Optimization of a heterogeneous computing system architecture based on its coordination with a sensors group of a mobile unmanned platform

V S Stepanyuk, A M Emelyanov and D I Mirzoyan

Department of Corporate Information Systems, MIREA – Russian Technological University, 78 Vernadsky ave., Moscow, 119454, Russia

E-mail: stepanyuk.vladislav.1996@yandex.ru

Abstract. This article analyses the existing variety of sensors used in robotics and related fields and also proposes the architecture of a heterogeneous computing system designed to analyze data obtained from sensors of a mobile unmanned platform (MUP). A feature of unmanned platforms is the presence of tasks that require a significantly different level of performance of the on-board computing system for processing data from sensors of the corresponding type. Therefore, the adaptation of existing universal computing systems seems to be impractical, compared to the development of a specialized computing system with a heterogeneous architecture. The computing system is designed to solve problems of local navigation, stabilize the position of the MUP and control its movement, as well as control special equipment installed on the MUP. Often, if the goal is to ensure maximum efficiency, expressed in speed, accuracy and reliability, it is necessary to develop specialized devices. The article provides information on sensors of the main types used in robotics and indicates the requirements for the performance of a computing system necessary for processing data from sensors of this type. This, in turn, made it possible to propose a heterogeneous architecture containing processor subsystems focused on processing data from sensors requiring low, medium and high performance according to the considered classification.

1. Introduction

A feature of the MUP in comparison with existing vehicles is the different nature of the tasks of local navigation. For example, when ground vehicles move in urban areas or rough terrain, then we must first solve the problem of identifying obstacles. Then MUPs work in conditions when there are no local obstacles, but orientation on the ground using sensors of various types is required. In addition, the MUP faces the task of controlling the movement and providing a response to such specific disturbing influences as the movement of air masses, which is not required for ground vehicles. Finally, depending on the purpose of the MUP, it may be necessary to control special equipment, including video surveillance systems, communications, identification of ground objects, etc. It is advisable to solve these problems based on a specialized computer system developed to control the set of sensors and other onboard equipment, which is typical of a particular MUP model or the MUP class.

Modern work in the field of processor technology [1, 2] draws attention to the emerging possibilities of using specialized processors to solve heterogeneous computational problems within a single system.
2. Overview of sensor types used in mobile unmanned platforms

Sensors can be categorized into several categories by function, performance requirement, accuracy, etc. Using the example of the use of sensors in unmanned mobile platforms, they can be divided into outdoor and indoor sensors, i.e., interaction will occur with the environment or the internal systems of the platform.

Tactile, reflection sensors (beacons), rangefinders can be related to the system of interaction of the unmanned platform with the environment, they are necessary to determine obstacles in the path of the robot or its location in space. Accordingly, the requirements for the performance of the processing device (PD) need to be increased because it is necessary to group several sensors to obtain a complete picture of the environment surrounding the platform. Conversely, sensors that work with internal systems, such as motor sensors, axial, magnetic, do not require much power to process the information flow. To optimize the processing of information by the internal on-board computer of the platform, it is possible to implement a heterogeneous system of distributed processors. This will help to allocate separate channels to different types of high-performance and conventional sensors. It contributes to the modularity of the system, and simplifies the work on further optimization and prototyping of the mobile unmanned platform. In order to, help to determine the load on separate processors and allocate more power or redesign the system architecture to maximize optimization to avoid data loss.

At the moment, there is a wide range of sensors that play an important role in robotics – providing technical vision. All sensors are not always to work at once, using in the development those that are necessary to ensure the possibility of implementing the task set to the robot. The information received from the sensors is the basis for the formation of control signals by the actuators of the unmanned platform (propellers, special equipment, etc.) based on control algorithms implemented by the onboard computer system. Accordingly, the type, accuracy, and information content of the data received from the sensors has a decisive influence on the very possibility of making decisions on controlling robots, in particular cases by the platform, and generating control signals. The table below provides information about the sensors used in robotic processing devices (RPDs).

**Table 1.** Classification of statistically frequently used sensors in robotics (depending on the principle, purpose, and method of measurement).

| Sensor class     | Sensor type          | Purpose     | Active/Passive | Performance requirements |
|------------------|----------------------|-------------|----------------|-------------------------|
| Touch sensors    | Button / bumper      | External    | Passive        | Low                     |
|                  | Optical barrier      | External    | Active         | Low                     |
|                  | Gap sensor           | External    | Active/Passive | Low                     |
| Tactile sensors  | Contact Matrix       | External    | Passive        | Low                     |
|                  | Torque power sensor  | Prop/External| Passive        | Low                     |
|                  | Resistive sensor     | External    | Passive        | Low                     |
Table continuation 1. Classification of statistically frequently used sensors in robotics (depending on the principle, purpose, and method of measurement).

