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Control of Delivery of Water Capsule for the Explosive Generation of Water Spray***

1. Introduction

Using water aerosol for extinguishing small-scale fires is an efficient solution known and applied for a few years [1, 2]. The explosive method of producing water aerosol consists in the explosion of the explosive charge put inside the water container. Removing oxygen form the vicinity of the fire is an additional advantage of this method [3, 4]. On the other, hand due to the generation of a shock wave during the explosion this method can be applied only for the open area firefighting. A water capsule fastened to the helicopter is fast dispatched near the delivery area. The described system is able to release automatically the water capsule at such a distance from the destination that allows the water capsule to explode at an elevation of a dozen or so meters over the target and produces water spray which covers a circular area of 40 meters in diameter.

2. The assumptions concerning system operation

Determining the moment of the release of the capsule and the time-delay of the signal sent to the explosive charge inside the capsule is based on data concerning the speed and the location of the capsule relative to the centre of the fire. In the case of the described system the accuracy of the target hit by the capsule in the horizontal axis was assumed at the level +/– 10 meters. The optimal height of explosion above the fire is 12 +/– 4 m. It allows one to extinguish effectively the fire inside a disc of about 20 m in diameter of (which corresponds

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to the of 314 m^2). The assumed accuracy in the horizontal as well as the vertical axis requires reduction of the uncertainty of position measurements, because the drag coefficients (both the horizontal and the vertical) influence essentially the total error [5]. Finally it was assume, that the time necessary for making the decision to release the capsule should not exceed 20 ms. In such a time interval the water capsule having a capacity about 1200 liters, released at height of about 200 meters covers the distance of 1 meter in the horizontal and 2 meters in the vertical direction.

Since exceeding the above time limit would influence not only the airdrop precision but also the safety it was necessary to build a system based on reliable equipment and software working in the real-time regime.

3. Fudamentals of the system operations

The moment of the capsule release and the time delay of the explosion are determined by the computer using the Runge-Kutta RK(4,4) numerical method. The computations are based on the equations of motion [5, 6], which take into account the mass of the capsule, its initial velocity (at the moment of release) and the drag coefficients. The coordinate system for the capsule released at the height H above the ground mowing with the momentary velocity $\boldsymbol{v}(t)$ and covering the horizontal distance $x_{\max}$ in the air is shown in Figure 1.

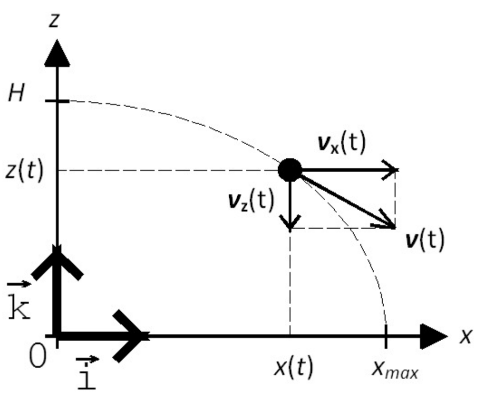

Fig. 1. The coordinate system for the flight of the capsule

Computations were conducted for a few different values of integration step, the results were compared with the results obtained in Matlab for the step of 0.00001 s. Numerical computations were performed for a 10 seconds flight of the water capsule, which corresponds to a flight of the capsule from the height of 454 meters. Such a large distances were not planned for the real system, and they were used for the sake of the reliability of the numerical tests. The differences in results for the horizontal and vertical axis are shown in Table 1.

As is clear definitely the larger difference for all sizes of integration steps is observed for the coordinates along the vertical axis, which is consisted with the fact that the vertical component of velocity is higher, except for the initial stage of the flight. Based on these tests the maximum integration step dt = 0.01 second was assumed.

