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Localization and Navigation of Mobile Robot for Outdoor Area with Motion Recognition

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Abstract This article introduces a prototype of the mobile device intended for monitoring industrial area. The mobile device is designed mainly for outdoor environment. Its main function is manual or automatic remote patrolling. The Paper presents control system and other functions like video recognition and localization sensors. Principles of trajectory navigation by means of GPS system. Monitoring of mobile device position and movements is possible by web interface or desktop solution.

Keywords: *localization, navigation, mobile devices, monitoring, sensors*

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1. Introduction

Automatically guided outdoor vehicles are mostly used in transport system. We can easy modify these systems for monitoring or patrolling devices. Common Transport systems intended for indoor part transport are not suitable for outdoor monitoring because there are implemented only sensors for local navigation and carriage for plain surface.

The present state of autonomous transport of inside environment is based on mobile devices following the line on the floor, based on track following magnetic field of conductors inbuilt to floor, or navigation based on reference marks placed, for example, on the factory walls. These solutions are for inside environment fully sufficient, there is relatively low probability of destruction, damage, or pollution of reference marks and lines on the floor.

The situation would change for the described solution when we want to use it in outdoor environments. There is a big probability of dirtying of reference marks and following floor lines. The most suitable solution for outdoor environments is the inductive transport system. There is a problem when the trajectory is too long, there are many junctions. There is a place for alternative solution of navigation for interoperation transport.

This article introduces the solution based on GPS navigation intended for monitoring in outdoor environments. Automatic guard system can be used for night patrolling in production area. All system used in interoperation transport can be used in Guard system. Patrolling system need especially video motion recognition and audio noise level measuring.

Other similar solution of four wheeled mobile robot with car carriage based on GPS navigation are described in these articles [1,2,3].

2. Robot Prototype

The introduced robot construction is a dimension reduced prototype of four-wheeled vehicle. The size of device was modified for experiments in inside environments even though the vehicle is intended only for outdoor environment.

This mobile robot construction has some limitations. For example, the four-wheeled robot is not able to turn in one place, but this limitation has been solved by kinematics estimation. Main structure of the mobile robot was built from aluminum profiles mainly carriage of the robot, other parts as holders etc. are manufactured from acrylic glass. In Figure 1 is shown two prototypes of mobile robot solutions. Final design of device was created in collaboration with Faculty of art, Department of design.

Figure 1. Monitoring robot in outdoor environment

3. Kinematics and Position Estimation

We need some estimation of robot position especially after turning of the robot, because there is used Ackerman type of steering like is described in [4]. This estimation can be used for precising of GPS information. There has been designed the easy system robot position based on speed of its back wheels and the angle of its front wheels. There was abandoned up trust of wheels by turning, front wheels were replaced by one wheel in the axis of the robot. The mathematical model is parametric and it is possible to use it for any four-wheeled mobile carriage with other parameters. Position of the front wheel gives the actual position of the robot. Position of the robot is described by coordinates x, y and by angle of the front wheel α. The principal scheme of solution and software implementation is shown in Fig. 2. The same algorithm is implemented in 3D environment. There can be mapped satellite maps to environment ground.

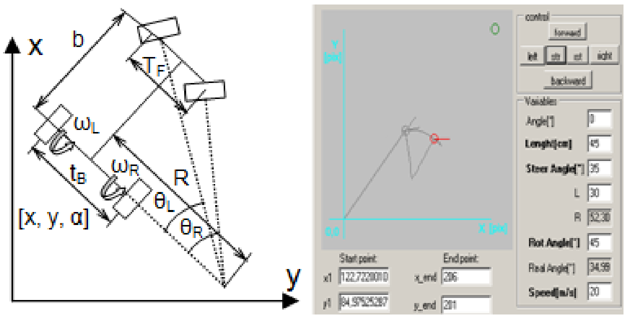

Figure 2. Kinematics scheme for estimation of position in 2D

For a four-wheeled carriage with different front and rear tracks, the mathematical relationship between the speeds of the drive wheels and the steer angles is described in [4] by equation (1), (2).

