Grígora S: A Low-Cost, High Performance Micromouse Kit

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Abstract. There is a need to attract students to science and engineering courses. Robotic contests are one of the most promising ways to attract students to the field of robotics and thereby to science and technology. Micromouse contest is one of promising contests where a small autonomous robot has to navigate its way through an unknown 16×16 cells maze. Since the design and construction of robots is interesting but difficult, this paper presents a high performance, low-cost robot kit for high school and university students participate on micromouse robot contests. This micromouse kit, developed at University of Trás-os-Montes and Alto Douro (UTAD), fits on a 10×8 cm rectangle and uses very small stepper motors allowing a maximum speed of about 4 m/s thus comparing to state-of-the-art micromice. The kit also incorporates a popular microcontroller hardware module (Arduino Leonardo) which facilitates all programming tasks.

Keywords: Micromouse Kit, Micromouse robot, Arduino, Odometry

1 Introduction

The enchantment of robots for many children (and adults) is noticeable in the surge of robotics animation films, such us *Wall-E* and *Robots*, in the proliferation of affordable robot toys and construction sets, and in the publication of robotics magazines and websites. At the same time, there is a generalized concern about the falling numbers of science and technology students leaving to the need to attract them to these courses as early as possible [1]. Marian Petre [1] described examples of children learning subjects that they previously considered difficult and inaccessible, in order to solve problems in robotics. Furthermore, secondary school students working in teams learned that this programming and engineering

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knowledge has a social context. Robotic contests are one of the most promising ways to attract students to the field of robotics, since winning a award at a competition not only gives students a sense of accomplishment but also gives pride and visibility to schools. In RoboCup Jnr., Robot World Cup Initiative [2] for primary and secondary school children, there are competitions in specific challenges: *Soccer* - matches between 2-on-2 teams of autonomous robots on a 90×150 cm grey-scale pitch; *Rescue* - autonomous robots race to identify 'victims' in a line-following task incorporating obstacles and uneven terrain; *Dance* - one or more autonomous robots perform to music in a competition judged for creativity. In the recent years a 35 years-old contest is become very popular - the Micromouse Contest. These contests are very visual attractive and they be held around the world (UK [3], USA [4], Japan [5], Singapore [6], and Taiwan [7]). In 2013 the University of Trás-os-Montes and Alto Douro starts to organize the Portuguese Micromouse Contest [8] trying to attract students to robotic and engineering courses. In 2013 only high level university students participate but the contest aims the participation of high school students and, in a near future, people from 8 to 80 years old.

Micromouse is a small autonomous microcontrolled robot vehicle that has to navigate its way through an unknown maze. The main challenge for the contestant is to impart to the micromouse an adaptive intelligence to explore different maze configurations and to work out the optimum route for the shortest travel time from start to finish. The maze, depicted in Fig. 1, consists of 16×16 squares of 18 cm $\times$ 18 cm each. The horizontals and verticals passageways are 16.8 cm wide and the diagonals are 11.03 cm. The walls are 5 cm high, white on the sides and white on the top (in some events the top is red). The floor of the maze is black. The start of the maze is in one corner (S); the goal (G) is the center four squares.

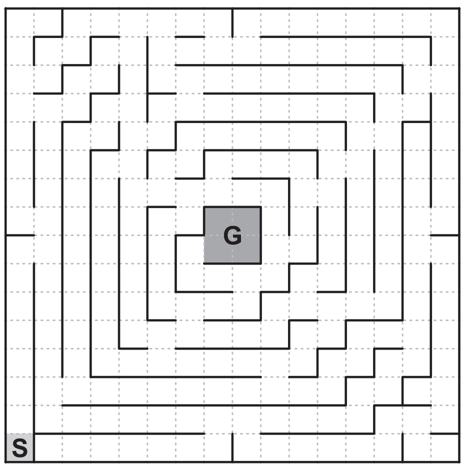


Fig. 1: Typical maze layout.

The scoring procedure is quite complicated, rewarding efficient maze exploration algorithms, and penalising inefficient ones. It is not only speed that determines the winner; reliability and intelligence are also taken into account. For example, if a mouse is touched in anyway, then it is heavily penalised. State-of-the-art micromouse can even run at a speed of 3 m/s and in a diagonal path. The combination of easily defined goals, plus a scoring system that rewards efficient and reliable design makes micromouse an ideal student project that can be taken from low to high level students.