Table 1
Differences between the results for the horizontal – OX and vertical – OZ axes, obtained by solving numerically differential equations with the Matlab and the dedicated program written in the C language and using the (RK (4.4)) algorithm depending on the integration step

Integration step s	Differences – OX m	Differences – OZ m
0.00001	<<0.0001	0.0005
0.0001		0.0043
0.001		0.0424
0.01	0.0001	0.4233
0.1	0.0004	4.2302
1	0.0032	42.033

4. Elements of the system

The core of the system is formed by the controlling computer located on the board of the helicopter. In this role we use the National Instruments CompactRIO specialized controller (Fig. 2) equipped with a 400 MHz 32-bit processor, FGPA programmable system (Fig. 3) and communication modules with serial ports and digital I/O-s. The controller is immune to large amplitude electromagnetic and mechanical perturbations and works well in a broad range of temperature and humidity of the air.

Fig. 2. CompactRIO Real-Time Controller and Reconfigurable FPGA Chassis [7]

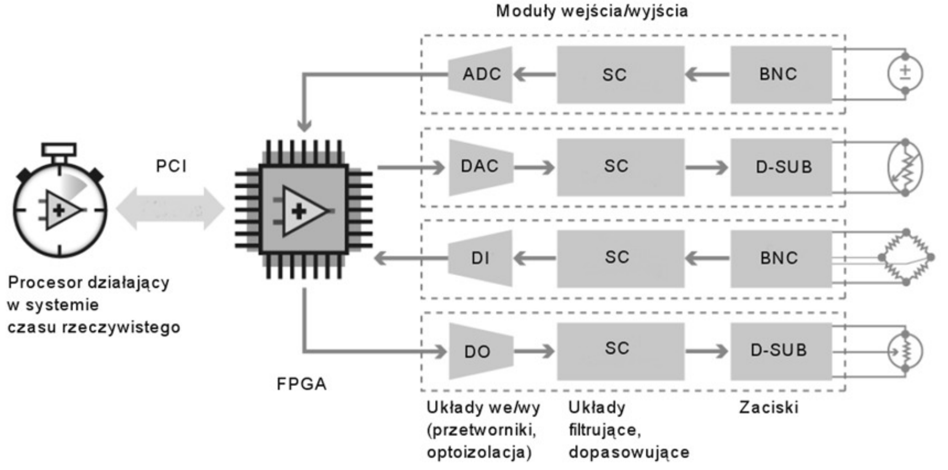

Fig. 3. CompactRIO System Architecture [7]

Communication between various components is carried by serial ports or Ethernet (Fig. 4).

The helicopter installed GPS receiver provides real-time data on the helicopter's position and velocity in the form of the NMEA (National Marine Electronics Association) strings. The communication microcomputer MOXA coupled to a radio-modem allows to receive important information (e.g. target's coordinates) from the commanding center and sending data on the flight parameters [5, 8].

