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ANALYZING OPPORTUNITIES FOR OPTIMIZING THE ENERGY EFFICIENCY OF MOBILE ROBOTS

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Abstract: The offered paper emphasizes the energy efficiency of mobile platforms. Featured are planned and implemented trials with a mobile platform using suitable combinations of conventional and omni-direction wheels, electric drives, path and velocity. The control system is based on the "ATMEL 2560" microcontroller integrated in the "ARDUINOmega 2560" universal development environment. Analyzed are the experimental results and the subsequently drawn conclusions concerning the efficiency/application areas are shared.

Key words: mobile robot, microcontroller unit; mechatronics system; embedded control.

1. INTRODUCTION

As technologies evolve mobile robots are gaining on implementation in a wide range of areas, e. g. scientific research and education; rescue operations; handling of unsafe materials in aggressive environments; routine service and support activities such as cleaning, maintenance of grasslands and water areas and transportation [1, 2, 3]. It’s worth mentioning that at present the sector of mass-produced robotic devices for the household incl. robotic vacuum cleaners and lawnmowers where expectations of law prices meet with such of high autonomy is particularly active [4].

Autonomy is straightly related to improving the energy efficiency of mobile robots.

To achieve practically evident and economically watertight effect requires an integrated approach as well as merging of conceivable specific methods aimed at improving the energy efficiency. Among the basic ingredients addressed in the presented energy-consumption-experiment are:

Optimization of electric motors: The majority of contemporary mobile robots rely on electric drives which are the biggest energy consuming element of a mobile robot. Investigations prove that over 70% of the total energy is consumed by electric drives [5], so the latter require a cautious consideration in the process of energy optimization.

Optimization of the robot's kinematic structure: Mobile robots are usually motioned by wheels, chains or walk on legs. Each type features both advantages and shortages and is selected for specific applications. The present experiment is limited within the wheeled-robot-configurations. Those are the most common type of mobile robots implemented in practically all areas of manufacturing, scientific research, education and entertainment as well as in the household activities. The kinematic structures of wheeled mobile robots differ in the type and number of wheels and the positioning of the latter on the chassis of the robot. The driving wheels of the wheeled kinematic structures are of three types: conventional (traditional), omni-wheels and mecanum-wheel [6].

Optimization of the robot's path: Setting the optimal kinematic structure can significantly provide for improving the energy efficiency of a mobile robot. However, the effect would be lesser without an accompanying optimization of the robotic path, e. g. the ability to avoid repeatable visits. The motion also needs to proceed with minimal delays and halts. Barili et al. [7] develop a scheme for path planning that includes speed control and avoidance of unforced halts in order to achieve a reduced number of speeds altering along with upholding the set time limits. Mei et al. [8] analyze the energy efficiency in association with the covered area, peeks in achieved speed and the route and accounting for the energy spent on turns and accelerations.

Most contemporary mechatronic products are modularly built and mobile robots offer no exception. This is in favor of the energy optimization of mobile robots since the separate components and modules of the latter are interchangeable with such allowing higher energy efficiency without affecting the robot's overall architecture or the rest of the components/modules.

Generally speaking, tracked robots are suitable for soft and relatively uneven surfaces; walking robots match tough surfaces with complex topography; wheeled robots fit solid flat terrains.

2. DESIGN OF THE EXPERIMENT

The mobile-platform-experiment includes multiple tests of alternative configurations of the platform with preset trajectories and motion speeds. The aim is to study the behavior of radically different wheels and the control functions within the basic courses. Possible test variants were generated from the combination of the following factors:

Kinematic structure of the mobile platform: Applied are two variants: (1) a differential drive with four conventional wheels (Figure 1.) and (2) a structure of the type with Uranus with mecanum-wheels (Fig. 2). Both variants differ only in the robot's-wheel-type; the location of the electric motors against the robot's chassis remains the same. The first variant features four plastic wheels with 12-cm-tyres; the second – four 10cm VEX mecanum wheels.

