An Intelligent Framework to Manage and Control an Autonomous Platform for Detection, Inspection and Monitoring Applications in Chemical Environments

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Implementing an intelligent framework using an autonomous robotic platform offers an effective and versatile solution for monitoring chemical environments. The robotic platform can be customized by adding different types of sensors depending on the desired application. The intelligent control system is realized using a PID control line tracker algorithm allowing it to cover a larger area for data acquisition for further analysis. The data is logged in terms of platform position based on GPS coordinates and time stamp and time interval between sampling. We were able to test the behavior of the developed robot in aggressive chemical environments- acid and base- as well as in experimental ambient conditions (variable concentrations of O_2 and CO_2). The only limitation we found this moment is the concentrations of acids and bases to be used (Perchloric acid, Hydrochloric acid, Sulfuric acid, Acetic acid, Methanesulfonic acid, Sodium hydroxide, Potassium hydroxide, Sodium carbonate, Sodium sulfate, Sodium fluoride) starting from the observed and proved damage on the plastics of the wheel.

Keywords: environment monitoring, intelligent framework, autonomous platform, acid, base, chemical environments

Integrating intelligent frameworks represented by versatile robotic platforms in different domains of applications such as assistive medicine, environmental study or automated systems is a research direction that requires both technical implementation and adaptability of the framework to the desired application [1].

Chemical environment monitoring using a robotic platform can offer information over a longer period of time and the data obtained through this system will show a more in depth analysis of the studied environment [2]. Due the mobility of the platform there is also the possibility of monitoring a larger area by defining a route that the robot will follow in order to obtain samples. This action can be automated by customizing an experiment protocol that will include the exact position at which samples will be obtained based on GPS coordinates and the exact time stamp and time interval [3].

The monitoring system has to be miniaturized, in order to increase its versatility in terms of environments it can be used in, either outdoor or indoor [4]. The system also has to allow the use of different sensors that will offer the information that has to be analyzed. Another feature that has to be implemented for this type of environment monitoring is the data transmission [5]. This feature is extremely useful when collecting data from chemically hazardous environments or high risk environments such as explosion risk or unsuitable life conditions (low oxygen concentration).

The purpose of this paper is to present the implementation of an integrated framework that can be used in different chemical environments (toxic environments). The robotic platform used to implement the integrated framework presented is the Lego Mindstorms EV3 platform [6]. The advantage of using this platform is its high level of customization with different sensors, either own sensors or third party specialized sensors [7]. The platform can also be programmed using different software applications which add to the customization aspect.

Experimental part

Materials and methods

Mindstorms EV3 Robotic platform

The Mindstorms EV3 robotic platform is a suitable solution for developing customizable applications due to the fact that it is easy to use and has the possibility to add different components for platform control or data acquisition through sensors (fig. 1).

The platform is based on an ARM9 300 MHz microprocessor incorporated in the programmable brick. The brick has 4 output ports used to connect motors for the robot command and control and 4 input ports for sensors. The platform autonomy is provided by a 2050 mAh lithium ion accumulator with 4 h of life in use [8].

Fig. 1. Mindstorms EV3 robotic platform

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The programmable brick presents a Bluetooth module that can be used for data transmission for short range applications or the possibility to adapt the programmable brick to long range applications through a Wi-Fi module that can be plugged in the brick's USB port [9]. Data logging is possible also due to the fact that the brick has extended memory by means of an SD card of up to 32 GB. The sampling rate can be up to 1000 samples/second [10].

Framework implementation

The intelligent framework is represented by the mobile platform and the control algorithm implemented. The algorithm has three components with different functionality. The first component controls platform motors and manage its movements. The platform movement is done using a line follower algorithm with PID control, depending on the desired application [11]. The second component is represented by the sensor data acquisition. The third component is the data logging and data transmission. The framework structure is presented in figure 2.

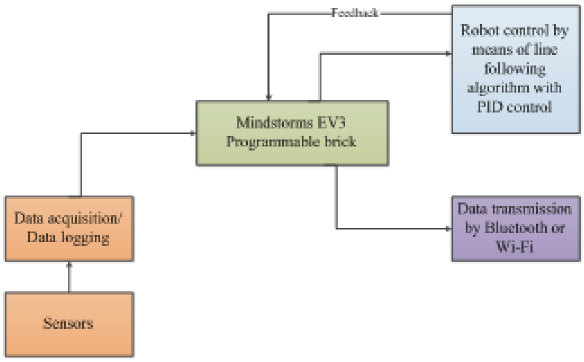

Fig. 2. Structure of the intelligent framework for environment monitoring

The robot control by means of line tracker algorithms requires a color sensor attached to the programmable brick. The sensor for this application is set into reflective mode. The sensor can take values from 0 to 100, 0 corresponding to black and 100 to white [12]. The light is emitted by an infrared LED and the sensor detects the reflected light from the surface it comes into contact with. The application is developed in order for the robotic platform to follow the midpoint between a black line and the surface it is on, meaning the reflective value read by the sensor has to be lower than 50 for the robot to maintain its movement trajectory. If the sensor detects a value over 50 the trajectory will be modified by turning the robot to the left until the value detected is again under the threshold value 50 [13].

