Machine Vision in Mobile Robots Guidance

Mobile Security Robot can be automatically guided using computer vision systems. Peculiarities of robot's application require moving along the route with high accuracy. The area of patrolling may sometimes be unfavorable for receiving signals from satellite navigation systems. Therefore it is impossible to use differential SNS, widely used in parallel driving systems in precision agriculture. Lidars installed in unmanned vehicles are very expensive. Multibeam laser scanners require high electric power, supplied to them. So do high capacity calculating machines processing data received from them.

At the same time machine vision systems are widely used in industrial robotics. Engineering community has gained extensive experience, creating reliable machine vision systems for operation under conditions of artificial illumination. Using existing achievements, manufacturer developed a number of solutions to be applied in the street under conditions of unstable natural illumination.

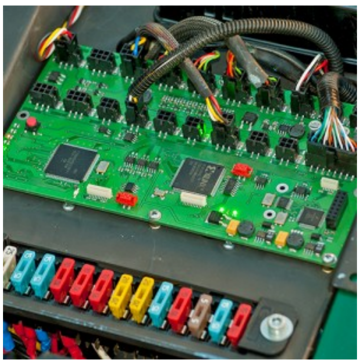
Due to application of machine vision systems the price of motion control system became acceptable in spite of using six built-in computers. As computing power of microprocessors grows, the quantity of built-in calculating machines will be reduced. The cost of control system will be lower and the maximum speed of robot's movement will be substantially higher.

Recognizing Obstacles and Driving Around Them

A pair of cameras, building up a stereo system, is used to recognize obstacles and drive around them. The algorithm of machine vision system compares identic elements of pictures obtained from both cameras and produces 3D image of space, located in front of cameras. This allows creating a depth map and calculating distance to obstacles that came in cameras view. Stereo base defines the distance from stereo pair, at which it is possible to get reliable and valid data. Regarding robot the distance comprises 4 - 5 meters. Increasing the stereo base and the resolution of video cameras included into the machine vision system, it is possible to significantly improve the accuracy and depth of produced disparity map.

Moving forward the robot builds up a 3D map of surrounding space. Autopilot's computer makes a route and plans movement of robot according to this map.

Driving Path Adjustment



Generally, the robot is designed for moving along paved territories, asphalt paths or other hard-surface roads. Hence it is necessary to avoid robot's exiting the hard surface of the road, for example, driving out to the lawn through which the road goes. In some cases width of the path is only 10-20 centimeters larger than robot's wheel track that is why requirements to the accuracy of motion control system are quite high.

Moving along a narrow path with surface coating becomes possible due to machine vision system. It receives data from the camera, faced forward and downward. Picture taken from this camera shows the road in front of the robot, its borders and the surface outside the asphalt coating. Using original algorithm to compare underlying surface textures, computer of the road camera adjusts robot's moving direction in case, the surface of preferred route is visually different in color or texture from the rest of the surface.

Robot's Autonomous Image Navigation

To successfully drive along the patrolling route in automatic mode, it necessary to cope with the task of navigation, to locate the current position of a robot. In spite of the fact that the robot is equipped with satellite navigation system receiver, the accuracy of positioning it provides won't allow driving along the route with acceptable accuracy. Moreover, reliability of data arrival from SNS greatly depends on receiving conditions, on location of receiving antenna relative to buildings and trees.

In presented project navigation has been implemented with the help of machine vision system according to the image, obtained from the forward looking video camera. The processing algorithm stores images, captured during test driving along the patrolling route in the manual control mode. Later on driving in the automatic mode it compares stored images with the ones, taken at the moment of driving. Having found differences it adjusts driving route in order to make the current path as close to the previously run as possible. Implementation of the present solution allows locating current position with the accuracy of less than one meter.

Inertial Navigation and BINS in Robot Control System

During those moments of robot's movement, when the image of navigation system contains not enough marks and guides, the robot continues moving based on processing data received from built-in BINS (Block of Inertial Navigation System). The block contains relatively cheap micro mechanical systems (MEMS), gyroscopes and tilt meters. Drift of micro mechanical instruments used in this block is filtered. This allows restoring the route of robot's movement for several dozens of meters accurately enough, until valid data arrive from visual navigation system of machine vision.

