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HARDWARE-IN-THE-LOOP SIMULATION OF 3D COORDINATES DETERMINATION SUBSYSTEM BY USING MODIFIED METHOD OF STEREOPAIRS

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Abstract: The question of determining three-dimensional coordinates of a visual object (aircraft) arises in the air and runway areas of airports where radar systems are ineffective. The main objective of the work is to develop and improve basic algorithms and basic hardware structures for optimal calculation of three-dimensional coordinates of a visual object in real time. This article discusses hardware-in-the loop simulation and further development of subsystems for determining coordinates of an object identified on the video image of an airport's runway and surrounding area. This paper documents the hardware and software implementation of an algorithm used to calculate three-dimensional coordinates of a visual object by using the modified method of stereopairs. Namely, processing of incoming analog signals, binarization of the frame taken from a video by cropping, and determining coordinates of the object for each image (out of three images) by its center of weight, and then calculation of 3-dimensional coordinates by using the modified method of stereopairs. The developed system is designed to support the existing flight safety control systems used at control towers, and to provide a display of a real situation at airports within view of a video camera. For the subsystem to be modeled and verified for proper operation, we used a video with known coordinates of a reference plane for each frame. The results obtained through the simulation of an automatic subsystem for the determination of aircraft coordinates are quite close to the actual coordinates of a real object and do not exceed 2 % error. Apparently, the program testing has shown good outcomes that indicate the correct implementation of the algorithm.

Key words: 3-dimensional coordinates, modified method of stereopairs, determination of coordinates, binarization, visual control.

1. Introduction

One of the actual tasks concerning an airport airspace monitoring is identification and determination of spatial coordinates of airplanes in order to prevent emergencies in the air and land areas of the airport because of the possibility of unauthorized access to runways. Among such unauthorized accesses are airplane landing to wrong runways, landing without keeping correct altitude and direction settings, etc. These problems are emphasized when visual monitoring of the airspace is carried out either at dusk, dawn, or in difficult weather conditions such as rain, fog, mist, etc., that lead to poor visibility.

Therefore, solving the tasks of visual identification of airplanes and determination of their spatial coordinates becomes topical. These tasks having been solved, it will be possible to design cheap distributed computation modules capable to automatically detect landing airplanes and determine their coordinates. These modules will enable the images to be loaded, processed and transferred to the airport's personnel computers. This is the place for processing images of the airport airspace with the airplanes marked and the spatial position determined even in conditions of poor visibility and outside the radar visibility at low altitudes. Consequently, safety of vehicles and people being at airports near the place of airplane maneuvering will increase.

2. Statement of the problem

The main aim is hardware-in-the loop simulation and further development of subsystems for determining coordinates of the object identified on a video image of the runway and of the airport airspace. The objective of these studies is to develop competent means for calculating coordinates of an identified aircraft.

3. Coordinate determination subsystem

An automatic subsystem of coordinate determination provides a visual determination of coordinates of the planes identified in the runway area and in the airspace adjacent to the airport in real time. The system developed is intended to support the existing flight safety control systems used at control towers, and to provide a display of a real situation at airports within view of a video camera.

Technically such system consists of (Fig. 1):

- a camera, which forms images;
- an image input block, which converts a digital signal into an analogue one;
- an image processing block, which provides binary images and determines coordinates of an aircraft within view of a video camera;

