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# Analysis of Basic Principles for Sensor System Design Process Mobile Robots

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**Abstract**

*This work considers general classification of SS, which is grouped according to their functional tasks and consists of three groups of devices, as result, an analysis is carried out and features that must be taken into account when designing such sensor systems are determined. The paper proposes a general principle for design of sensor systems of mobile robots, which differs in that an initial model is proposed, which will be one of key components for further design concept. General principles of sensory systems organization are proposed: sensitivity, modality, adaptation and speed.*

## Introduction

Recent advances in information technology make it possible to create more and more sophisticated sensory systems (SS). SS robots constitute main part of their information and measurement systems, purpose of which is to form and provide information about state of objects and processes in environment and about robot itself, for functioning of which this information is required (Matarneh et al., 2017); (Jung et al., 2019). Today there are 5 trends in robotics: neural networks, speech and emotion recognition, navigation and security systems (Lyashenko, 2016); (Rabotiahov et al., 2018). In terms of emotion recognition and navigation, they are not possible without sensory systems. Modern sensors operate on different physical principles that also determine range of conditions in which required quality of «measurements» can be provided. Sensory support is used to further build models of external environment, control, navigation and traffic safety (do not injure a person who is nearby or in direct contact). For example, sensory information about location of mobile robots (MR), objects of external environment and its general 3D picture with possible obstacles are basis for building model of surrounding space, choosing direction and trajectory of movement in accordance with tasks being performed. In course of movement, such information quickly obtained provides process of traffic control, including overcoming and avoiding obstacles (Sotnik, 2020).

In sense, robots try to copy senses that humans or animals have, but often robots have better systems. One of main tasks of MR is to perform various operations with objects, that is, to functionally simulate hands, which means that a SS is needed.



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Also, in connection with development of personal robotics, sensors for multimodal interaction with humans, including, for example, combined sensors for simultaneous reading of audio and visual information for further processing of natural language (natural language processing) should receive wider adoption (Novak & Riner,2015).

Thus, sensor systems for MRs are especially in demand. Today, a lot of effort is invested in designing CCs that are affordable, not only affordable, but also of high quality with optimal accuracy and speed, which is especially important when trying to evaluate dynamically changing environment. The constant process of increasing accuracy and resolution of mobile robots created systems is basis for creation of more complex devices, therefore, analysis of design principles is relevant to this day. The authors (Nikolic, 2014; Beetz, 2015) disclosed issues related to obtaining from modern high-precision sensor systems and further processing of information received. In (Beetz, 2015), a modern mobile robot Robosherlock and its perception, and interpretation of realistic scene of environment formed by sensory system are described. The application of principle of unstructured information management (UIM) supports implementation of sensing systems that can respond to actual queries about objects in environment, improve performance of object recognition by combining strengths of several perception algorithms. In (Bräunl, 2020), an overview of mobile robots and embedded systems from entry to intermediate level is presented, as well as complete information on classifications of sensors and their features. Most of practical aspects related to design and control of an autonomous robot equipped with modern sensor system are described. The principles of developing sensor system of human-interactive robot «RI-MAN» are described in (Mukai, 2008).

In (Cifuentes, 2012), development principles of wearable sensor system ZigBee for robotics in rehabilitation of upper limbs are considered. The described sensory nodes made it possible to measure kinematic and electrical muscle activity of patients during continuous therapeutic movement in all body segments in form of body sensor network (BSN).

**Design Features of Sensor Systems**

The SS of mobile robot includes number of sensors for perceiving environment, number of executive devices (effectors) for influencing environment and control system that allows robot to perform targeted and useful actions (Figure 1) (Mohanan & Salgoankar, 2018; Leonard & Bahr, 2016).