Implementation of Machine Vision Algorithms

Algorithms for processing of video data obtained from machine vision system are implemented in onboard computers built on the basis of Cortex A9 processors. Robot uses five computers, interconnected with high-speed local area network. All of them work under control of Linux operating system. They provide data flow to another computer, "Autopilot", allowing it to automatically guide the robot. "Autopilot" processes data received from sensors and machine vision systems as well as gives commands to operating mechanisms and drives in the "real-time" mode. Moreover it does not use operating system.

Accumulator Batteries

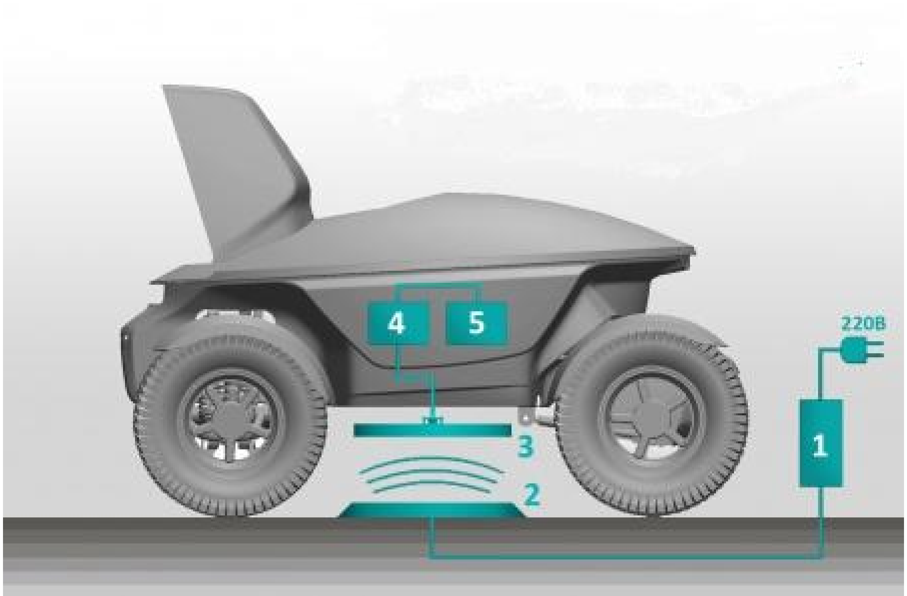
Depending on operation conditions, mobile video surveillance robot may be equipped with two types of accumulator batteries: lead/acid or iron phosphate.

Accumulators of the first type are widely spread and quite cheap, but they weight twice as much and require much more time for recharging. The second type of accumulators appeared a couple of years ago. They cost five times as much as the first type, but weight twice as little, having the same dimensions. Their capacity is a little bit higher and allows quick recharging. One robot has three accumulator batteries: two of them are connected in series and serve to power the engine unit and energy intensive equipment; a separate battery powers electronics.

Accumulator batteries can be recharged using external charging unit. In winter accumulator batteries are heated by charging unit current to make recharging more efficient. The charging unit has low-voltage output. Its design allows mounting in unheated space or in the open air under the roof. Robot is connected to the charging unit with high-current connector of bayonet coupling type that allows more than 1000 connections. A wireless charging unit can be supplied as an option.

Dimensions of one accumulator	345 x 175 x 240 mm
Capacity and Weight of lead-acid accumulators	100 A/h 32kg
Capacity and Weight of iron-phosphate accumulators	120 A/h 17kg
Typical charging time of lead-acid accumulators	7 hours
Typical charging time of iron-phosphate accumulators	4 hours
Charging unit power	1 kW, 220 V

Wireless Charging of Wheeled Robot Accumulator



1. Voltage converter.
2. Transmitting antenna of the wireless charger.
3. Receiving antenna of the wireless charger.
4. Voltage converter.
5. Accumulator.

Wireless Charging of Wheeled Robot Accumulator

Unmanned ground vehicles, supplied by the company, use accumulators of different systems as a source of energy for movement. For some power consumption applications a built-in gasoline powered generator is used. However, in most cases electrical vehicle batteries are recharged from stationary recharging unit. To achieve maximum self-sufficiency of the unit in these conditions, the most efficient way to transmit energy on board of a robot is wireless charging.

A wireless system of charging has been developed that utilizes quasi-resonant transmission of electric energy with output power of 0.7 kW. Two antennas are situated one above the other with a gap of several centimeters between them. The first antenna is placed on the surface of the road or service zone. The second one is on the underside of the robot. The system of automatic robot motion control provides runover and overlapping of antennas one above the other. To increase the efficiency of energy transmission antennas are moved closer mechanically.

