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How does a mobile robot navigate in space?

One of the main problems in developing an autonomous mobile robot is navigation, particularly accurately determining the robot's orientation in space. Precise determination of the robot's orientation is necessary for:

- Short- and long-term route planning
- Trajectory plotting
- Precise workout of the planned actions
- An adequate response to external influences.

That is why the overall majority of mobile robots shall be equipped with systems for determining their orientation in space.

There are three basic types of navigation systems:

Global	Definition of the absolute coordinates of the device
Local	Definition of the device coordinates in flux relatively to any point
Personal	Coordinate determination of device's mobile components relatively to a conditionally fixed base (typical to manipulators).

Attitude control systems are also divided into:

• Passive - receiving accurate location and motion characteristics information. It is performed from external sources

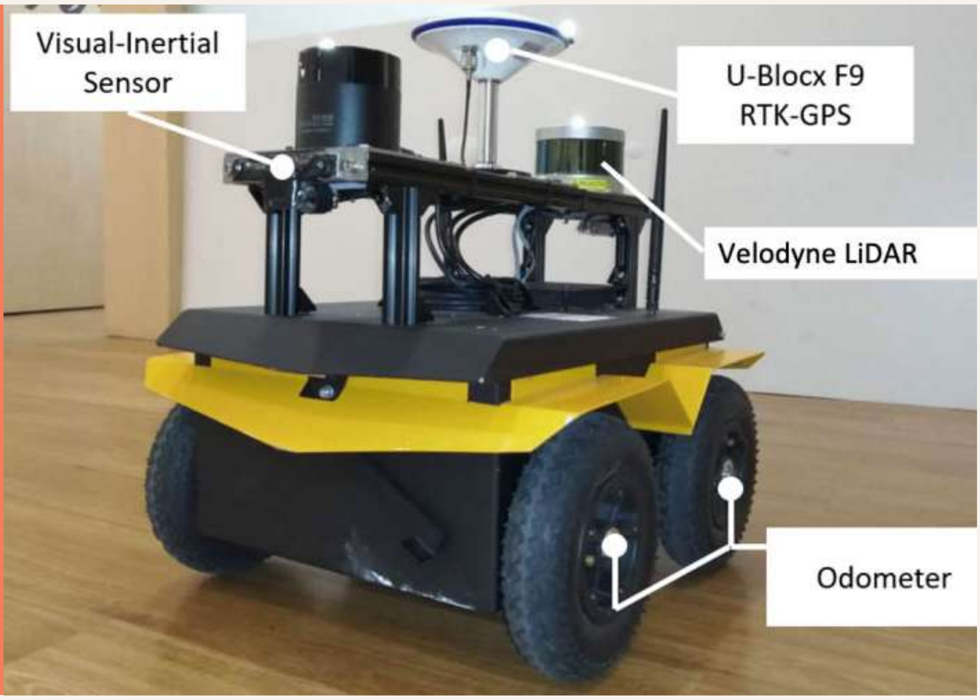
• Active - determination of coordinates and motion characteristics is carried out without external sources. It is implemented using the means installed on the mobile robot.
As a rule, global systems are passive, personal systems are active, and local ones can be both or mixed. The global passive system also includes satellite navigation.

The local passive system can include:

• Marker navigation - a visual system of indoor navigation using tags, augmented reality, and special radio beacons in real-time

• The navigation tracker - a system that uses a particular device, GPS-tracker, which through the GLONASS and Jipice satellite signals can determine the coordinates of the relevant object.

The local active navigation system includes



- Visualization system. This system is the "eyes" of the robot, that is able via the camera to digitize the surrounding area and provide information about the physical characteristics of objects located in it in the form of data about:
  - Dimensions
  - Position in space
  - Appearance (color, surface condition, etc.)
  - Markings (recognition of logos, barcodes, etc.)