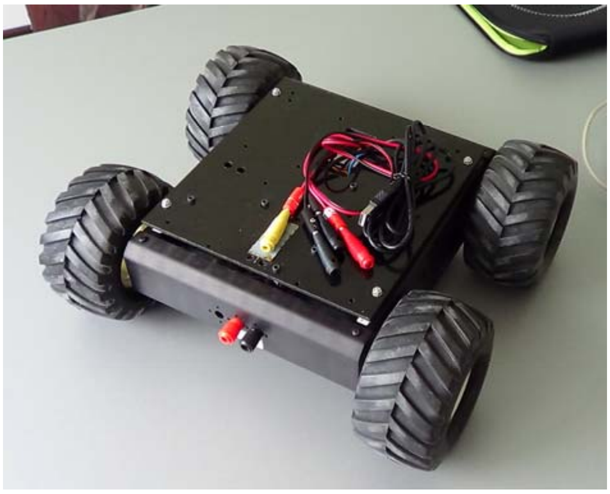


Fig.1. Test platform with conventional wheels

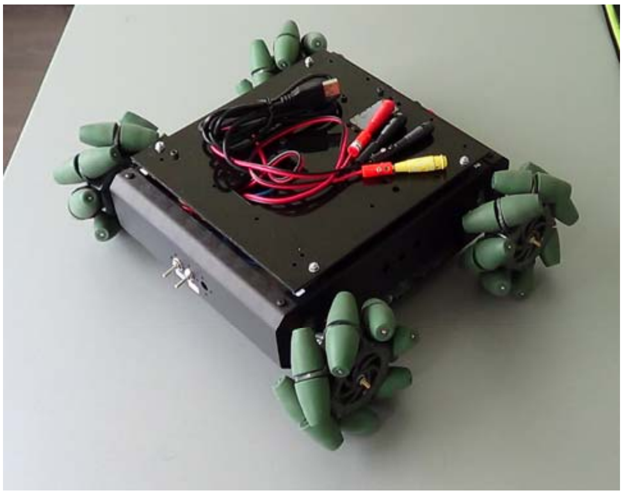


Fig. 2. Test platform with mecanum wheels

Electric motors: Each kinematic structure is involved in the test with two different models of ∅37 mm motors with embedded reducers. Motors **A** have a 131:1 gear ratio, 80RPM at idling speed and torque of blocking 1.8Nm at a current of 5A; motors **B** have a 30:1 gear ratio, 200RPM at idling speed and torque of blocking 0.25Nm at a current of 1.65A.

Motions path and speed: The tests with the different configurations of the mobile platform were conducted in four different trajectories - square, triangle, trapezium and rhombus (Fig. 3). For each separate path the platform is tested at two speeds: low of 0.17m/s and high of 0.34m/s.

A separate control algorithm is written for each of the 32 planned experiments. The algorithms are written in C in the IDE Arduino environment, using the included standard libraries [9,10]. The algorithms are very similar to one another, so for briefness a representative algorithm for quadrangular trajectory at a low speed for conventional wheels is shown. The motions of the mobile platform are defined by control functions. For instance, in the case of a quadrangular trajectory and a kinematic structure with conventional wheels the functions are: **`go_forward;`** **`go_reverse`**; **`turn_left;`** **`turn_right;`** and **`stop.`**