Unfortunately, learning the design philosophy of robots is interesting but difficult, because it includes several areas of knowledge, e.g., mechanics and electronics (a robot is a mechatronic device), automatic control theory, software programming of microcontrollers, among others. Building a micromouse, which has dimensions constrains, become even more difficult and time consuming for university level students and almost impossible for high school students. The dimension constrains and necessary good performance also discourages the use of popular modules (e.g. modules from Pololu [9]). But these kinds of microcontroller modules, very popular nowadays with attractive IDE (Integrated Development Environment) and with significant easy to use amount of software modules on internet, have to be taken in consideration. One of the most popular of these microcontroller module is Arduino [10]. Therefore, the development of a micromouse kit based on Arduino will be a breakthrough for high school and university students.

Some of the problems with commercially available robot kits ([11–13]) or other kits [14] for micromouse contest are that they are usually expensive and have very low performance essentially due to high dimensions and/or motor type. Therefore, a low-cost micromouse kit has been devised in the University of Trás-os-Montes and Alto Douro to help to raise high school students interest to science and technology. The kit is based on Arduino Leonardo, have two wheels differential drive with a stepper motor on each wheel, and infrared hall detection sensors.

2 Micromouse Kit

The micromouse kit, whose block diagram is shown in Fig. 2, is steered with NEMA 8 (very small, only 20mm $\times$ 20mm by 30mm long) 1.8° steeper motors. The micromouse controls four infrared light emitting diodes (IR LED) in three directions (front, diagonal left and diagonal right), and detects the intensity of the reflected light to determine the maze wall information and to correct robot navigation. The main unit (controller unit) is based on Arduino Leonardo [15] containing a 16 MHz ATmega32U4 microcontroller from ATMEL with 32 kb of flash memory and 2.5 kb of SRAM.

The microcontroller is programmed through a micro USB port who can also be used as serial communication port (useful for debug). The firmware in the microcontroller can interact with the user with buttons, LED, buzzer, and serial port connector (could be used to plug a Bluetooth module for debug - not allowed

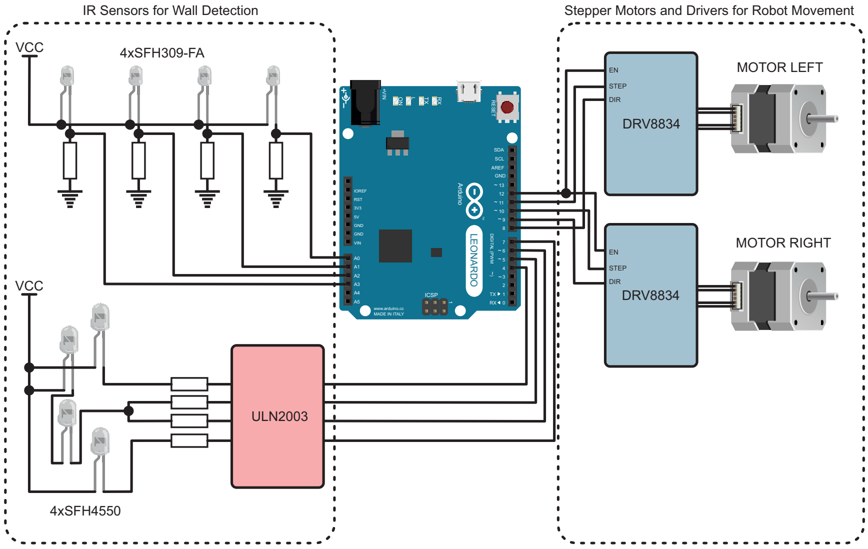


Fig. 2: Micromouse kit block diagram.

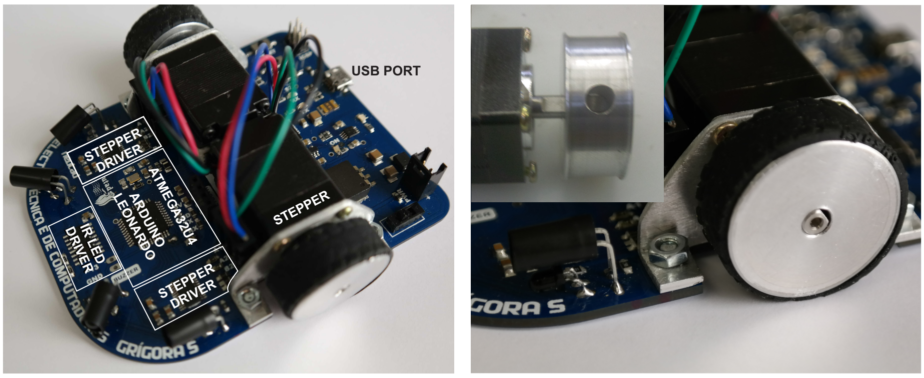
during official runs). By using the functions libraries (C and C++), students should contrive their own maze-solving algorithm to help the micromouse find out the goal and decide and optimal route from the start to de goal.