- Odometry (using motion data from actuators to estimate movement). It is the process of determining the position and orientation of the robot by analyzing relevant camera images. This system uses motion data to assess changes in place over time using devices such as rotary encoders to measure wheel revolutions. While traditional odometry methods are helpful for many wheeled or tracked vehicles, they cannot be applied to mobile robots with non-standard methods of movement, such as robots on legs. In addition, odometry is affected by accuracy problems everywhere because the wheels tend to slip and slide on the floor, resulting in imbalances in travel compared to wheel turns. The error is exacerbated when the vehicle travels on uneven surfaces. Odometry readings become increasingly unreliable as these errors accumulate and worsen over time

- Visual odometry. It is the process of determining equivalent odometry information using successive camera images to estimate the distance traveled. Visual odometry improves navigation accuracy in robots or vehicles utilizing any movement on any surface

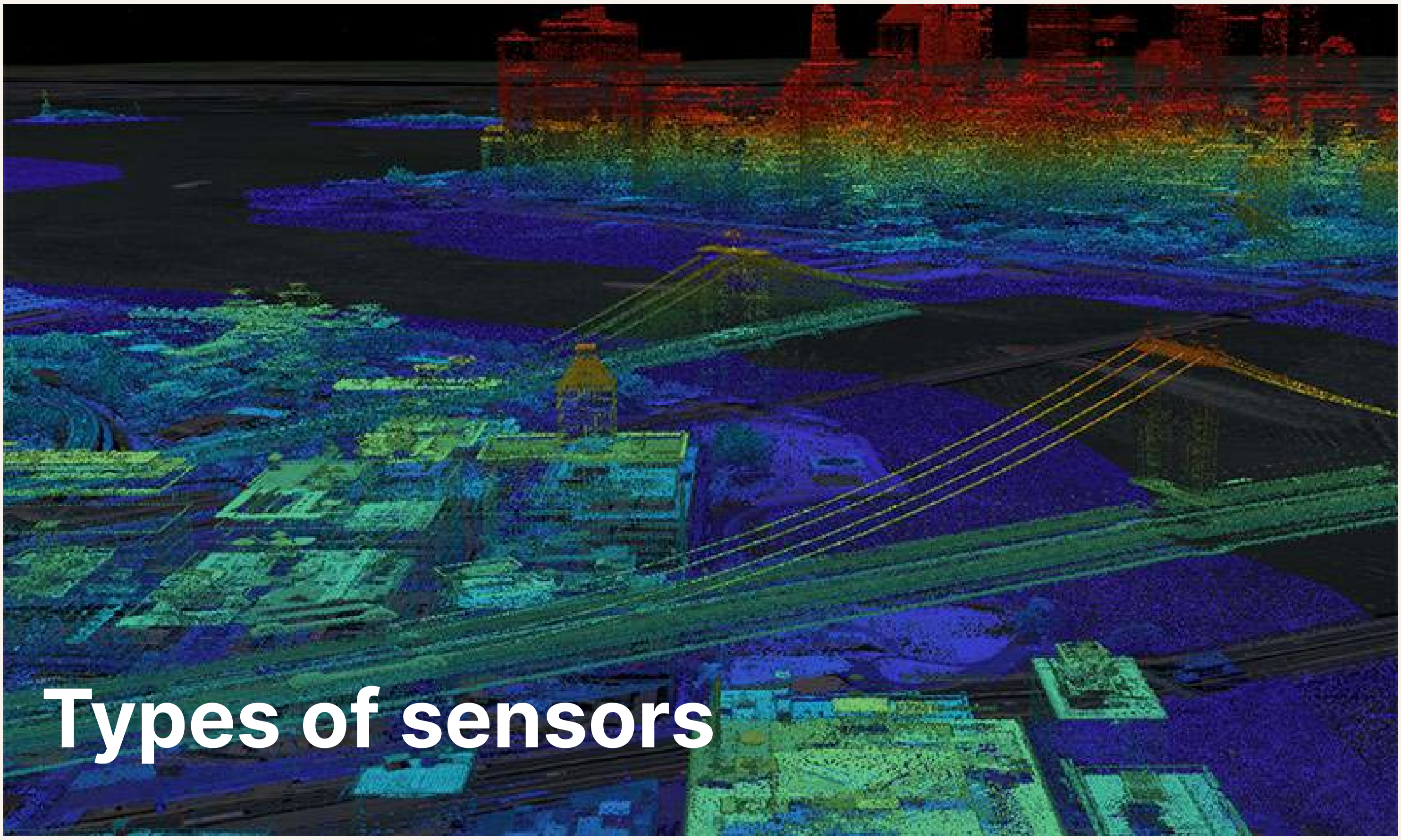
- Inertial navigation systems. This method is based on the properties of the inertia of bodies, which is autonomous (it does not require the presence of external reference points or signals coming from the outside). The essence of inertial navigation is to determine the object's acceleration and angular velocity using devices and units (sensors) installed on the moving object