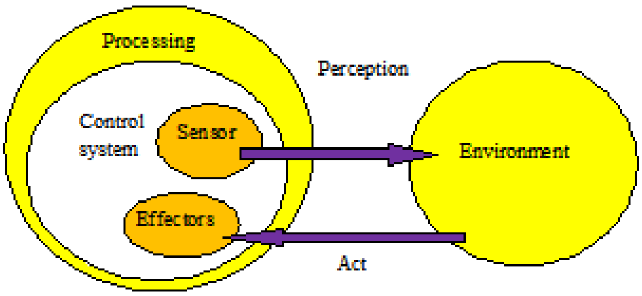


*Figure 1. Basic elements of all robotic systems*

Among other possible classification methods, in course of analysis carried out, it is customary to group SS according to their functional tasks.

In robotics, as in living world, main type of sensation is vision.

Therefore, first type in classification will be computer vision system (CVS) (Figure 2) (Mohanan & Salgoankar, 2018; Leonard & Bahr, 2016).



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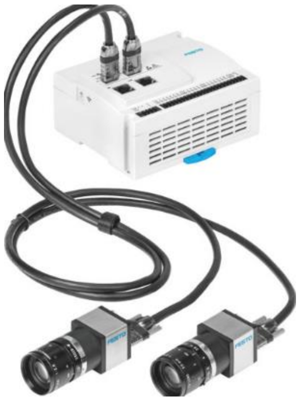

*Figure 2. Example of CVS*

A well-designed CVS significantly increases accuracy and speed of robot control.

Features that must be taken into account when designing an CVS: (1) integration of CVS with other sensor systems (joint use of such systems to expand range of tasks to be solved); (2) multi-angle (when moving MR not only horizontally, but also perpendicular to direction of vision), as well as vertical and horizontal resolution; (3) sensitivity (minimum perceived illumination); (4) spectral characteristic (frequency range of registered electromagnetic oscillations); (5) resolution. Next, consider – sensory systems that determine geometric and other parameters of external environment. Such systems include: (1) range finders and locators are based on solid-state pulsed lasers and are used at ranges up to several km, (2) tactile sensory systems – set of touch sensors, pressure, slippage, they use strain-sensitive materials, electrically conductive polymers, microswitches, hericons. Devices of «artificial leather» type are used on elastomers (baristors), polyvinyl fluoride films and composite materials with graphite fibers; (3) sensory systems that determine position in space these systems include gyroscopic systems (Figure 3) (Mohanan & Salgoankar, 2018; Leonard & Bahr, 2016), accelerometers, magnetometers, satellite navigation systems and odometers. (4) global satellite positioning systems (positioning); (5) magnetometers and odometers.

*Figure 3. Example of gyroscope*

Features that must be taken into account when designing sensor systems that determine geometric and other parameters of external environment: (1) use of such devices on non-stabilized platforms; (2) sensitivity (minimum perceived illumination); (4) conditions for use of such devices (for example, wheel slip, deformation of soil and wheels themselves should be corrected using data obtained from sensor systems; ambient temperature range, etc.); (5) resolution; (6) specifics of determining «geometric parameters» of external environment. The third group in classification will be systems of force-moment sensing MR (devices for obtaining information about its position, movement and force interaction with external environment). The main element of force sensing system are force sensors, which provide primary information about force (moment) (Figure 4) (Jung, Park, Kim & Kim, 2019; Novak & Riner,2015).



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Features to consider when designing such sensor systems: (1) maximum strength; (2) conditions for use of such devices; (3) need for direct contact with environmental objects; (4) method for separating components (there are 6, 5 and three-component sensors of forces and moments); (5) speed (conversion time) no more than 0,01 s; (6) high rigidity (natural resonance frequencies with characteristic mass, for example, a gripper, not less than 50 Hz).

*Figure 4. Six-component force-torque sensor FTC-L-50-40*

We will offer general principles for organizing sensory systems: (1) sensitivity (ability to detect weak, short or small stimuli); (2) modality (for example, visual, auditory, «olfactory»); (3) adaptation –process of SS adaptation to changing environmental conditions; (4) performance.

