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Investigation of Time and Energy Consumption using the Physical Model

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Introduction

A flexible physical model for the research robots is developed and published by the authors [1]. The purpose of this paper is to show the results of the physical model's usage in real time systems. Investigations in this field are perspective for the general purpose robot design. At present a lot of autonomous general purpose *indoor* robots are produced for hospitals, housekeeping and etc. [2, 3]. Autonomous non-military *outdoor* research robot Seekur and SegwayRMP400 are the wheel-drive based robots that is not a good choice for the mobile robots in a hard environment. For such conditions different military legged [4, 5] and caterpillar track based robots are proposed. Our autonomous mobile robot physical model platform is developed for the *caterpillar track* motion. Different machine vision, image analysis systems and navigation sensor modules were tested during the physical model development. Also different route planning algorithms were implemented and analyzed. Physical model is used for an autonomous outdoor mobile robot software development and student education.

Autonomous mobile robot physical model

The developed physical model (Fig. 1) for the new autonomous mobile caterpillar track based robot design is proposed. It is capable for an autonomous movement in a hard environment.

The physical model consists of the hull with a caterpillar track, video camera, motor driver, sensor network, robot's control firmware and energy supply module.

The sensor network has a star topology with a flexible Atmega32 microcontroller as a central node. The selected microcontroller is used for sensor data acquisition and processing, motor driver control, optimal route planning and the main algorithm execution. Different machine vision, image analysis systems and navigation sensor modules were tested during the physical model development.

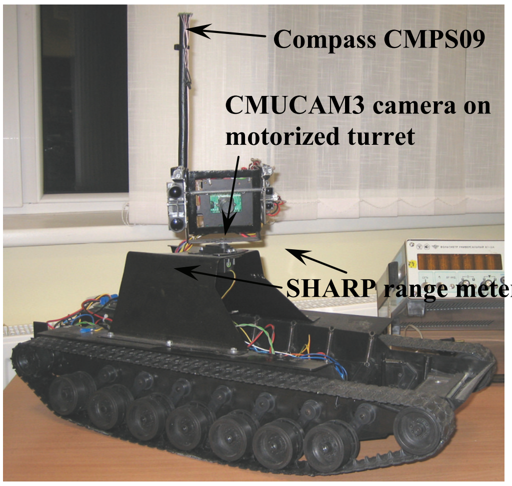

Fig.1. Autonomous mobile robot physical model aerial view

Sensor system for navigation, space investigation and surrounding objects' characteristic perception was created. It includes image recognition system, digital compass, range measuring system, traveled distance and deviation from the route measurement module.

Objects' recognition, their color and size determination is being held using an image recognition system - CmuCam3 module built on Phillips LP2105 Arm7 processor and Omni vision OV7630 CMOS sensor base. Image recognition module has a built-in servo controller which can drive up to four servomotors. It is used to direct robot's turret in a required direction.

Two types of sensors were tested to find an optimal method of distance measurement:

- Ultrasonic range measuring sensor SRF08 is able to determine distances for objects detect objects on distance from 3 centimeters to 6 meters;
- Optical sensor system consists of R316-GP2Y0A710YK module measuring distances from 100 centimeters to 550 centimeters and R144-GP2Y0A02YK module measuring distances from 20 centimeters to 150 centimeters.

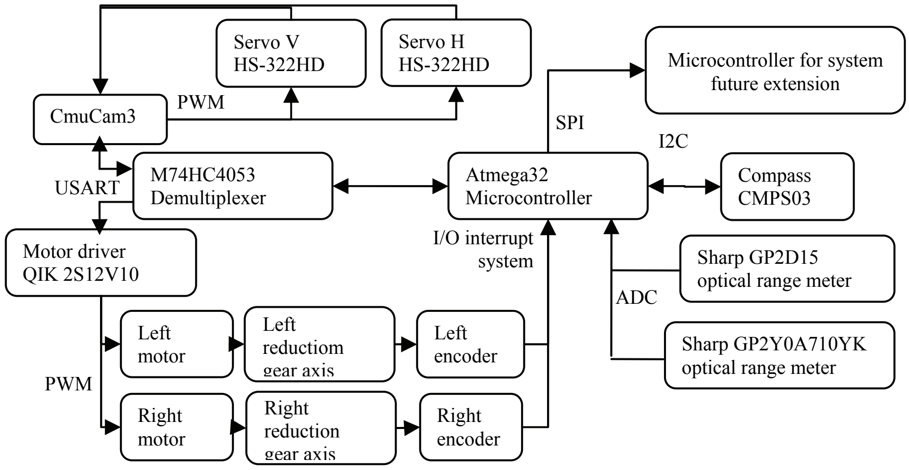

Fig. 2. Autonomous mobile robot physical model block scheme

Digital tilt compensated compass CMPS09 is used to determine a direction. It has magnetometer and accelerometer sensors inside. For the future robot physical model extension GPS and IMU integrated navigation solution is planned.