The line follower algorithm was implemented using Matlab Simulink Toolbox for Mindstorms EV3. The diagram of the control program is presented in figure 3.

The PID control refers to the gain coefficient with which the robot turns, which are the proportional values P, the integral component I and the derivative component D.

The proportional response is represented by the difference between the midpoint between the black line and the surface and the distance the robot is from this point. The proportional gain is responsible for the response time of the system, meaning that the higher the value the lower the response time, but this has a breakpoint for which if the gain is too large the system will start oscillating [14].

The integral response is influenced by the error of positioning. The gain value Ki will increase until the positioning error is zero [15]. The problem appears when the system cannot return to the zero error state or steady-state, which leads to a phenomenon called integral windup.

The derivative response has the role to attenuate the rapid increase of the PID control coefficient caused by the proportional and integral responses. The intensity of the response depends on the value of the first order derivative filter time constant Tf [16]. The derivative response is sensitive to noise for the color sensor used for the application, thus the positioning of this component on the robotic platform has to be stable.

The errors for these gain components are defined by the following formulas [17]:

$$\varepsilon_p = K_p e(t) \tag{1}$$

where ε_p is the error for the proportional gain Kp with which the robot has to turn.

$$\varepsilon_i = K_i \int_0^t e(\tau)\, d\tau \tag{2}$$

where ε_i is the error for the integrator gain Ki.

$$\varepsilon_d = K_d \frac{de(t)}{dt} \tag{3}$$

where ε_d is the error for the derivative gain Kd.

Based on the gain values we can create a time continuous PID controller. The controller is defined by the following formula [18]:

$$C = K_p + \frac{K_i}{s} + \frac{K_d s}{T_f s + 1} \tag{4}$$

where C is the controller value, Tf is a first order derivative filter time constant and s is the analyzed sample obtained from the sensor.

The gain values are determined experimentally by observing the platform movement when following the midpoint between the black line and the surface. We determine the gain values as Kp = 2, Ki = 0.05, Kd = 5. The first order derivative filter time constant is Tf = 0.5. The PID controller responses for tuned and untuned parameters values were assessed. The untuned values are

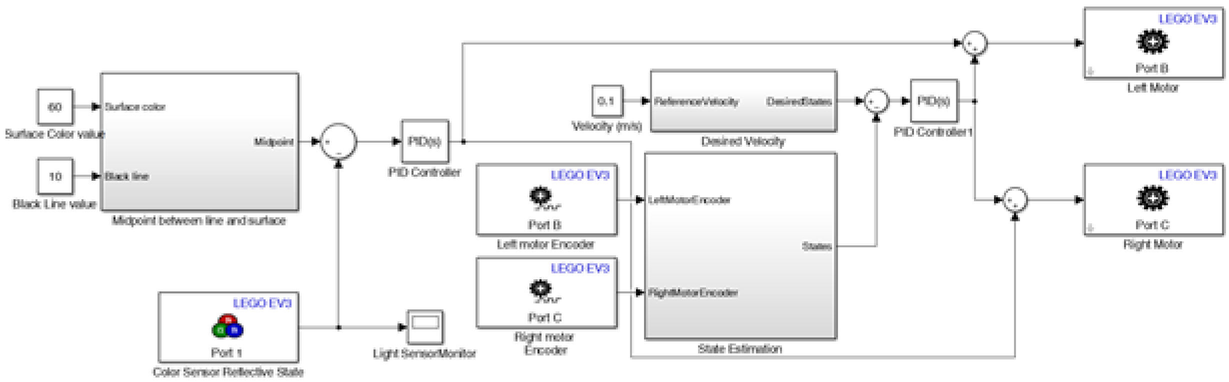

Fig. 3. Diagram of the platform control based on line following algorithm with PID correction implemented in Simulink

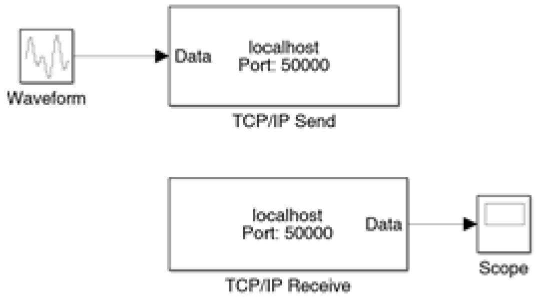

Fig. 4. Simulink data transmission via Wi-Fi

the ones set defined by the user and the tuned values are improved results from the simulation of the optimized output of the PID controller.