2.1 Hardware and mechanics

As state-of-the-art micromouse robots (e.g. Min7 a 2011 winner of the 31st All Japan Micromouse Contest [16]), the micromouse kit uses the printed circuit board (PCB) as chassis, as showed on Fig. 3a. It is possible to see the major blocks of the micromouse kit: the stepper drivers (for left and right motor), the infrared LED driver for the four LED, and the 'Arduino Leonardo'-like block that includes the microcontroller and the remaining of the board (power module, LED, USB port, In-Circuit Serial Programming port, and switches).

The steppers where mounted directly on PCB and screwed on a L-shaped support made of aluminum, as represented on Fig. 3b. The wheels, made of aluminum rod with 24.5 mm diameter and 5 mm thick, are directly attached (internal screw) to the shaft (4 mm). The kit uses standard Mini-Z rubber tires making the total wheel diameter of 27.5 mm.

The motors used are small NEMA 8 size hybrid bipolar stepping motor with 1.8° step angle (200 steps/revolution). Each phase draws 600 mA at 3.6 V, allowing for a holding torque of 180 $\mathrm{g} \cdot \mathrm{m}$. These stepper motors only weight 60 g each allowing them to be a good alternative to DC motors. The use of DC motors with encoder, use by state-of-the-art micromouse robots, must be avoided in this kind of kits because they are expensive and very difficult to control. The students must have some knowledge of control theory, e.g. PID control, in order



(a) Major blocks (b) Steeper and wheel mount.

Fig. 3: Grígora S: Micromouse kit photos.

to control the robot movement. For high school students and even first years university, the use of stepper motors is strongly recommended.

2.2 Maze wall detection

For wall detection, the micromouse kit, uses infrared LED emitters (SFH4550) with a narrow emission angle of $\pm 3°$ and a typical peak wavelenght of 850 nm. The infrared LED emitters are driven by ULN8003 Darlington transistor array in order to achieve a short pulse forward current of $I_F = 500\,\text{mA}$ wich led to a typical radiation intensity of 2800 mW/sr. The infrared LED emitters are paired with SFH309-FA phototransistors with 95 % relative spectral sensitivity at 850 nm.

Since the IR phototransistors don't have an ambient light filter it is necessary to do the filtering in the digital domain, i.e., in software. To accomplish this the Alg. 1 is used, which calculates the difference between the 'dark' (IR emitter OFF, ambient light) reads and the 'light' (IR emitter ON) ones. This is a simple and efficient method to filter the ambient light.

The data obtained, showed on Fig. 4, from infrared sensor calibration (using Alg. 1) was used to fill a vector of 1024×3 values (maximum ADC value - 10 bits by three power types of sensor pulse - front, diagonal, and diagonal high power). This vector is used to calculate the micromouse distance from values obtained through `ReadIRSensorDistance`. With this procedure floating point calculations was avoided which speeds up wall detection. From the data presented on Fig. 4 we can find that wall detection is must efficient between 2 cm to 20 cm which is acceptable as a cell only measure 18 cm and if the robot have is axis in the center of a cell it is possible to detect a front wall placed on the next cell (26.75 cm from the robot axis and 22.5 cm from the IR receiver). Also, as can be showed on Fig. 4, the diagonal detection uses a pulse with higher power and have a even higher power pulse to detect lateral walls and long diagonal paths, respectively.

Algorithm 1: ReadIRSensorDistance

Data: IRsensor = $\{FRONT\_RIGHT, FRONT\_LEFT, DIAG, DIAG\_H\}$
Result: Value
begin

```
    IR LED off and read dark value;
    pin(IRsensor) ⟵ 0;
    wait to stabilize;
    delay(15 µs);
    darkValue ⟵ analogRead(IRsensor);
    IR LED on and read light value;
    pin(IRsensor) ⟵ 1;
    wait to stabilize;
    delay(15 µs);
    lightValue ⟵ analogRead(IRsensor);
    Value ⟵ lightValue − darkValue;
```