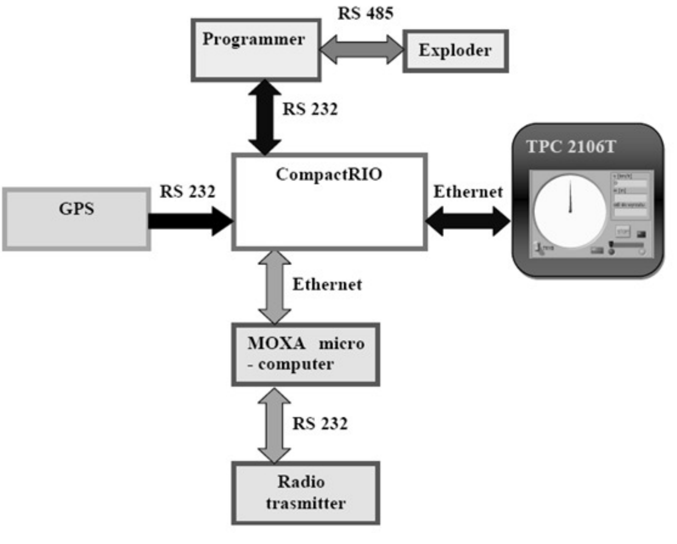

Fig. 4. Components of the water-bag delivery control system

The applied solution disburdens the main computer from the job of controlling radio network. The control appliances are expected only to transmit data within the specific protocol. Communication microcomputers perform all tasks associated with data transmission. It allows the controlling computer at the helicopter to use its full computing power for the trajectory calculation. This increases the system's reliability. The controlling computer determines the water-bag trajectory using the Runge-Kutta numerical method. The computed value of the optimum delay-time for the explosion is transmitted to the programmable exploder. All important pieces of information on the current status of the applications are displayed at the pilot's control panel (TPC-2106T).

According to the assumptions the maximum time for elaborating the decision on the release of the capsule is 20 ms. Therefore calculations are conducted on the target CompactRIO platform for a few different times of integration which fulfills the earlier conditions – $dt \leq 0.01$ s. (Tab. 2). Eventually an intermediate value $dt = 0.005$ s was chosen as the integration step, and the computations were performed for the time interval 12 ms.

In Table 2 values of computation times are also given for the industrial PXI computer, which was not considered for construction of the system on account of much higher price and lower reliability.

Table 2
Computation times for three values of integration step

Integration step s	Release from 100 m above the ground ms		Release from 400 m above the ground ms	
	CompactRIO	PXI	cRIO	PXI
0.01	2	<1	3	<1
0.005	6	<1	12	1
0.001	30	3	60	6

5. Application

A multithread application of a control computer was built in the LabVIEW environment [7, 9] and is working in real time system VxWorks.

After starting the computer a 1 s pause occurs (frame 0 of sequential external structure). Next frame of the sequential structure (1) contains the endless WHILE loop, inside which the main sequential structure, composed of 5 frame was inserted:

1) loading the files containing fixed parameters values used in the application,
2) optional loading of configuration files,
3) allocation of FIFO queues for the transmission of data between various threads,
4) main loop of the program transmitting control to the threads (Fig. 5),
5) writing-down information on disc errors.