Data acquisition and data logging is done using sensors that can be attached to the robotic platform. These sensors can be found in the development kit of the robot and are mostly designed for environment navigation. Sensors specialized for chemical environment monitoring can be obtained from third party manufacturers [19]. Such sensors are used to analyze pH level, atmospheric oxygen or carbon dioxide levels, atmospheric pressure, temperature or magnetic fields. The data acquired can be transmitted for further processing and storage via Bluetooth for short range applications or Wi-Fi for long range applications to a computer, as presented in figure 4.

In order to ensure feedback from the robot to the user we have mounted a 640x480 web camera with an independent energy source that is designed to transmit a video over Wi-Fi to a specified IP address [20]. This allows the user to check if the samples are correctly acquired or if the robot is functioning correctly.

In order to test the system, we designed a line trajectory in our laboratory and acquired temperature and atmospheric pressure data every five minutes for one hour (fig. 5). The process was repeated ten different times, for each instance we determined the total number of movement errors of the platform and if the samples were acquired at the specified time intervals.

Further, we tested the behaviour of the developed robot in aggressive chemical environments. We used the robot on acid- and base-resistant floor in our laboratory (ceramic tiles). As acids were scattered dilutions of Perchloric acid ($HClO_4$), Hydrochloric acid (HCl), Sulfuric acid (H_2SO_4), Acetic acid CH_3CO_2H) and Methanesulfonic acid (CH_3SO_3H). All these acids were applied as a maximum 10% dilution taking into account the damages induced on the plastic wheels of the robot.

On the other side, we used as scattered bases Sodium hydroxide (NaOH), Potassium hydroxide (KOH), Sodium carbonate (Na_2CO_3), Sodium sulfate (Na_2SO_4) and Sodium fluoride (NaF), also as 10% dilutions.

The third type of experiments (preliminary experiments this time) was performed using CO_2 and O_2 from tanks down, the same used for cell cultures. By the help of an usual indoor air quality monitor, attached to the robot, we were able to follow the O_2 (%) and CO_2 concentrations (ppm), although the method was not really accurate.

Results and discussions

In order to test the system, we designed a line trajectory in our laboratory and acquired temperature and atmospheric pressure data every five minutes for one hour (fig. 5). The process was repeated ten different times, for each instance we determined the total number of movement errors of the platform and if the samples were acquired at the specified time intervals.

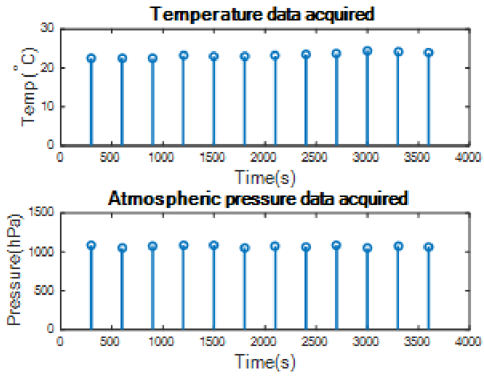

Fig. 5. Accurate data acquired (temperature and atmospheric pressure) during one hour of testing

The movement errors were identified by a human observer that oversaw the testing recordings. The movement error observed was due to the robotic platform losing the position of the midpoint between the black line and the surface which resulted in the robot completing and entire loop before finding the line position and continuing its normal trajectory. These occurrences were very rare, with only four incidents during the total testing period of 10 hours.

We were able to test the behavior of the developed robot in aggressive chemical environments- acid and base- as well as in experimental ambient conditions (variable concentrations of O_2 and CO_2).

The only limitation we found this moment is the concentrations of acids and bases to be used (Perchloric acid, Hydrochloric acid, Sulfuric acid, Acetic acid, Methanesulfonic acid, Sodium hydroxide, Potassium hydroxide, Sodium carbonate, Sodium sulfate, Sodium fluoride) starting from the observed and proved damage on the plastics of the wheel.

This subject is a very important and actual one since there are many possibilities to produce wheels from resistant plastics using the 3D printing techniques [21, 22].

The plastics and recyclable plastics are all over around us in such high amounts that often surpass the local and general removal capacities [23-26].

There are also many improvements in plastics industry, helping the development of such integrated systems [27-29]. Such improvements might have also an important social component [30].

There are many chemical environment studies, emphasizing the importance of the subject [31-33].

Conclusions

The intelligent framework implemented based on the Mindstorms EV3 robotic platform is a versatile and highly customizable development kit that can be adapted to different applications for monitoring the environment.

The robotic platform is easy to use and program for specific applications and allows access to data through data logging or data transmission via Bluetooth or Wi-Fi.

The platform is designed for long term monitoring of a larger area. The trajectory can be established and the platform location can be determined through GPS coordinates. The data logging is done at precise time stamps and intervals.

The platform was successfully tested in acid and base environments, as well as experimental conditions (variable concentrations of O_2 and CO_2). Thus, it might monitor the e.g. low-oxygen or high CO_2 or CO environments.

The management of the platform (financial costs) remain a subject to be developed by future research.

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