- Navigation based on radio generators or any other signals (ultrasonic, infrared).

Based on the analysis of different ways of building orientation systems for the mobile robots, it was chosen a final principle on which the developed system should be based. The choice was made using the method of expert evaluations based on the table of weighting coefficients. The analysis was implemented according to the following criteria: accuracy, versatility, resistance to interference, ease of implementation, and cost.

Drone Sensors

Robotic drones almost always use sensors to determine motion parameters, recognize their surroundings, and interact with them. For example, via sensors drones define their speed, coordinates, and distance to objects.



Types of sensors

Sensors are divided into two types depending on the measured data. Internal sensors diagnose the state of the drone and inform about its dynamic parameters: speed, position, and orientation. External sensors determine the class of obstacles and objects' motion parameters and are responsible for communication with other vehicles and infrastructure elements. Internal sensors include, for example, the inertial navigation system. It allows an object's acceleration and angular velocity to be determined using an accelerometer, gyroscope, and compass. These instruments determine the location, orientation, and speed of the relevant object.

External sensors include lidar, radar, cameras, and a global navigation satellite system. Lidar scans space with laser beams and creates a cloud of dots that describes the external environment for the drone. Radar scans area with electromagnetic waves. It determines the phase difference between outgoing and incoming radiation. With radar and lidar, the drone learns its position in space, distance to objects, and speed. Lidars have high accuracy and speed. They give little interference but are expensive and require relatively good computing capabilities. Lidars are unreliable in complex meteorological conditions, so drones use radar or cameras to ensure safety when interacting with their surroundings.

The Sensor Problem

The main problem with sensors is noise. It occurs with poor weather conditions, environmental pollution, or external influences. The problem can't be solved at the hardware level, so the algorithms for processing data from sensors use the Kalman filter, a mathematical algorithm that considers measurements from different types of sensors, a mathematical model of motion, and noise. First is the prediction stage: a prediction about the position and orientation of the vehicle is calculated.

The algorithm relies only on the mathematical model of vehicle motion. Then the measurement model comes into play, which gives its view of the position and orientation of the vehicle. The last step is to merge the prediction data and the measurement model and estimate the actual values. The combined data will go to the unmanned computer to solve the navigation problem.

Perspectives on sensor development

The development of new sensors increases a drone's reliability, which consists of the reliability of all its components. Reliability refers to a vehicle's ability to perform a given function in a given environment. Robotics is receptive to the new reliable sensors' emergence. They optimize and extend the current capabilities of drones. The more reliable the sensor, the more minor motion diagnostics can be realized. It has a direct impact on the energy consumption of the robotic device.

Connecting with infrastructure and other drones can also be seen as a kind of sensor. The main trend in sensor development is the emergence of intelligent sensors. Such sensors pre-process the measured data and diagnose their condition and have less measurement noise. The intelligent sensor technologies being developed aim for one thing: to simplify drone navigation algorithms.