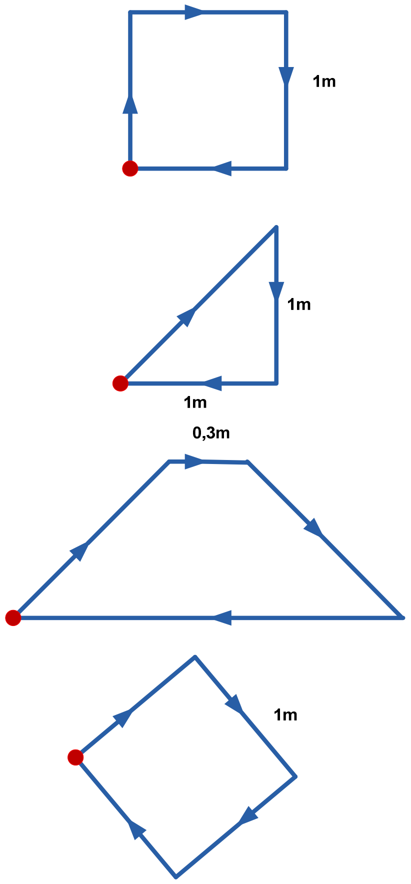


Fig. 3. Mobile platforms paths during the conducted experiments.

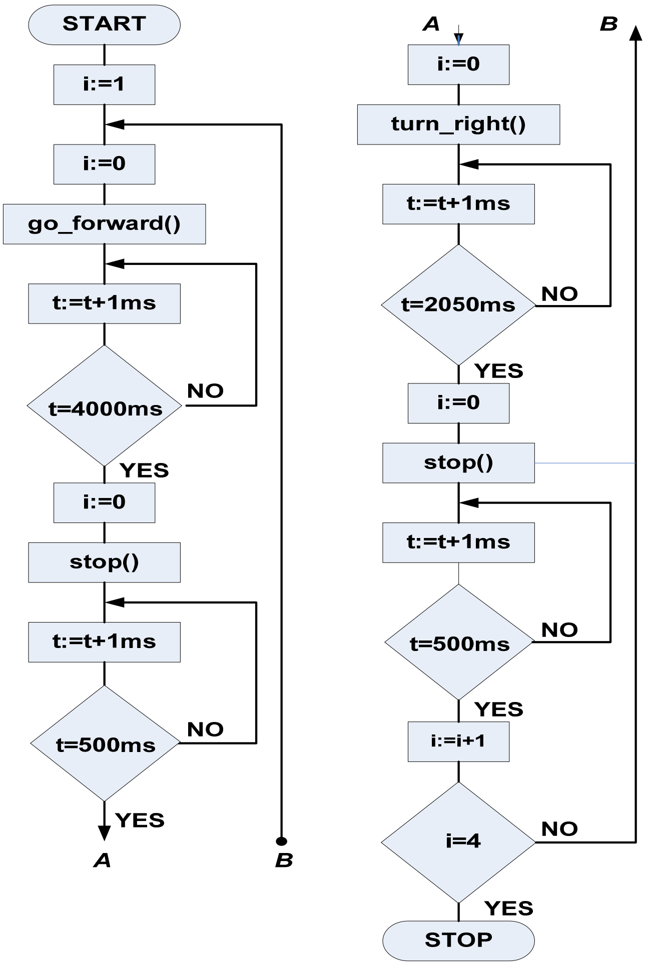


Fig. 4.Quadrat path algorithm at low speed for conventional wheels

All motion related functions comprise the same components:

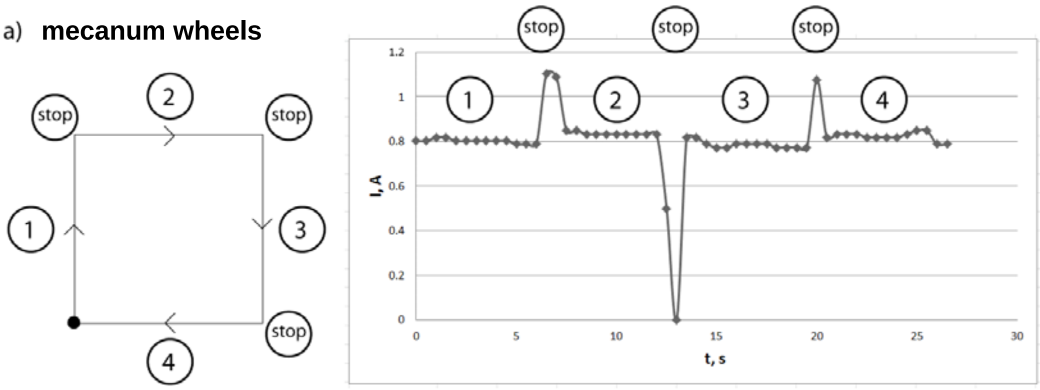
- Parameter **`time`**: defines the duration of the functions activeness, resp. the distance covered by the robot in a given direction at a constant speed;
- Sub-function **`digitalWrite`**, which points a logical low or high level of those driver pins, which set the direction of rotation of the corresponding electric motor;
- Sub-function **`analogWrite`**, which originates the PWM signal of the drivers controlling the speed of the corresponding electric motor. The speed is given in general and applies to the entire algorithm through the variable **`speed`** in the section **`variables`**. Nevertheless, if needed, it can be individually altered and specified for every separate motion related function. The range of the variable **`speed`** is (0-255), which corresponds with a (0-100%) filling of the PWM signal; i. e. covers the values from zero to maximum speed of the electric motor.