$$\theta_L = \tan^{-1}\left[\frac{2b(\omega_L - \omega_R)}{\omega_L(t_B + t_F) + \omega_R(t_B - t_F)}\right] \quad (1)$$

$$\theta_R = \tan^{-1}\left[\frac{2b(\omega_L - \omega_R)}{\omega_L(t_B - t_F) + \omega_R(t_B + t_F)}\right]. \quad (2)$$

For a four-wheeled carriage with equal front and rear tracks $t_F = t_B = t$ is described in [5] by equation (3), (4).

$$\theta_L = \tan^{-1}\left[\frac{b}{t}\left(1 - \frac{\omega_R}{\omega_L}\right)\right] \quad (3)$$

$$\theta_L = \tan^{-1}\left[\frac{b}{t}\left(\frac{\omega_L}{\omega_R} - 1\right)\right]. \quad (4)$$

For a vehicle with one steerable wheel at the front, we have the case where $t_F=0$ by equation (5).

$$\theta = \tan^{-1}\left[\frac{2b(\omega_L - \omega_R)}{t(\omega_L + \omega_R)}\right]. \quad (5)$$

4. Control System

The mobile robot control system is based on hierarchical (three level) principle: the low, upper and remote level of control. Low level system generates signals for hardware of the robot (motor, sensors). Upper level of control operates as communication interface for the remote level of control. Upper system is based on Linux OS and handles video, sound and Wi-Fi hardware. The remote level of control has three variants, the desktop application, PDA application or internet interface for web browser based on ASPX technology with AJAX. Every part of the mobile robot control system is described in next chapter. Main principle scheme of control is shown in Figure 3.

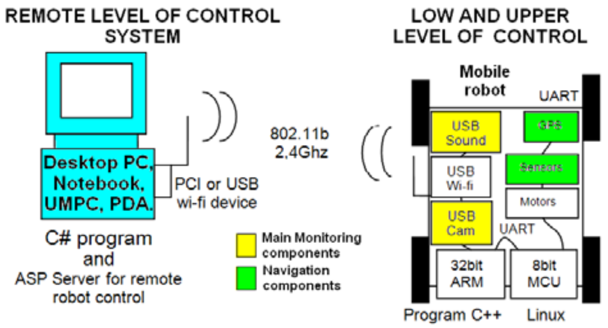

Figure 3. Principle scheme of mobile robot control based on GPS navigation

The low level of control system is designed for these operations: 3x Servo control, 2x DC control, GPS data receiving, monitoring battery status and charging battery. The low level of control system is designated for these operations: 3x Servo control, 1x DC control, GPS data receive, monitoring battery status, charge battery circuit. Battery charge function is designed for 3x Lithium Polymer or Lithium Ion battery pack (11,3V). The board is based on microcontroller ATMEGA128. This microcontroller generates signals for all servomotors and DC motor by internal PWM generator. DC motor drives robot forward and backward. One of servomotors changes direction of the front wheel to the right or to the left. Last two servomotors set position of the camera one for turning the camera left and right, the other for rolling the camera up and down. This board communicates with GPS device with MNEA protocol through the UART communication interface. The second UART communication canal works as the communication interface with the upper level of control by Robot API protocol. We are designed own PCBs for low, upper control system. Both levels of PCB board for control are shown in Figure 4. [6,7]. The control system is designed especially for mobile solution based on Ackerman steering and includes interfaces for all used sensor.

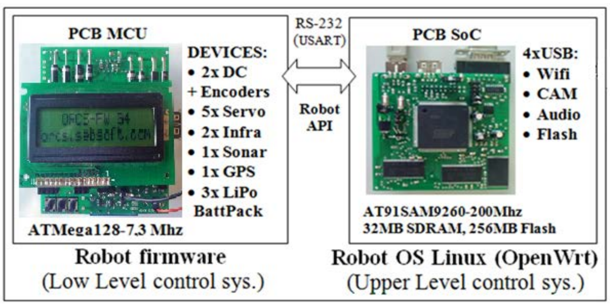

Figure 4. Principle scheme of control system of mobile robot

The low level of control is written in C++ programming language. There is possibility to change the program through the serial port or wirelessly through the implemented boot loader. It is possible to turn off power from camera, servos, GPS…etc. This feature can markedly increase mobile robot working time. The upper level control system is based on PCB board with ARM9 AT91sam9260 SoC. There is installed Linux OS Openwrt console version. Board handles USB webcam, USB audio stick and USB Wi-Fi thru Linux 2.6 device drivers [8]. There is used UART for communication with low level control system. For communication with remote control is used TCP protocol by Wi-Fi connection. Linux application ser2net provides transformation of UART data to TCP packets.