| Sensor class          | Sensor type          | Purpose          | Active/Passive | Performance requirements |
|-----------------------|----------------------|------------------|----------------|--------------------------|
| Motor sensors/axial   | With brush contacts  | Proprioceptive   | Passive        | Low                      |
|                       | Potentiometer        | Proprioceptive   | Active         | Low                      |
|                       | Coordinate resolver  | Proprioceptive   | Active         | Low                      |
|                       | Optical encoder      | Proprioceptive   | Active         | Low/Average              |
|                       | Magnetic encoder     | Proprioceptive   | Active         | Low/Average              |
|                       | Inductive encoder    | Proprioceptive   | Active         | Low/Average              |
|                       | Capacitive encoder   | External         | Active         | Low/Average              |
| Position Sensors      | Compass              | External         | Passive        | Low                      |
|                       | Gyroscope            | Proprioceptive   | Passive        | Low                      |
|                       | Inclinometer         | External         | Active/Passive | Low                      |
| Based on beacons      | GPS/GLONASS/…        | External         | Active         | Low                      |
| (position relative to | Active optical       | External         | Active         | Low                      |
| the inertial coordinate system) | RF beacon          | External         | Active         | Average/High             |
|                       | Ultrasonic beacon    | External         | Active         | Average/High             |
|                       | Reflective beacon    | External         | Active         | Average/High             |
| Range finders         | Capacitive sensor    | External         | Passive        | Low/Average              |
|                       | Magnetometers        | External         | Active/Passive | Low                      |
|                       | Camera               | External         | Active/Passive | High                     |
|                       | Sonar                | External         | Active         | High                     |
|                       | Laser rangefinder    | External         | Active         | Low                      |
|                       | Structured light     | External         | Active         | High                     |
|                       | sensor               |                  |                |                          |
| Speed/motion sensors  | Doppler radar        | External         | Active         | High                     |
|                       | Doppler sound sensor | External         | Active         | Average                  |
|                       | Camera               | External         | Passive        | High                     |
|                       | Accelerometer        | External         | Passive        | Low                      |
Table continuation 1. Classification of statistically frequently used sensors in robotics (depending on the principle, purpose, and method of measurement).

| Sensor class          | Sensor type            | Purpose | Active/Passive | Performance requirements |
|-----------------------|------------------------|---------|----------------|--------------------------|
| Identification sensors| Camera                 | External| Passive        | High                     |
| Identification sensors| Radio Frequency Identifier (RFID) | External| Active        | Average                  |
| Identification sensors| Laser rangefinder      | External| Active        | Low                      |
| Identification sensors| Radar                  | External| Active        | High                     |
| Identification sensors| Ultrasonic sensor      | External| Active        | Average                  |
| Identification sensors| Sound sensor           | External| Passive        | Low                      |

After examining the table, you can see the structuring of the sensors, according to 3 categories: the purpose of the sensor, the measurement method (active / passive), the requirements for the performance of the processing device (PD). All this is considered on condition of interaction with computational modules and is based on publicly available data that can be obtained on both the Internet and specialized, but publicly available, literature. During the structuring process, the following conditions were applied:

1. Low requirements correspond to receiving data using one of the standardized protocols (SPI, I2C, UART, 1-wire), and the data source is a functionally complete subsystem that represents information in the form of cardinal or proportional measurements. Such data practically does not require additional transformations.

2. Medium requirements correspond to a situation where the data stream received from the sensor cannot be directly used for making control decisions. For example, the echo of an ultrasonic transducer does not correspond directly to the distance of an obstacle and requires a measurement of the time between emission and reception of the reflected signal. Moreover, examples of processing can be digital filtering, determination of spectral or statistical characteristics of primary information coming from the sensor.

3. An example of the architecture of a computing system for use as an on-board complex of an unmanned quadcopter

The using of the sensors groups that require different computing power from the computing system of a mobile unmanned platform intensively loads the on-board system. To optimize the routing of data and signal streams, additional subsystems can be deployed using processor cores that individually interact with separate groups of sensors.

Such system helps to reserve certain capacities for critical tasks without using an interrupting algorithm. The distribution of tasks into separate cores helps to increase the performance of the system when interacting with sensors, both in general and in individual cases.

The heterogeneous system should help in processing large amounts of data, which are necessary for the onboard system to make real-time control decisions for a mobile unmanned platform. The architecture of such system must be built with sets of sensors, made for internal or external use. There is implementation of support for external interfaces through which information will be exchanged with the server or with the operator's console.