3. EXECUTION OF THE EXPERIMENT

For each experiment, i.e. for each configuration of the mobile platform throughout completing the given trajectory two parameters are recorded in real time: (1) the value of the electricity-sensor-output-voltage, which indicates the consumed electric power and (2) the battery voltage. In both cases, this is done using a digital USB multimeter UNI-T UT61B; simultaneously, the unit is connected via a 4-m USB cable to a personal computer that records the obtained values at a 2Hz frequency of measuring and recording. The value data is recorded as .xls files thus simplifying the processing of the recorded data.

Fig. 5 is added for enabling the interpretation of the graphs and the recorded results. Fig. 5 matches the graphs of the measured consumed power for both kinematic configurations accordingly to the trajectory performed by the robot, a quadrangle in the discussed case.

a) **mecanum wheels**



b) **conventional wheels**

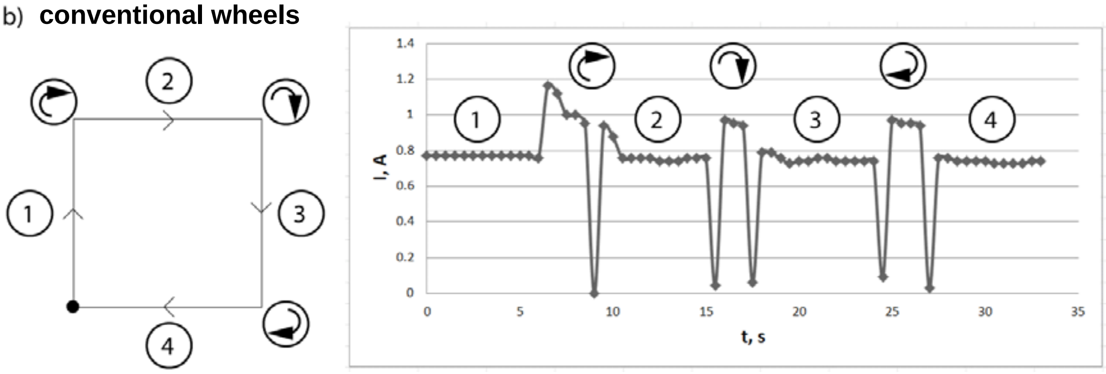


Fig. 5: Correspondence between the resulting mobile platform-trajectory-graphs

The horizontal sections of the graph with numbers 1-4 match the linear sections of the robot's path. In the mecanum wheels test the horizontal section are divided by sharp ups and downs in the electric power values. This corresponds with the moments when the robot stops in the trajectory altering points. Theoretically, at these points the graph should show a sharp drop to zero value in the electricity consuming matching the moment when the robot completely halts, followed by a sharp peak corresponding to the initial power value when the robot starts moving in a new direction. As far as those transitional periods are short while, unfortunately, the measurement frequency of the applied UT61B device – rather low, the graphs do not reflect in the most visualizing mode the drops and peaks, often the latter happens to go unnoticed.