The remote control system provides Robot programming and monitoring interface. This level provides for developers communication protocol, the so called ROBOT API, published on web pages [17]. This feature makes it possible to create fast and effectively the new application based on the introduced hardware solution. We can control robot by Desktop or PDA Application. There is a simple Web interface for Robot monitoring too.

Desktop or PDA application offers connection to the Robot by TCP Client, TCP Server or Serial port. There is described basic functions: you can manual control robot movement by joystick and camera position in two axis by joystick sliders, remote on/off all device, watch robot cam, hear sound and send real-time voice, send simple command to GPS automatic navigation (based on local and global sensors), you can check GPS precision (how many satellites are available and if the GPS has signal).

The web pages for the remote robot control of the mobile robot are based on ASPX in combination with the AJAX technology. The AJAX technology provides maximal speed for web application, especially in page refresh.

The example of web interface for the mobile robot is shown in Figure 5. Only one User will get access to control the mobile robot. Monitoring position of the robot and watching the robot camera is user unlimited. All users are logged to MySQL database and trajectory which they passed. Trajectory is logged as GPS position in 1 second interval [9].

Figure 5. Web application for remote robot control

5. Localization and Navigation

There is described principle of combination global navigation with local sensor object detection.

Navigation of the mobile robot is realized through the acquiring of the position of the robot based on GPS sensor. This sensor sends data in the NMEA protocol. GPS sends several data strings with necessary information about actual position. The introduced solution processes string RMC, which is providing basic data (position, speed, time) [9].

Navigation of the mobile robot is realized by acquiring the position of longitude and latitude transformed to the Cartesian coordinating system and shown on maps of environments. Planned (selected) trajectory of the mobile robot in the Technical University of Kosice is shown in Figure 6. Global navigation working on comparison real robot angle acquired from GPS and required angle counted from checkpoint on planned trajectory.

Figure 6. Example of monitoring trajectory in Google Maps

The complex navigation algorithm consists of combination of three separate parts (technologies, theories) combined to one subject:

1. GPS position data.
2. Raster satellite maps.
3. Path search algorithm.

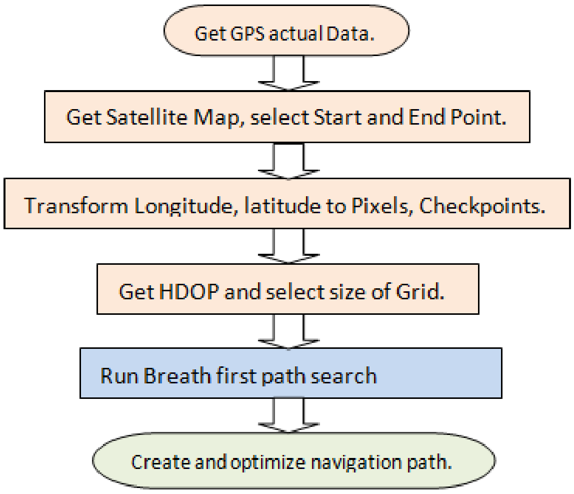

Figure 7. Path planning algorithm principle

There is briefly described navigation algorithm in basic steps. First step is download actual Satellite maps according acquired actual GPS data for start position on maps and selecting manually end position. We must next transfer GPS data to pixels and create vector from start to end point. Next step is measuring distance and create checkpoints for long distances to reduce computing time for breath first algorithm. Actual HDOP acquired from GPS provides input to select size of search algorithm grid. There is executed set of filters for edge detection algorithms to estimate position of obstacles in the map. Then there is started breath first algorithm to find ideal plan path. Last step of algorithm is creating optimized navigation path and segmentation. Simplified diagram of algorithms principle is depicted in Figure 7.