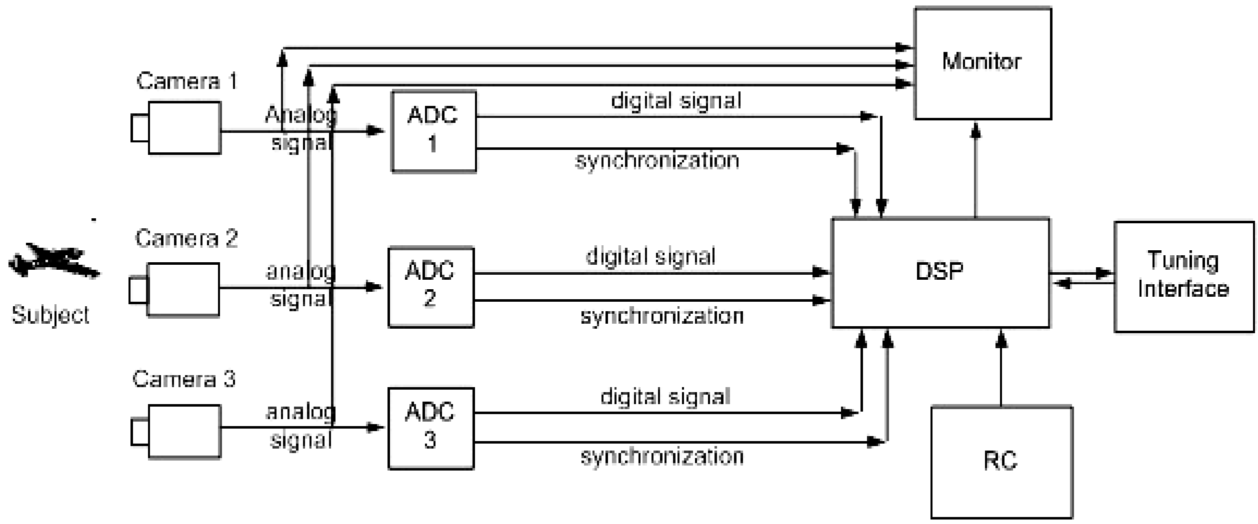

Fig. 1. Block diagram of a coordinate determination subsystem.

- a monitor for an operator to observe an air situation;
- a control panel for adjusting of the system for its real-time operation;
- an adjusting (tuning) interface, which provides a connection with a PC.

The microprocessor subsystem has been built based on a DSP56F8367 as a part of the MC56F8367EVM module. This microprocessor does not need a large number of enhancements, as it contains a basic set of peripherals required for the system.

4. Coordinate determination method

Having previously been compressed, the data from the cameras are stored in the memory of the microprocessor. An identified object is represented by an array, which stores the coordinates of the object's pixels. Accordingly, by finding a minimum value with respect to *x* and a minimum with respect to *y*, a minimum with respect to *x* and a maximum with respect to *y*, a maximum value with respect to *x* and a minimum with respect to *y*, a maximum with respect to *x* and a maximum with respect to *y*, four key points – "corners" of the object - are determined. Another point is taken as the geometric center of the target by the arithmetic mean of the coordinates of opposite "corners". The coordinates of the points obtained are saved for subsequent calculations.

We have pairs of video frame coordinates that correspond to a point of the object. For example, the coordinates of the first pair are (*av*1, *bv*1), second pair - (*av*2, *bv*2), and third pair - (*av*3, *bv*3).

Let us switch from the internal coordinate system of the image to the coordinate system that exists at the time of shooting. After being projected through the optical center of the matrix, the image gets inverted and reflected. Next, it is reflected relative to the center. We need to switch to the initial (non-reflected) coordinate system. These coordinates are determined in the following way:

$$a1 = xpix1 - av1, a2 = xpix2 - av2, a3 = xpix3 - av3 \quad (1)$$

$$b1 = ypix1 - bv1, b2 = ypix2 - bv2, b3 = ypix3 - bv3 \quad (2)$$

where *xpix, ypix* are the dimensions of an image in pixels.

Let us switch to the coordinate system with the origin located in the center of the pictures as the origin must coincide with the projection of the optical center. Then, the coordinates of the selected point will be as follows:

$$\begin{aligned} x1 &= a1 - (xpix1/2), \\ x2 &= a2 - (xpix2/2), \\ x2 &= a3 - (xpix3/2) \end{aligned} \quad (3)$$

$$\begin{aligned} y1 &= b1 - (ypix1/2), \\ y2 &= b2 - (ypix2/2), \\ y2 &= b3 - (xpix3/2) \end{aligned} \quad (4)$$

The resulting coordinates are represented in pixels. But in order to match the results of the real world and the projection onto the matrix of the camera, we need to transfer these data to a single system of measurement. In order to do this, we need to know the real (physical) matrix size. For example, let the dimensions of the matrix be 4.3 x 5.8 mm. That is, within a 0.58-cm distance, there are 2288 pixels, so the value of a pixel in the camera matrix is 0.58/2288 = 0.0002535 cm. Multiplying the coordinates *x*1 and *y*1 by this constant, we shall obtain data in centimeters. Similarly, for $x2$, $x3$, $y2$, and $y3$.