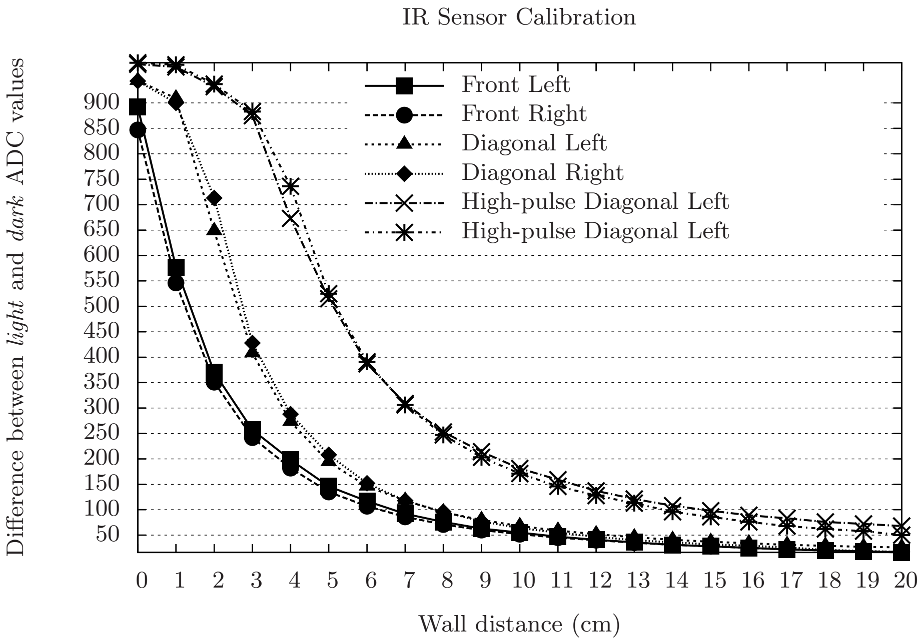


Fig. 4: Infra-red sensor calibration curve.

2.3 Motion control

The micromouse kit uses stepper motors to move itself around in a maze. Therefore, it is very important to control adequately the acceleration and speed of the stepper motors. An integrated circuit DRV8834 from Texas Instruments is used as stepper motor driver (one for each motor). The driver controls the motor current, the direction of rotation, and rotates the motor according to programmed running modes and input pulses. The time interval between these consecutive input pulses determine the speed of step motors, being the acceleration the rate of change of the velocity in the time interval. Consider Fig. 5 as an example showing pulses from microcontroller to stepper driver. Each rising edge of the pulse will rotate the motor one step, according to the direction set by the driver DIR pin. The number of steps required for one full rotation depends on the selected mode (select modes can be from full-step to 32 microsteps/step). Considering K_s a parameter regarding the number of steps required for one full rotation, $K_s = MODE \times 200\,\text{pulse/round}, \quad MODE = \{1, 2, 4, 8, 16, 32\}$, and d_w the wheel diameter, the velocity and acceleration can be calculated by:

$$v_i = \frac{d_w \pi}{K_s T_i} \quad (\text{ m/s}), \quad i = 1, 2, 3, \ldots, \tag{1}$$

$$a_i \approx \frac{v_{i+1} - v_i}{T_i} \quad (\text{ m/s}^2), \quad i = 1, 2, 3, \ldots, \tag{2}$$

Combining Eq. 1 and Eq. 2 we can determine, Eq 3, the next pulse time interval, T_{i+1}, given the present time interval T_i and the desired acceleration a_i.

$$T_{i+1} = \frac{d_w \pi T_i}{k_s T_i^2 a_i + d_w \pi} \quad (\text{ s}), \quad i = 1, 2, 3, \ldots, \tag{3}$$

In pratice, the desired acceleration should be changed gradually and limited by the output torque of the step motors to prevent loss of steps and robot slipping. The velocity and acceleration profiles are stored in the firmware of the micromouse kit to save time for the microcontroller.

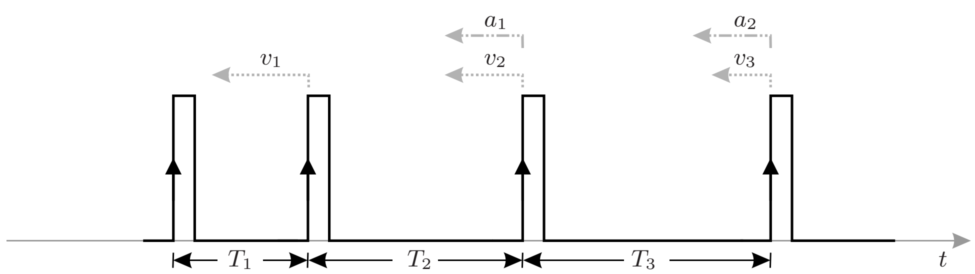


Fig. 5: Microcontroller step pulses sent to the stepper driver.