The developed mobile physical model performs tasks of the marker search and their coordinate determination, navigation map's compilation, the shortest circular route computation, passing along the route.

Route planning algorithms

Investigated and analyzed route planning algorithms include method of defining routes, Brute-force and Ant-colony algorithms.

Simulator on Java language was developed for the algorithm accuracy and performance comparison. It was found that the brute force algorithm is ineffective. As the number of graph vertexes increases linearly, so the amount of calculations increases in a factorial progression.

"Method of defining routes" is a recursive algorithm and it requires a big amount of operative memory for the storage of the carried calculation structure.

In the environment with the lack of the processing power and memory amount, Ant-colony algorithm seems to be the best choice. It gives an opportunity to find an optimal solution of the traveling salesman's problem using a technique of the graph edges' weight alteration. The disadvantage of this algorithm is the need of the empirical selection of the initial parameters.

Ant-colony algorithm

The Ant-colony algorithm simulates the ant colony behavior within an area finding the shortest route with a help of pheromone. This is one of the most efficient optimization algorithms developed by the Belgian scientist Marco Dorigo.

During the initialization stage ants are uniformly distributed over the vertices of a graph. After that ants start moving according to the underlying rules:

- Each ant k located in the i-th vertex has a memory to store the visited vertex list $J_{i,k}$;
- Each vertex can be visited only once;
- The probability of ant's movement from the i-th vertex to the j-th vertex depends on value inversely proportional to the distance between vertexes

$$\eta_{ij} = \frac{1}{D_{ij}}; \quad (1)$$

- The probability of ant's movement is a function $\tau_{ij}(t)$ which depends on the amount of "pheromone" on the graph edge (i,j) and iteration t.

Above mentioned rules can be combined into a single one to define the total probability of ant's movement from the i-th vertex to the j-th vertex:

$$\begin{cases} P_{ij,k}(t) = \dfrac{[\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}}{\sum\limits_{m \in J_{i,k}} [\tau_{im}(t)]^{\alpha} \cdot [\eta_{im}]^{\beta}}, j \in J_{i,k}; \\ P_{ij,k}(t) = 0, j \notin J_{i,k}; \end{cases} \quad (2)$$

here α and β are the parameters that define the distance and pheromone influence on the calculation of the total probability, m is index of vertexes which were not visited yet. Setting $\alpha = 0$ algorithm starts acting like a greedy algorithm so ants will choose the nearest vertex to go to on each iteration step.

Each time ant completes the route, $\tau_{ij}(t)$ is increased on the value inversely proportional to the found route length:

$$\Delta\tau_{ij}(t) = \begin{cases} \dfrac{Q}{L_k(t)}, (i,j) \in T_k(t); \\ 0, (i,j) \notin T_k(t); \end{cases} \quad (3)$$

where Q is a predefined coefficient having the value of the same order as the length of the optimal path and $L_k(t)$ is a length of the route on the current iteration.

Pheromone vaporizes in the end of each iteration. This effect can be described in the following way:

$$\tau_{ij}(t+1) = (1-p) \cdot \tau_{ij}(t) + \Delta\tau_{ij}(t); \quad (4)$$

$$\Delta\tau_{ij}(t) = \sum_{k-1}^{n} \Delta\tau_{ij,k}(t); \qquad (5)$$

where n is ant count in the colony and *p* is a empirically-set coefficient changing pheromone vaporization speed.

The algorithm has a probabilistic form so its multiple execution increases the probability of finding an optimal result.

The main tasks of an autonomous mobile robot

There is a set of typical tasks for an autonomous mobile robot which includes:

- Robot start position estimation;
- Camera turning to the object;
- Other object and obstacle search;
- Area map compilation and completion;
- Route map compilation using the selected algorithm;
- Robot turning to the required direction;
- Robot movement to the required position;
- Obstacle estimation and avoidance;
- The selected object investigation;
- Returning to start position.

The following algorithms for the image recognition system's control were developed:

- Algorithm for the objects' search by the predefined parameters;
- Camera turret's pointing algorithm.

Real time processes and energy consumption

Time consumption's estimation was made and experimentally verified. The following results were obtained:

- Image processing rate ≈ 300 ms/frame;
- Range measurement rate ≈ 50 ms/measurement;
- Range measurement uncertainty +/- 5 cm/m;
- Azimuth measurement rate ≈ 50 ms/measurement;
- Azimuth measurement uncertainty +/- 5 deg;
- Maximum movement speed ≈ 1 m/s;
- Maximum turning speed ≈ 1/3 turn/s.