Electronic power converters mounted onboard of the robot provide output voltage of 12/24V for accumulator batteries charging and heating. Power for electronic converters of stationary antenna is supplied from the 220V line.

A unique feature of the present engineering solution allows recharging robot's accumulator in several points of its route. This increases overall distance the robot runs without full battery discharge. Moreover, all charging points require no operator. Everything is done automatically.

Remote Control of Robot's Technical Status

To monitor robot's performance and technical status the following solutions have been provided. The lower headlamp of colored light shows the status of robot in the course of its movement, driving direction, visibility of marks and guides, deviation from the route, battery charge level, its temperature, etc. Light intensity of colored LEDs allows evaluating robot's technical status from up to 10 meters.

There is a key selector switch for operating mode selection under the flap hatch at the robot's front panel. There are status indicators connected to electronic units of control systems here. They allow immediate malfunction diagnosing and, in case problems arise, fixing them. For example, the following problems may happen: tire pressure decrease, pollution of glass plate covering the system of video driving, malfunctions in communication systems or computers.

Within cellular networks coverage it is possible to remotely monitor the status of one or several robots. Data from self-diagnostics systems of the robot are transmitted by built-in GSM-modem to the number of cellular phone user. Network and tariff plan are selected with consideration to optimal billing increment. Transmission format allows exchanging digital data through voice communication channels. Data are received by a similar GSM-modem, connected to a computer that displays electronic map and robots' operational status. If computer is connected to the Internet, there is a special resource there for archiving and displaying data regarding robot's status in a web-browser. This allows monitoring the robots' status from anywhere in the world. Access to this resource is protected with username and password, so only authorized users can login and view their personal accounts.

Note that the above described service can only display robot's location and status of its systems. It does not provide video picture transmission. Broadcasting of video to the Internet is possible, if local WiFi network is connected to the Internet.

Wireless communication channel of robot's technical status	EGSM 900/1800 CSD SMS
Data transmission speed	9.6 Kbit/s

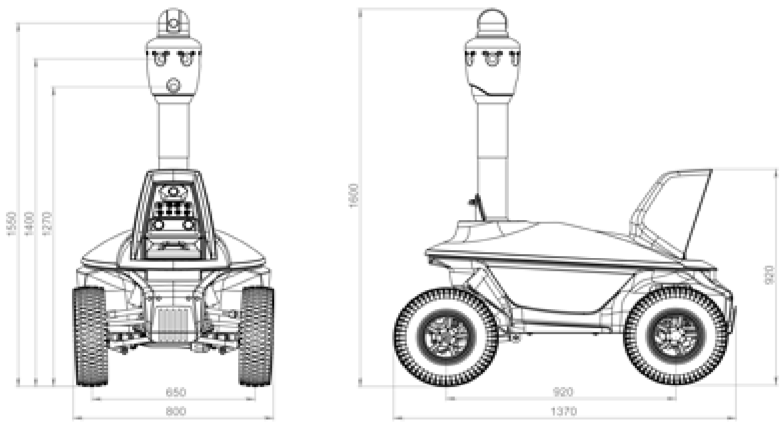
Manual Robot Control

To teach the robot its patrolling routes, it is necessary that operator guides the robot in manual mode along all possible routes for the first time. A short range manual control panel is used for this purpose. With its help operator teaches the robot and maps out all routes to be displayed on tablet PC.

If automatic driving system breaks down, the robot should be returned to the service point under control of the operator using remote control panel.

Security Robot Manual Control Panel

Manual control panel frequency	433.92 MHz
Frequency channels quantity	30
Operating range, up to	30 m
Control panel protection level	IP65



Dimensions, WxHxL	800 x 1600 x 1370 mm
Weight, if supplied with lead-acid accumulator	140kg
Weight, if supplied with iron-phosphate accumulator	95kg
Dimensions of partially disassembled robot, packed	980 x 1200 x 1500 mm

Dimensions and maneuvering capabilities of "Tral Patrol" robot allow using it for mobile video surveillance in large roofed sites and facilities: warehouses, aircraft hangars and interior space of stadiums.

Width of mobile video surveillance robot allows it to drive through a standard doorway.