Micromouse stepper tests show that the minimum time interval T_i achieved was 4 µs (maximum allowed step frequency of the DRV8834, 250 kHz) with $MODE = 16$. The diameter of the wheel with tire is 27.5 mm thus giving a maximum velocity of 6.75 m/s with wheels running free (not touching the floor). State-of-the-art micromouse have a straight line speed of approx. 4 m/s.

2.4 Odometry

Signal applied to stepper motors (left and right) will also be used to calculate the position of the micromouse in the maze. Considering Fig. 6, if the robot starts from a position $p(x, y, \theta)$, and the right and left wheels move respectively the linear distances ΔS_R and ΔS_L, the new position $p'(x', y', \theta')$ is given by

$$p' = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta\theta \end{bmatrix} \tag{4}$$

where,

$$\Delta x = \Delta S \cos(\theta + \frac{\Delta\theta}{2}) \tag{5}$$

$$\Delta y = \Delta S \sin(\theta + \frac{\Delta\theta}{2}) \tag{6}$$

$$\Delta\theta = \frac{\Delta S_R - \Delta S_L}{L} \tag{7}$$

and

$$\Delta S = \frac{\Delta S_R - \Delta S_L}{2} \tag{8}$$

Combined equations (4), (5), (6), (7), and (8) will give the odometry equation modelling the micromouse motion,

$$p' = f(x, y, \theta, \Delta S_R, \Delta S_L) = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} + \begin{bmatrix} \frac{\Delta S_R - \Delta S_L}{2} \cos\left(\theta + \frac{\Delta S_R - \Delta S_L}{2L}\right) \\ \frac{\Delta S_R - \Delta S_L}{2} \sin\left(\theta + \frac{\Delta S_R - \Delta S_L}{2L}\right) \\ \frac{\Delta S_R - \Delta S_L}{L} \end{bmatrix} \tag{9}$$

Considering N_L and N_R the number of pulses used to move the respective left and right stepper motors since last move, ΔS_L and ΔS_R can be calculate from

$$\Delta S_L = N_L \frac{d_w \pi}{K_s} \tag{10}$$

$$\Delta S_R = N_R \frac{d_w \pi}{K_s} \tag{11}$$

3 Conclusions

A high performance, low-cost robot kit for high school and university students participate on micromouse robot contests were developed. The robot fits on

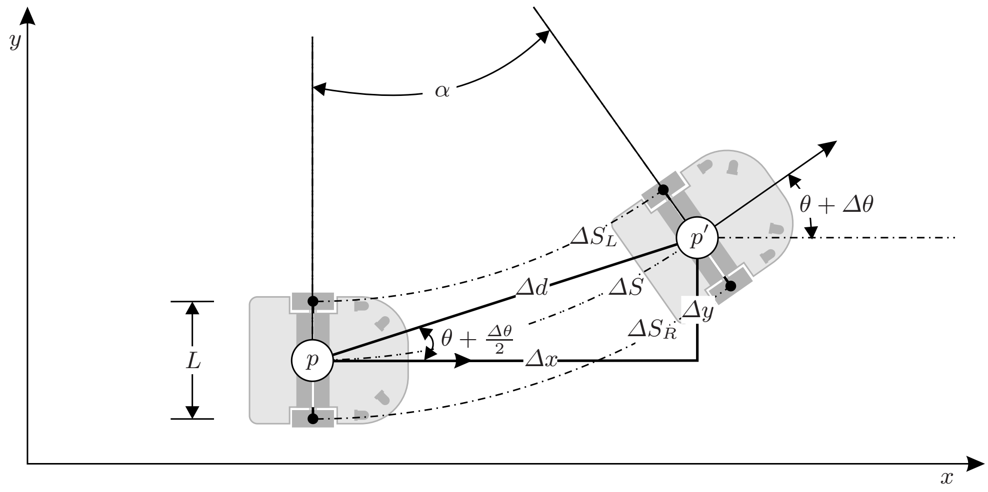


Fig. 6: Position calculation of the micromouse in a maze.

a 10 × 8 cm rectangle and uses very small stepper motors allowing more than 4 m/s maximum speed thus comparing to state-of-the-art micromice. The kit also incorporates a popular microcontroller hardware module (Arduino Leonardo) which facilitates all programming tasks.

The overall cost of the kit is below 100 €. The only drawback is the machining of mechanical parts (wheel and L-shaped stepper mount) that are time consuming since they are not standard or commercial parts easily accessible. In futures developments of the kit it will be considered the use of plastic parts from 3D printing or from custom online CNC machined parts.

Future developments also will consider the use of popular programming with blocks (Alice from Carnegie Mellon [17], Scratch from MIT [18], Blockly from Google [19], among others) removing syntax and therefor facilitating children participation on micromouse contests.

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