Tests with conventional wheels show again horizontal sections with numbers from 1 to 4 matching the linear parts of the path. In this case the horizontal graph segments are divided by sections reflecting the 90°-robot-turn in the new direction. Those sections must be viewed as peaks (in the moment of turning) surrounded by drops (the short stops before and after the turn is done). Again, due to the transition’s briefness and the measurement’s low frequency the graph do not always mirror the halts and turns in best visual way.

4. CONCLUSION

As the analysis of the experimental results generalized in Fig. 6 indicates, the matter of the most energy effective configuration has a rather ambiguous answer. In the discussed test the factors researched are speed, type of driving wheels and motion trajectory.

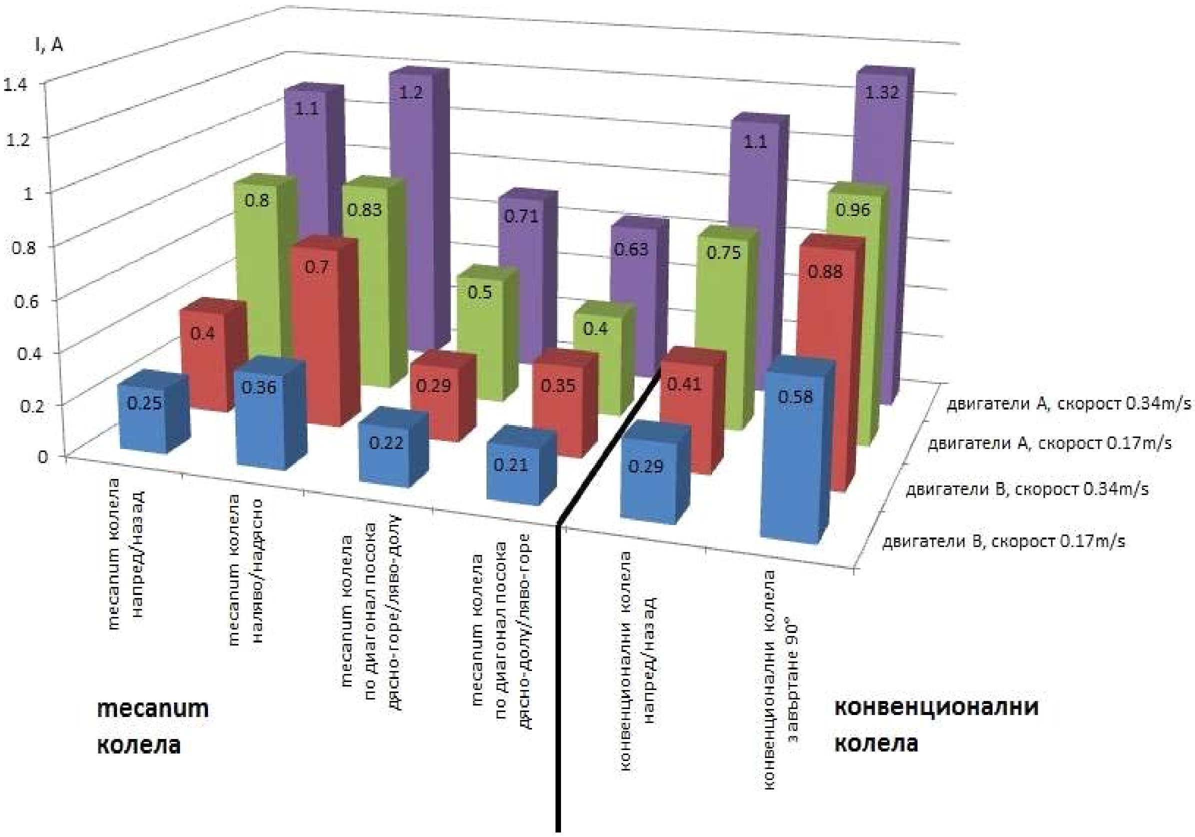


Fig. 6: Generalized results involving both kinematic structures

Overall, assignments requiring high-motion speeds justify the selection of configurations involving motors of the **B** type, i. e. such with a small gear ratio and low motor power. At high speeds these configurations are sufficiently stable and consume far less energy. If the task requires low speed configurations with **A** motors, aka with a bigger gear ratio make a good choice.