Now determine the 3D coordinates of the specified object in the video frame by using the following formulas:

$$Z1 = \frac{f \times b}{x1 - x2}, Z2 = \frac{f \times b}{x2 - x3}, Z3 = \frac{f \times b}{x1 - x3}, \quad Z = \frac{Z1+Z2+Z3}{3} \tag{5}$$

$$X1 = \frac{f \times b \times (x1 + x2)}{2 \times (x1 - x2)}, X2 = \frac{f \times b \times (x2 + x3)}{2 \times (x2 - x3)}, X3 = \frac{f \times b \times (x1 + x3)}{2 \times (x1 - x3)}, \quad X = \frac{X1+X2+X3}{3} \tag{6}$$

$$Y1 = \frac{f \times b \times (y1 + y2)}{2 \times (y1 - y2)}, Y2 = \frac{f \times b \times (y2 + y3)}{2 \times (y2 - y3)}, Y3 = \frac{f \times b \times (y1 + y3)}{2 \times (y1 - y3)}, \quad Y = \frac{Y1+Y2+Y3}{3} \tag{7}$$

where f is the camera focus, b is the distance between cameras.

These calculations are done for five key points, and to reduce the errors, we calculate the arithmetic means of the values. As a result of the program execution, it was found that the distance to the observed object equals 1751m. that corresponds to the actual distance.

5. Research into coordinate determination methods

The given algorithm determines coordinates of an object by analyzing a binary image of the object. In this case, it is the image of a plane on a gray background. The subsystem has been modeled and verified for proper operation; we have used for the verification a video with known coordinates of a reference plane for each frame captured by the analog camera Sony XC-ST30 with CCD-matrix.

The flowchart describing the hardware-in-the-loop simulation of the subsystem for determining aircraft coordinates is shown in Fig. 2.

