Differences between NXT and Wallaby controlled robots

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***Abstract*—Robotic controllers are a key element in the designing, construction and programming of a robot. The overall purpose of this paper is to provide possible solutions for difficulties arising during the transition from NXT to Wallaby controlled systems. Therefore we compared the Lego NXT and KIPR Wallaby in building robots based on the concept of a line follower.**

After introducing the similarities and differences of specific electronic parts like motors and sensors a detailed description about the design and construction of the line follower is given. In the experimental section the functionality of the controllers were outlined by analysing the motor power of both robots. Furthermore the robots were tested by evaluating the precision of the robots movements following a predefined track. The results demonstrate that both controller systems show advantages and disadvantages depending on the characteristics necessary for the experiment. Therefore we conclude that in principal both systems are appropriate to build a line follower. The decision of which system chosen depends on the robotic teams experiences and the task that has to be executed by the robot.

I. Introduction

Nearly every robotic team at the Department of Computer Science at HTL Wiener Neustadt starts by constructing their first robot with a Lego Mindstorms Kit and the Lego NXT. The NXT is an easy-to-handle controller and ideal for learning the basic construction and programming skills to build a simple robot. For more challenging tasks, other controllers are required. Since the KIPR Wallaby [1] is widely used for competitions like Botball® it was interesting to use this controller system for the experiments in this paper. Especially using these two controllers, the challenges caused by hardware and software differences have been described in detail. In addition the main differences in the construction and practical application using the KIPR Wallaby in comparison to the established controllers have been analysed.

For this purpose the concept of a so-called line follower [2] was used since it is one of the first and easiest tasks for a new robotic team. Such a robot is capable of following a track made of black tape on a white underground using light sensors. Such a robot is not only used for educational purposes. Generally speaking, it is also needed when a robot has to follow a defined route.

Using the concept of a line follower it was necessary to focus on the following tasks:

- Designing robots according to the concept of a line follower.
- Constructing and programming the robots using the Lego NXT and the KIPR Wallaby.
- Evaluation of the power to speed ratio.
- Precision of the experimental subjects following a curved track.

In order to point out the technical differences between the Lego NXT and the KIPR Wallaby their properties in terms of hardware and software are described in detail in the following section.

II. Components

A. The Lego NXT

Lego Mindstorms is a robotic kit, first introduced in 2006, which contains the NXT controller, many Lego components and a set of sensors such as a light sensor, touch sensor, ultrasonic sensor and a sound sensor. It is either powered by a set of batteries or a battery pack.

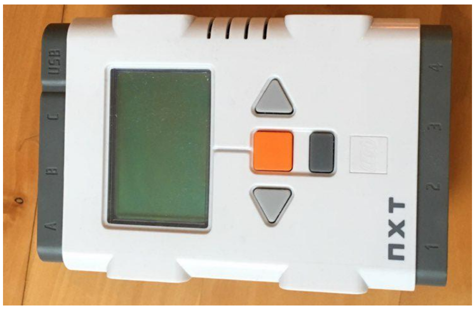

Fig. 1. Picture of a Lego NXT controller, introduced in the Lego Mindstorms Kit in 2006

The light sensor is capable of measuring reflection and returns data which ranges from 0 to 100. The accuracy of the sensors data is limited by the interference given by the sensor. Most interferences occur when the light sensor is either too close or too far away from the surface. As a consequence the sensor returns inaccurate readings. The ultrasonic sensor is able to determine the distance to an object. The distance is measured in centimeters and ranges from 4 to 255cm. In contrast, the sound sensor is capable of detecting volume levels measured in decibels and returns a value between 0 and 100. All of the mentioned sensors can only return analog data. The touch sensor is the only sensor from the Lego Mindstorms Kit which can operate digital and analog. When set up as an analog sensor it returns the position of the probe relative to the casing. Since the probe is spring loaded, the position of the probe is proportional to the force applied. However, when set up as a digital sensor it returns 1 if the analog reading is above the half, otherwise it returns 0. This property makes the sensor useable for many different touch sensing tasks like collision detection or user input. The kit also contains motors and the key component, the programmable brick. The brick is the ”brain” of the robot, controlling every task. ”For simple programs and to help beginners, the environment NXT-G is a good option. But to get the full potential of the NXT brick you need a programming environment that is more reliable and efficient than NXT-G”, says Daniele Benedettelli [3]. For this reason the commonly used solution is the BricxCC IDE and the language NXC. NXC stands for Not Exactly C and shares a few similarities with C. It is a solid and reliable language and can be used for many different purposes such as simple line followers.