Very simplified actual precision we can get from 2DRMS and HDOP value, estimated by (6). RMS error is directly proportional to HDOP, thus the RMS_Error points would lay on a straight line.

$$RMS\_Error = HDOP * 2DRMS. \quad (6)$$

Figure 8 shows implementation of complex navigation algorithm to path planning.

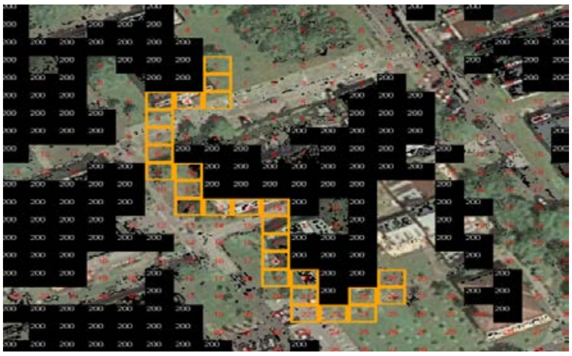

Figure 8. Search algorithm principle in Google maps

The robot can be programmed by teaching, it means that we control robot with a joystick according to the required trajectory, which we control during navigation visually through the camera system, we can check easy collision state, too. We can check the actual position on localization maps. Next kind of control is half automatic. We can enter GPS points which must mobile robot crossed. Last kind of control is entering of control command sequence for the robot without the assistance of GPS system. Last kind of control is not very suitable for outdoor environments and there is a problem in trajectory repeatability. There is a possibility to use it when we have problem with GPS system during very bad weather conditions, when the signal is weak or not available [10].

There is implemented infra sensor in front and back of mobile robot to detect near obstacles. For environment mapping there is implemented ultrasonic sensor with y axis rotation. There is possible to turn in 120° angle range by Servomotor. We can measure distance from 30mm to 3m. Robot must stop movements for environment mapping [11].

Example of mapping area scanned by mobile robot with ultrasonic sensor is shown on the Figure 9. The application calculates an ideal angle of movement between two obstacles.

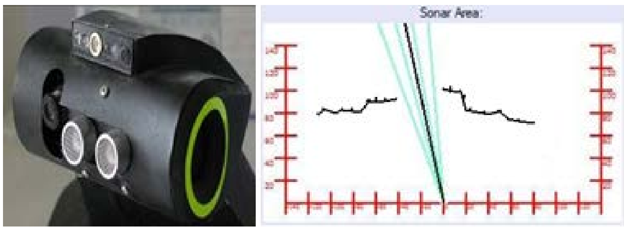

Figure 9. Ultrasonic sensor, simple environment mapping

Extened algorithm for navigation with obstacle avoiding is shown on the Figure 10.

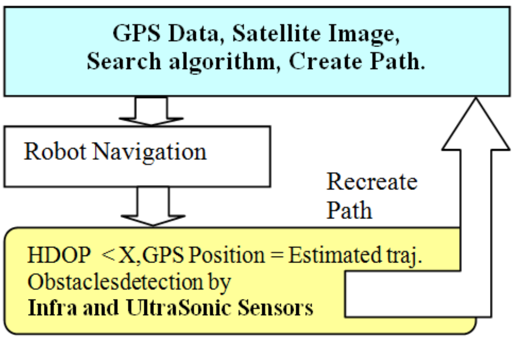

Figure 10. Extended navigation algorithm with sensors

6. Video Recognition System

The camera system consists of the USB camera device connected to Linux OS board. Camera position is controlled by servomotors. The used camera system generates video frames by motion jpeg technology in mjpeg-streamer application. We can get about 30 fps in low resolution 320x240 or 17fps by 640x480. We are acquiring video frames by desktop application C# Open source library. The video camera with resolution 320x240 is fully sufficient for monitoring and implementation of motion recognition. Motion recognition is realized by comparison of two pictures in sequence with variable level of sensitivity. Communication program for audio handling is Gstreamer application. We can get sound to desktop from microphone or send voice to speaker in real time. Alarm signalization is run mp3 sound files from robot by madplay, or generate synthesized voice thru flite program. We used mainly sound system for measuring db level of noise in high sensitive microphone as initial alarm. Mobile robot is monitoring noise during guard trajectories, when there is exceeded selected level of db, Robot stop and searching in vertical and horizontal plane (Servo1, Servo2) motion thru camera and creates screenshot and run alarm. Alarm system principle is showed Figure 11.