In the case of simple motion trajectories, especially big linear section configurations with conventional-wheeled-kinematic-structures would be more advantageous. Though their consummation of electric power while performing turns and U-turns is high, while doing the forth-back movements those platforms are sparser on electricity than the mecanum-wheeled-platforms. In turn, if the robot moves for most of the time along a straight line and does turns/U-turns just occasionally, conventionally-wheeled-platforms will demonstrate higher energy efficiency. E. g. moving on a large field following a "snake"- type-path (i. e. horizontal and vertical movement with 180°motion-inverting at both ends of the field) justifies the implementation of conventionally-wheeled kinematic structure.

On the other hand, paths requiring a frequent direction altering, aka multiple turns and direction changes, especially when short straight sections are concerned, a kinematic structure with mecanum wheels would be more appropriate. For the linear segments of the trajectory this platform would consume more power than the conventionally-wheeled one, the overall energy efficiency of the first would be higher since the platform would make advantage of the mecanum-wheels ability to move both sideways and along the diagonal and would significantly save on the energy needed for frequent turns. So moving around a furnished room by a robot vacuum cleaner would justify the use of a mecanum-wheeled-kinematic-structure.

The joint contemplation of factors like speed and trajectory and the analyses and considerations shared in the present paper should provide for choosing a kinematic structure configuration featuring optimal energy efficiency in accordance with the specific assignment of a particular mobile platform.

REFERENCES

[1] Davids, A. Urban Search and Rescue Robots: From Tragedy To Technology. Proc. IEEE Intelligent Systems, 17(2) pp. 81-83, March 2002.

[2] Drenner, A. et al. Mobility Enhancements to the Scout Robot Platform. Proc. International Conference on Robotics and Automation, pp. 1069-1074, 2002.

[3] Luo, C., Yang, S.X. A Real-Time Cooperative Sweeping Strategy for Multiple Cleaning Robots. Proc. International Symposium on Intelligent Control, pp. 660-665, 2002.

[4] Vaussard, F. et al. Cutting Down the Energy Consumed by Domestic Robots: Insights from Robotic Vacuum Cleaners, Advances in Autonomous Robotics Lecture Notes in Computer Science Volume 7429, pp. 128-139, 2012.

[5] Kim, C.H., Kim, B.K. *Minimum-Energy Motion Planning for Differential-Driven Wheeled Mobile Robots*, Motion Planning, Xing-Jian Jing (Ed.), 2008, ISBN: 978-953-7619-01-5.

[6] Chiong Kong Hyep. B.Sc. Diploma These “Development of Autonomous Laboratory Robot”, Technical Uiversity of Sofia. Bulgaria, 2013 (Чьонг Конг Хйеп. *Дипломна работа за ОКС „Бакалавър“ на тема „Разработка на автономен лабораторен робот“*. ТУ-София, Катерда „Автоматизация на дискретното производство“, София, 2013 (in Bulgarian).

[7] Barili, A. et al. *Energy-Saving Motion Control for An Autonomous Mobile Robot.* Proc. International Symposium on Industrial Electronics, 1995, pp. 674-676.

[8] Mei, Y. et al. *Energy-Efficient Motion Planning for Mobile Robots.* Proc. International Conference on Robotics and Automation, 2004, pp. 4344-4349.

[9] Cuartielles, D. *Arduino FAQ*. Malmö University, (*available at*: http://medea.mah.se/2013/04/arduino-faq/ 01.05.2014).

[10] *Arduino*. (*available at*: http://en.wikipedia.org/wiki/Arduino/ 01.05.2014)

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