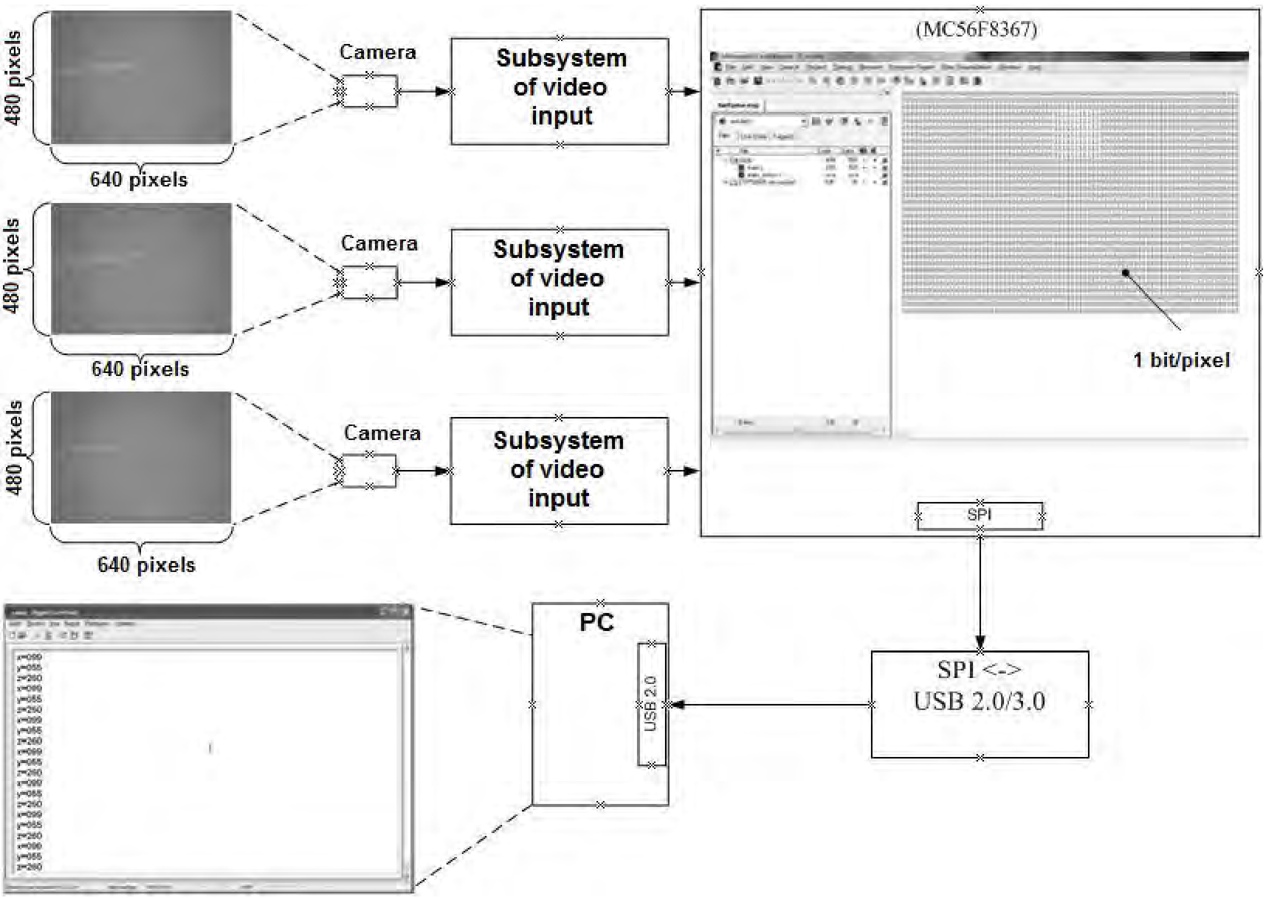

Fig. 2. Flowchart of hardware-in-the-loop simulation of the subsystem for determining aircraft coordinates.

As a result of the microcomputer work we have obtained coordinates of a dynamic object for each frame and loaded them to a computer via SPI to USB port connector. The data have been received using Hyper Terminal installed on the computer.

6. Conclusion

The results obtained through the simulation of an automatic subsystem of determination of aircraft coordinates are quite close to the actual coordinates of the object and do not exceed 2 % error (for example, calculation results for 745th frame X = 74m, Y = 427m., Z = 1751m., initial results for 745th frame X = 73m., Y = 431m., Z = 1753m.) that is acceptable for the systems of this type. The error in the measurements can, to a large extent, be explained by the type of the video camera used.

Apparently, the program testing has shown good outcomes that indicate the correct implementation of the algorithm.

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АПАРАТНО-ПРОГРАМНЕ МОДЕЛЮВАННЯ ПІДСИСТЕМИ ВИЗНАЧЕННЯ 3D-КООРДИНАТ ЗА МОДИФІКОВАНИМ МЕТОДОМ СТЕРЕОПАРИ

Андрій Миц

Питання визначення тривимірних координат візуального об'єкта (літака) виникає в повітряній та злітно-посадковій зонах аеропортів, де радіолокаційні системи (РЛС) є неефективними. Основне завдання роботи полягає у розробленні та вдосконаленні базових алгоритмів та базових апаратних структур для оптимального обчислення тривимірних координат візуального об'єкта в реальному режимі часу. Ця стаття розкиває апаратно-програмне моделювання та подальше розроблення підсистеми визначення координат об'єкта ідентифікованого на відеозображенні злітно-посадкової смуги та прилеглого простору аеропорту. Описано апаратно-програмну реалізацію алгоритму для розрахунку тривимірних координати візуального об'єкта за допомогою модифікованого методу стереопари, а саме опрацювання вхідного аналогового сигналу, бінаризацію кадру, який взятий з відеоряду шляхом кадрування, та визначення координат візуального об'єкта для кожного з трьох зображень по його центру мас, розрахунок тривимірних координат за допомогою модифікованого методу стереопари. Розроблена система призначена бути допоміжною для існуючих систем безпеки польотів контрольно-диспетчерських пунктів (КДП), і забезпечує відображення реальної обстановки в аеропорту та прилеглих зонах у межах поля зору відеокамери. Для моделювання підсистеми та перевірки на коректність її роботи використано еталонне відеозображення з відомими координатами літака для кожного кадру. У результаті моделювання автоматичної підсистеми визначення тривимірних координат літальних апаратів отримано результати, доволі близькі до реальних координат візуального об'єкта, що не перевищували 2 %. Отже, результати випробування програми є хорошими, що свідчить про правильну реалізацію алгоритму.

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