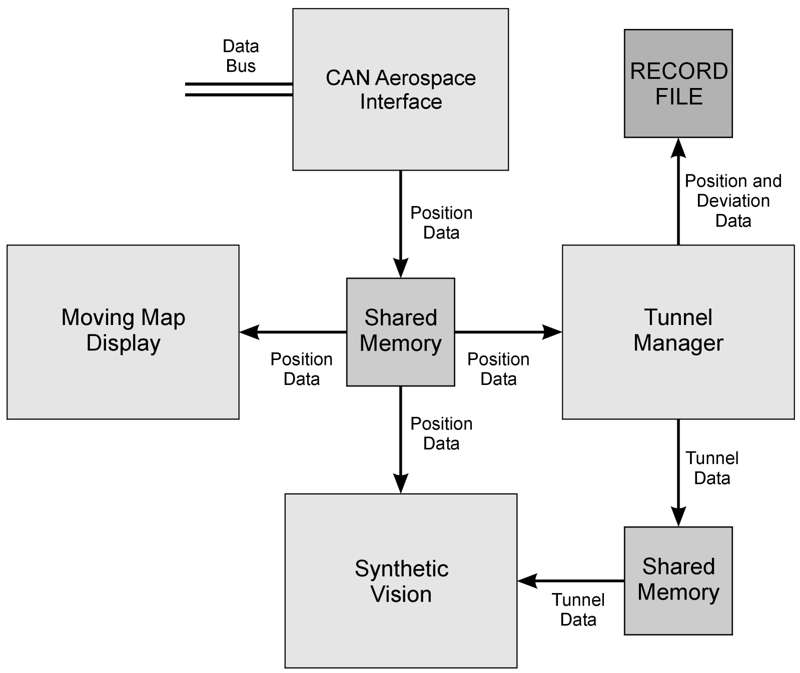

Fig. 4 Data management

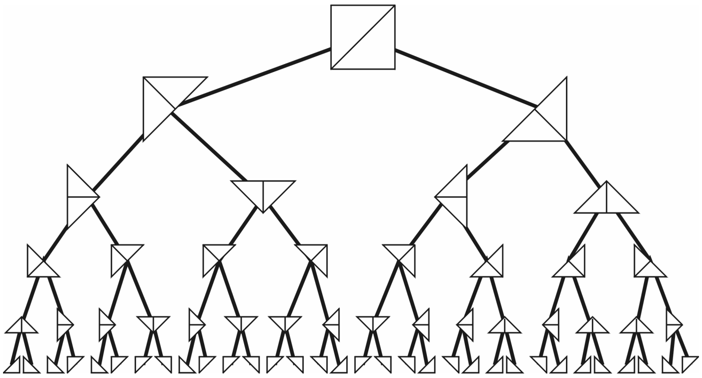

Fig. 5 Hierarchical adaptive triangulation of terrain elevation data

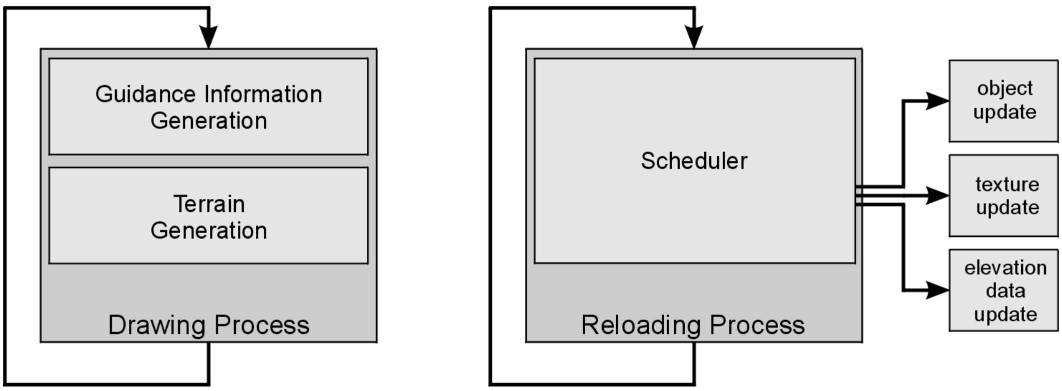

Fig. 6 Reloading scheme

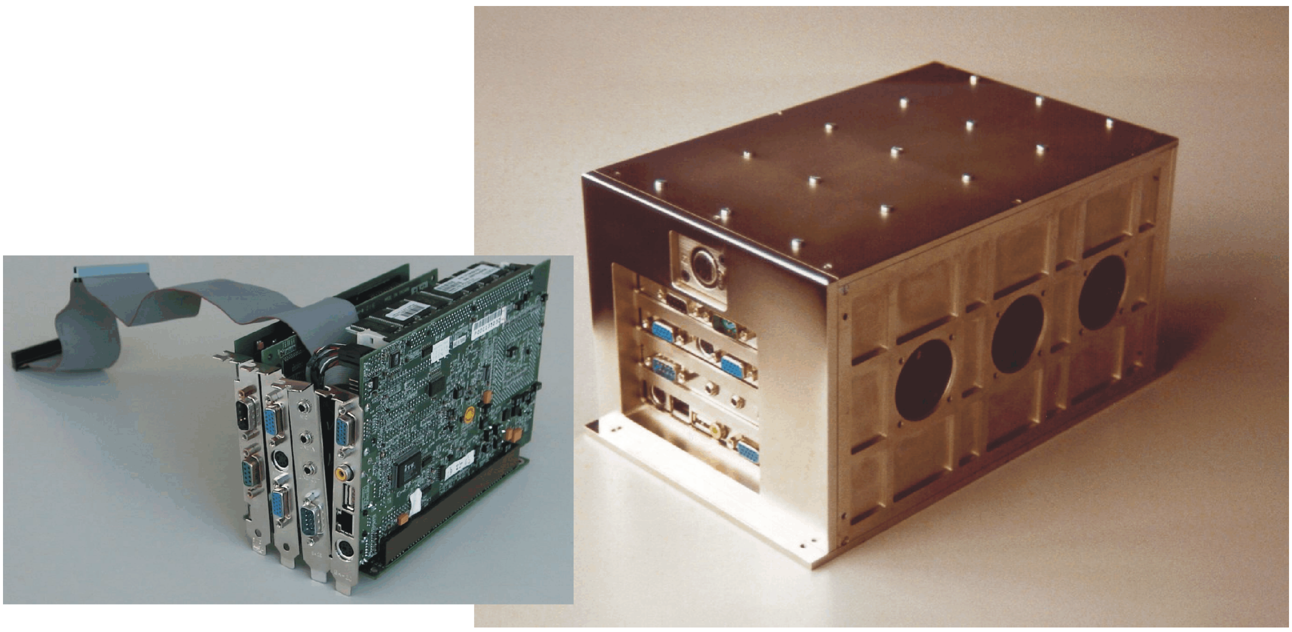

Fig. 7 Computer for 3D-Display

Fig. 8 Navigation component

Fig. 9 Display installed in research aircraft