**Development of Principle for Mobile Robots Forming Sensor Systems**

The basic principles of building SS can be presented as follows:

Analyze objects and scenes to determine problem to be solved. This is first significant step in design process. It happens that this stage is implemented incorrectly, or not completely, then «incorrect» development is obtained. It is enough to fundamentally identify «real problem» that needs to be solved, and not just accompanying signs of difficulty.

In analysis, it is proposed to synthesize initial model in form of: priori information (specific information) $I_p$ about working scene, about external environment $I_e$, about its own state $I_s$ and current information $I_c$ in process of functioning.

$$SM = \{I_p, I_e, I_s, I_c\}. \quad (1)$$

Analysis of similar systems and their features at all stages of their life cycle. At this stage, review and analysis of existing alternatives takes place, as result, it is necessary to study existing experience in solving similar problems, and output will be collected information about operating conditions $I_{oc}^a$, design $I_{df}^a$ and functional features $I_{ff}^a$, testing of analogue $I_t^a$, its maintenance $I_m^a$, repair $I_r^a$ and disposal $I_d^a$, taking into account which an interim decision is made

$$IM = \{I_{oc}^a, I_{df}^a, I_{ff}^a I_t^a, I_m^a, I_r^a, I_d^a\}. \quad (2)$$

Formalization of SS prototype. At this stage, preliminary solution is formed and formalized, which can become final one during design

$$PM_{ss} = \sum_{i=1}^{n} SM + \sum_{i=1}^{m} IM, \quad (3)$$

where:

n – number of possible variants of general model at i = 1 ... n;

m – number of possible variants of model of alternative systems at i = 1 ... m.



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Modeling prototype based on proposed formalized description of SS.

At this stage, some concepts of model are selected, which are adopted at stage 3 and their modeling is implemented for subject: (1) functioning in aggressive environments; (2) emergency situations (hitting an obstacle or falling from height), etc.

Development of prototypes. At this stage, prototyping takes place in order to determine how one of selected prototypes will work in real life and how priori interaction with objects in real environment will take place. At this stage, developer determines which aspects of prototypes are difficult to implement and which are not. Prototype mockups are still considered intermediate options, although informative enough for final decision. There is no need to mock up all prototype options.

Rarely, but it happens that in process of creating prototype, not entirely rational version of system is formed, although preliminary modeling was carried out.

**Choosing most suitable solution**

At this point in design process, developer already has several different possible solutions to «problem». At this stage, developers use only their own experience gained during development of prototype to determine necessary solution, which is best and will be used in future.

Verification – verification of received solution for compliance with terms of reference.

This is mandatory step, and if solution is not found, then it is necessary to correct input information.

Implementation. Once project has been completed and approved, it must be implemented. Depending on nature of task at hand, solutions to «problem» may differ from each other. Depending on type of solution, implementation may also change. Implementation may involve using newly developed process or even equipment.

Validation. At this stage, implemented solution is checked, as result, it is determined how well it is implemented. Implementation is also necessary in terms of defining what works, what doesn't, and perhaps something needs to be improved. The testing procedure and results obtained should be well «documented». The main thing to know at this stage is whether or not final implementation is working as planned and whether it meets technical requirements.

## Conclusion

The paper considers general classification parameters of external environment and systems of force-moment sensing. Some examples of CC elements are presented. Features that must be taken into account in design of such sensor systems and common to all such systems is such parameter as sensitivity. As a result of analysis, it was determined that main static and dynamic characteristics of sensors: transfer function, measurement range, accuracy, nonlinearity, hysteresis, saturation, dead zone, influence of environmental factors on parameters and reliability of sensors must be taken into account when designing SS. The paper proposes a general principle for designing sensor systems for mobile robots, which differs in that an initial model is proposed, which will be one of key components of further design concept. General principles of sensory systems organization are proposed: sensitivity, modality, adaptation and speed.

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