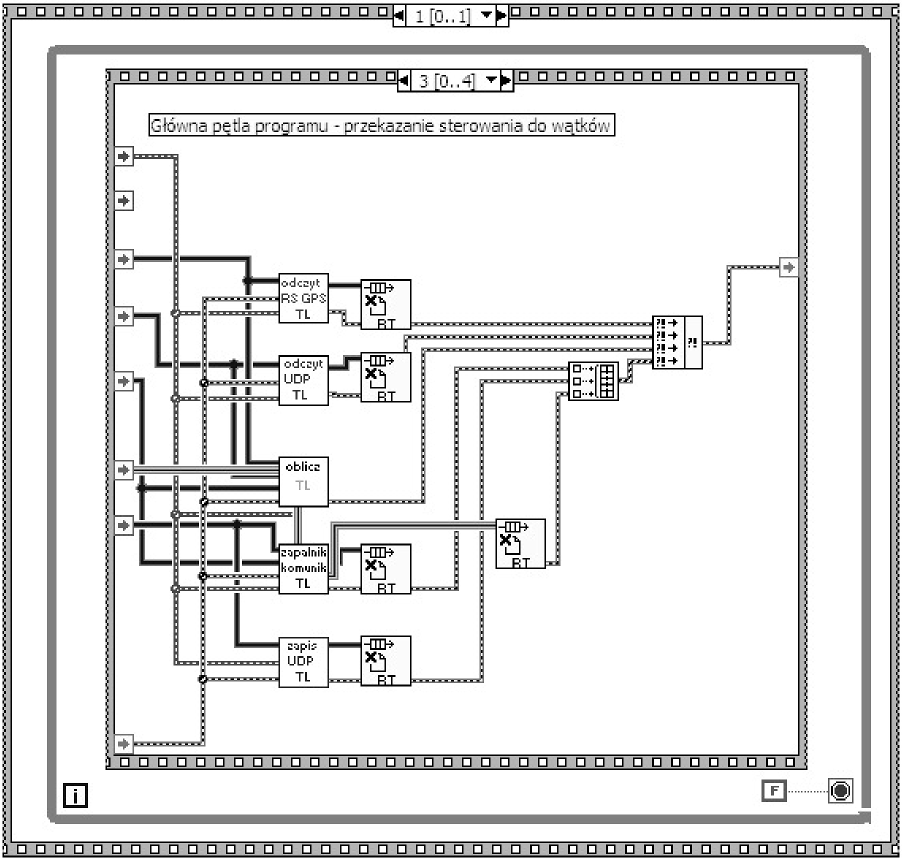

Fig. 5. View of the main application window

The threads concern:

- reception and analysis of data from the satellite receiver (GPS),
- reception of data from the ground computer (the server) playing role of the commanding center,
- transmission of the flight parameters to the commanding center
- processing the received information according to a suitable algorithm,
- export of data to the ground computer,
- sending to the initiator the information about the optimum time delay of the explosion with respect to the release moment.

The threads are located inside the Timed Loops [7, 9]. Such a structure (Fig. 6) enables to adjust *Period*, *Priority, Deadline* and *Source* name for each of threads and in the case of multiprocessor systems one can ascribe separate tasks to particular processors (*Processor*).

For the sake of system safety the highest priority was assigned for the threads of communication with the programmable detonator. The threads responsible for the communication with the ground station operate with the lowest priority.

From the point of view of the correct functioning of the system those fragments of the program are essential in which the communication with the programmable detonator and the GPS receiver, and computing the time-delay for the detonator take place. For all three above threads the maximum execution times are determined.

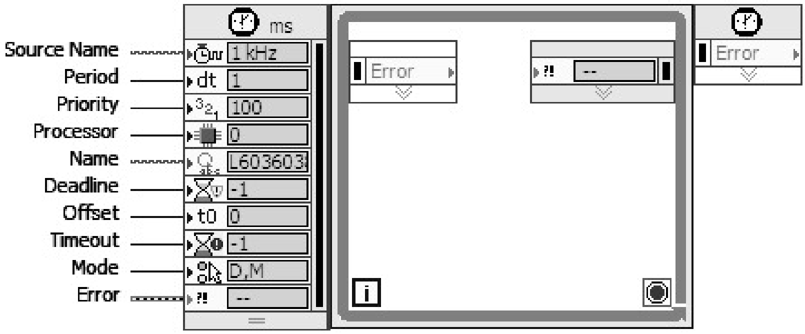

Fig. 6. Timed Loop

Figure 7 shows the fragment the application responsible for receiving the data from GPS. In the ‘RS reading’ subprogram a contents of the receiving register is checked. A $GNGGA string opening the data packet consisting of two NMEA messages is looked for – GGA and VTG. Finishing the subprogram is possible after completing the entire data packet (twofold occurrence of CR LF symbols) or after exceeding the assumed time limit.

After the completion of the subprogram the checksums of announcements and fields announcing the mode of reception (GGA) and status of received data (VTG) are checked. If the fields contain faulty values or checksums are incorrect, it means the communication between devices is incorrect or the signal of the positioning is absent. All data obtained from such a reading are disregarded. The correct data are writtten in the FIFO batch. Information about the correctness of the data is also transmitted in the form of the network shared variable [7, 9] to the touch panel of the pilot and is displayed on the LED indicator of the CompactRIO controller.

The airdrop of the capsule is not performed in the following cases:

- the computation time exceeds the set time limit intended for performing the given task,
- the pilot does not allow for the release of the capsule,
- errors in the communication with the programmable detonator appear,
- the data from the GPS are incorrect,
- the angle of approach to the destination exceeds 10 degrees.