The time diagram (Fig.3.) describes an activity of the robot located in the initial position while it is scanning the nearby territory searching for the markers. In this state the following actions are performed:

- Camera rotation to the extreme left position;
- Azimuth is read from the digital compass;
- Camera starts to search for the objects;
- If no objects were found, camera turns to the right by 30 degrees;
- If objects were found, camera starts turning to point in a direction of the nearest object to the right of the received frame's center;
- If camera points to the found object, azimuth is read from the digital compass and distance is read from the optical sensor system;
- If camera reached the extreme right position azimuth is read from the digital compass, camera rotates to the extreme left position and robot turns to the right by the earlier read azimuth value.

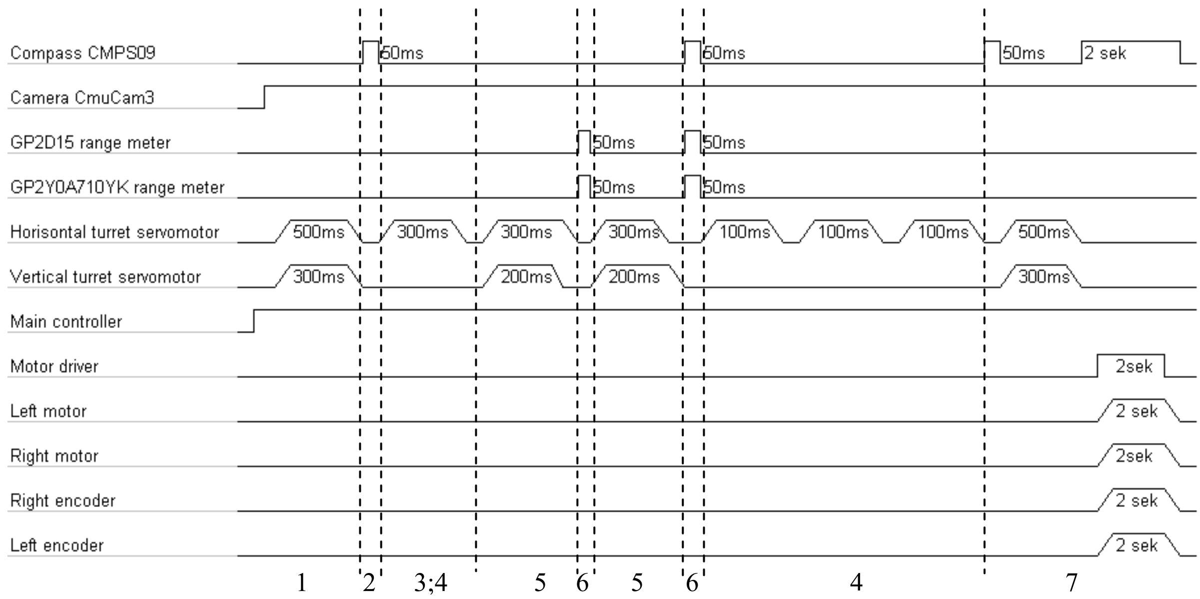

Fig. 3. Time diagram in robot start position

Physical model's energy consumption was experimentally estimated. The following results were obtained: CPU *Atmega 32* (5V · 50ma = 0. 250W); 2 range meter *GP2* (2 · 5V · 50ma = 0. 500W); 2 compass *CMPS09* (2 · 5V · 25ma = 0. 250W); camera *CmuCam3* (10V · 450ma = 4.5W); 2 camera motor (2 · 5V · 750ma = 7.5W); motor driver (5V · 50ma = 0.250W), 2 motor (2 · 10V · 3.50a = 70 W); maximal energy consumption: $\sum_{ei}$ ~ 83W.

For the physical model's power supply Li-Po 4500mAh 12,4V battery is used. The battery can provide up to 45 minute of continuous activity of the robot.

Conclusions

The developed and investigated physical model is useful for an autonomous mobile robot design that is intended for the movement in a hard environment.

A flexible sensor network used in the model has a star topology.

Different machine vision, image analysis systems and navigation sensor modules were tested during the physical model development, the most conformable was selected.

Different route planning algorithms were implemented and analyzed. The best result is obtained using the *Ant-colony* algorithm.

The physical model is used for an autonomous outdoor mobile robot software development and student education.

The following physical model's extensions are planned: GPS and IMU integrated navigation solution, 3D vision system, new hard hull and more powerful energy supply.

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Išanalizuoti konkretaus mobilaus įtaiso bandymų sensorinėje sistemoje rezultatai. Aprašyti ir išanalizuoti konkretūs kelionės planavimo algoritmai. Geriausi rezultatai gauti taikant skruzdžių kolonijos algoritmą. Pasiūlytas fizinio modelio algoritmas gali būti panaudotas mobiliųjų robotų programinei įrangai kurti ir studentams mokyti. Il. 3, bibl. 5 (anglų kalba; santraukos anglų ir lietuvių k.).