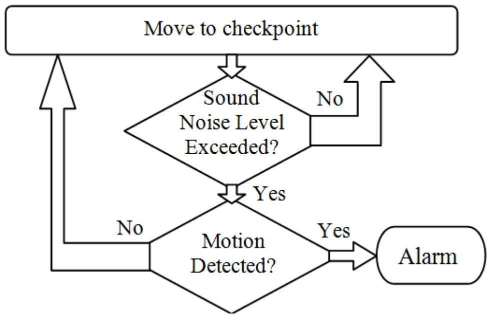

Figure 11. Audio and video system alarm principle

Video and sound hardware implementation is showed in Figure 12 [10].

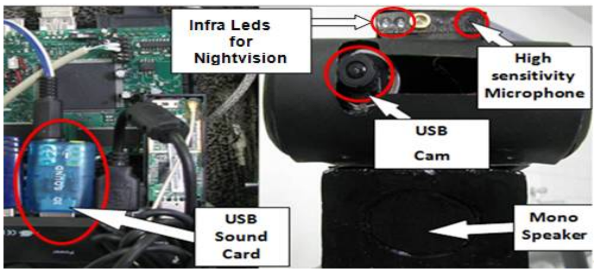

Figure 12. Audio and video system, motion detection

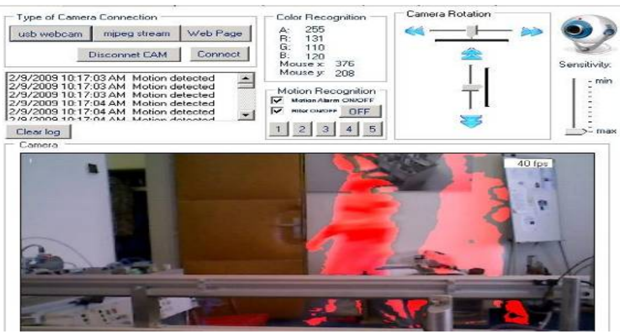

Figure 13. Video system for motion detection

There is possible to change sensitivity of object detection, which helps to filter small object from detection log. Motion detection application is shown on the Figure 13 [11].

7. Example of Implementation to Praxis

There is described example of using the mobile robot in real production conditions as a device for guard system between several halls. This solution is suitable for small companies. There is necessary only one person to setup device, run automatic monitoring or manual remote control. There is possibility to reprogram the trajectory of the mobile robot rapidly and easily without any modification in outdoor environment. The introduced mobile solutions have implemented infra led's for guard and monitor area of production complex in night condition. There is implemented motion recognition for violator detect. The example model situation of using the mobile robot based on GPS navigation is shown in Figure 14 [12].

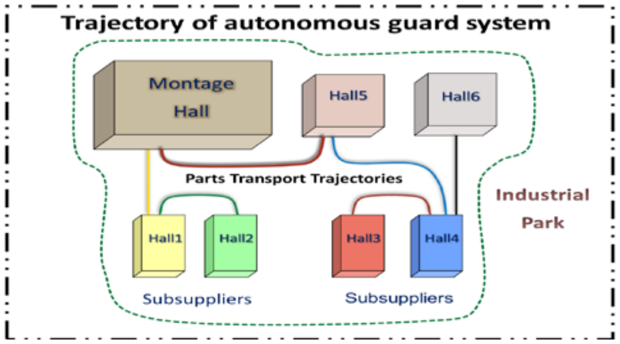

Figure 14. Model situation for monitoring industrial park.

8. Conclusion

The solution introduces mobile robot and its possibility of implementation to guard system based on GPS navigation for outdoor environment. This system does not need any reference marks in outdoor environment. Fast and flexible preprogramming possibility is the next advantage. New feature is Web monitoring of robot state and logging of robot position from GPS. There can be implemented many extension only by changes in software solution. There are two automatic alarm system based on video motion and sound noise level. Next works will be aimed to debugging all system, mainly test reliability of GPS navigation system and implementation of advanced technics of computational intelligence for robot control [13,14].

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