The table above shows groups of sensors with a description of common types and clarification of the average consumption of the computing power of the system, based on open data sources. In this
connection, it can be assumed that the most advantageous, from the perspective of system optimization, will be the grouping of sensors of the same type with low performance consumption on separate processor cores. In a particular case, one can assume an ideal system in which several sensors can be suspended on each core.

However, it should be borne in mind that for the possibility of reassigning tasks to the cores, you need to have a programmable switch inside the FPGA or when used in the development of VLSI. In this way, we support dynamic sensor reassignment within the cores. The sensors inside the mobile unmanned platform can be connected using static or switching methods.

If the sensor requires large computing power, then it is necessary to consider a technique for supplementing a heterogeneous system with external modules for hardware acceleration of computations, such as, for example, video codecs or neural networks. Due to the distribution of tasks to separate cores within the system, it is possible to place accelerators both inside the system and as a separate hardware accelerator based on FPGAs.

The figure below shows an example of a developed heterogeneous system for a mobile unmanned platform such as a quadcopter.

![Heterogeneous computing system architecture](image)

**Figure 1.** Heterogeneous computing system architecture.

This architecture contributes to the allocation of separate capacities for engine control systems, allocating computing resources for stabilization systems in space and the development of a direct video processing unit in real time using several hardware accelerators. In the future, it is possible to achieve the possibility of using a neural network for additional processing of information flows. Subsystems of low and medium performance levels differ in the use of specialized accelerators that perform pre-processing of signals.

4. Potential application
The capabilities of the proposed system are wide enough. The structure has a large degree of customization so that it is possible to redesign its structure to work in a specific area and with specific tasks. This gives practically unlimited areas of application, depending entirely on the development abilities of a specific group (group of people, company, state), and the ability to affect all layers of human life. Thanks to modern developments in related areas, such as innovative designs of sensors and information processing devices, such systems can be placed in almost any form factor of the device. Although it should be borne in mind that with certain requirements for functionality, there is a physical
minimum of the occupied volume, which is almost impossible to reduce without losses occurred in possible operations and impacts. There is also a possibility that with the development of new types of sensors, possibly hybrid ones, the areas of application will only expand. Considering the fact that with innovations in related fields, the convenience of modelling new complexes will improve, the learning ability can be brought to a new, simpler, but effective level.

5. Conclusions
The use of a heterogeneous structure of a computing system is best justified when designing mobile unmanned platforms using sensors of various types and with a different set of performance requirements. The multiprocessing of the system allows you to fixate individual computing power, only for use when performing important tasks, thereby increasing the reliability of the system in general. So, other tasks will be performed without the use of critical interruptions of the system. All this speeds up the exchange of data within the MBE and facilitates the use of additional devices on board the system for hardware acceleration of computations.

The heterogeneous structure of a computing system shows its implementation better when applied to the design of automated devices.

References
[1] Hennessy J L and Patterson D A 2018 Proceedings of the 2018 ACM/IEEE 45th Annual International Symposium on Computer Architecture (ISCA), Los Angeles, CA, USA, 1–6 June 2018. doi:10.1109/ISCA.2018.00011
[2] Hennessy J L and Patterson D A 2017 Computer Architecture. 6th Edition. A Quantitative Approach. (The Morgan Kaufmann Series in Computer Architecture and Design)
[3] Hodge V, Hawkins R and Rob A 2018 Deep reinforcement learning for drone navigation using sensor data. DOI: 10.1007/s00521-020-05097-x
[4] Rezende J d C V, Silva R I d and Souza M J F 2020 Sensors 20(23) 6954. DOI: 10.3390/s20236954
[5] Zeng J, Ju R, Qin L, Hu Y, Yin Q and Hu C 2019 Sensors 19(18) 3837
[6] Li Y, Dai S, Shi Y, Zhao L and Ding M 2019 Sensors 19(13) 2976
[7] Gonzalez L, Montes G, Puig E, Johnson S, Mengersen K and Gaston K 2016 Sensors 16(1) 97
[8] Beard R W and McLain T W 2015 Small unmanned aerial vehicles: theory and practice (Moscow: Publishing House “Technosphere”) p 312. ISBN 978-5-94836-393-6 (in Russian)
[9] Tingwu Yang 2021 Aviation Sensors and Their Calibration. DOI: 10.1007/978-981-33-4737-3_3
[10] Castaño F J G, Gil-Castineira F, Rodriguez-Pereira D and Regueiro-Janeiro J A 2020 IEEE Access PP(99) 1-1. DOI: 10.1109/ACCESS.2020.3048194
[11] Romanov A M, Romanov M P, Manko S V, Volkova M A, Wei-Yu Chiu and Hsi-Pin Ma 2020 Proc. of Conf. “Control systems and devices” (Moscow: Publishing House “Pilyugin Research and Production Center for Automation and Instrumentation”). ISSN: 1991-5950 (in Russian)