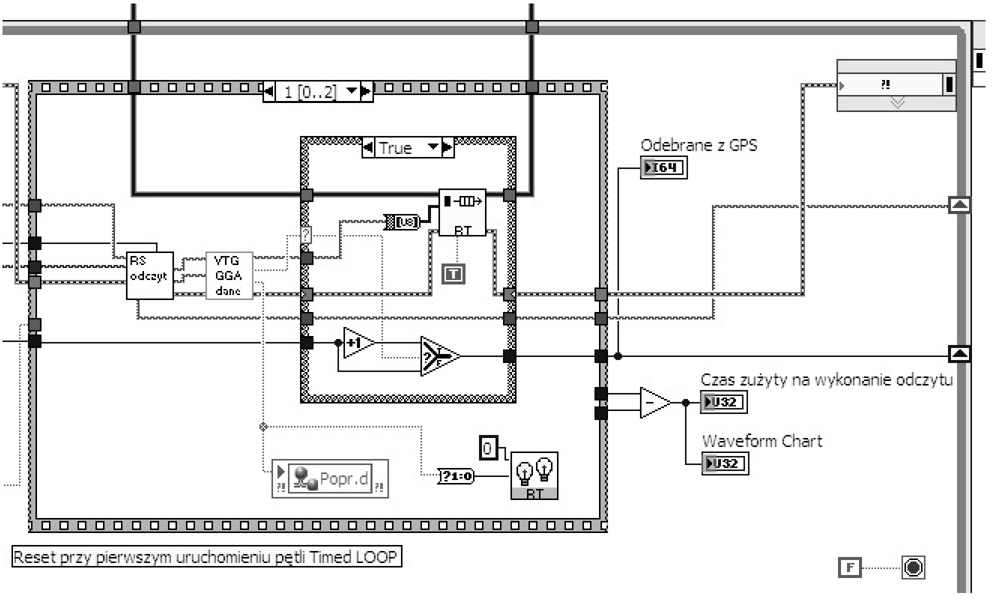

Fig. 7. A part of the application responsible for communication with the GPS receiver inside the timed loop

The value of the yaw angle from the required direction of flight; the distance to the release point of the capsule, the distance to the target, the velocity and coordinates of the fire are transmitted via Ethernet in the form of shared variables to the touch panel in the pilot's cockpit. The visualization of the yaw angle from the required direction of flight enables the pilot to correct the path of the flight.

6. Verification

The verification was conducted in a few stages. Tests using Execution Tracing Toolkit available under the LabVIEW Real-Time applications allowed to analyze the processor time sharing between various threads and the influence of the assumed priority level and their execution for the functioning of applications. Simulators of GPS receiver and programmable exploder were used for the tests.

The built application allows to display the values of execution times for various tasks on the host computer, which allows for the full control of the functioning of the system during the test flights. The application allows to count cases of exceeding execution times too. In this case the output *Finished Late* was used. During the tests no case of exceeding established times was registered. It gives an evidence that the selection of the value of integration steps was correct.

The verification of the correctness of the algorithm consisted in carrying out field tests consisting in the release of the capsule by the signal given by the control system. Coordinates of the mark – corresponding to the fire focus and the mass of the water-bag were transmitted via the server to the on-board computer at the beginning of each flight. The trials were recorded with a high-speed camera, and additional data concerning the speed and position of the capsule and the status of the system were registered by the ground control station (Fig. 8).

The expanded uncertainties (accuracy) of the target hit were $U(x)$ = 10.5 m and 5.9 m horizontally and the registered explosion heights above the ground were contained between 3 and 17 meters.

Fig. 8. Explosion of the water-capsule 16 meters over the ground – based on the registered film

7. Summary

The results obtained on the basis of the tests will allow for the practical implementation of the system after performing additional works. The proposed system should ultimately cooperate with the numerical map from which information concerning the place of the fire will be obtained.

The system can be applied also in the remote deactivation of contaminated areas and destroying of selected objects or the areas.

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