B. The KIPR Wallaby

The KIPR Wallaby is the currently used controller at the Botball® competitions. It was developed based on the KIPR Link and was first introduced in 2016 [4]. It includes a touch display and can be connected to Wi-Fi with its built in adapter but for reliability reasons it's recommended to use a dongle especially when trying to connect to specific networks. On the upper side are 2 USB ports, a micro HDMI port, a USB download port. A total of 24 additional ports are placed at the bottom of the device.

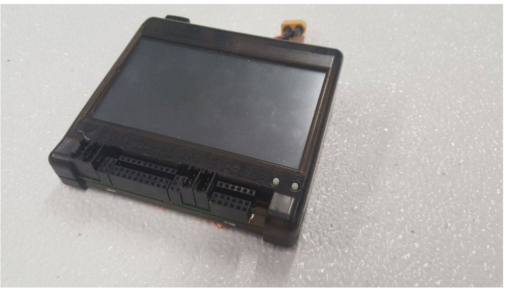

Fig. 2. Image of a KIPR Wallaby, introduced for the Botball® competitions in 2016

On these ports, external devices can be connected. As described by Brenner et al. in [4] the Wallaby is powered by a 6.6 Volt battery which is connected via an XT-60 connector.

As mentioned above there are 24 ports to connect motors, servos, sensors and other peripherals to the Wallaby. They are subdivided in 4 motor and 4 servo ports as outputs as well as 10 digital and 6 analog ports used for analog or digital sensor input. These can be controlled directly by their port number. Digital touch sensors get plugged into a digital port and return a boolean value, which is either 1 or 0 and interpreted as true or false, respectively. Besides the sensors described for the Lego NXT, there are three common types of touch sensors which include a small sensor, a larger one and one with a lever attached to it. They can be used as push buttons or for detecting collisions. This also applies to analog sensors which get plugged into an analog port. Their return values are in a range from 0 to 4095.

In the Wallaby's system there are two types of light sensors, the simple light sensor and a more complicated, so-called ”TopHat”. The simple light sensor can exclusively measure the ambient light and the TopHat can additionally detect the reflection from the surface. In order to do so it's emitting a beam of infrared light and measuring the intensity of the reflected beam. Simple light sensors are used at Botball® to start all robots at the same time. The TopHat, for instance, can be used to detect a line on the floor and follow it, as needed for line followers, which are described in more detail in section III-A.

The Wallaby has its own web IDE for programming, the so-called Harrogate, which can be accessed by entering the URL ”http//<IP>:8888/” into the browser. A direct connection between the Wallaby and a computer by using a USB cable on non Windows devices is possible without any major difficulties. Only on Windows a special driver is required. Executable programs can be started in the Web-IDE or directly on the device using the built in touch display of the Wallaby. The Wallaby supports the programming languages C and Python.

III. CONSTRUCTIONS AND PROGRAMMING

For comparability, for the design of the robots only one light sensor was used in both cases. The experimental facilities of the HTL Wiener Neustadt are placed in the basement of the building without external light, thus ensuring that all experiments were performed under the same conditions.

A. Programming of a line follower

For the experimental setting a program was required, which could regulate the engine power of the motors according to the values read by the reflection sensor. For this purpose a pseudo code was developed based on the idea of a PID-controller. PID is short for proportional, integral and derivative and has been widely used for line followers allowing the adjustment of the P-I-D constants thereby adapting the robots reactions to the track settings. Listing 1 shows the pseudocode that was used as a template for the line follower programs. Finally the pseudocode was adapted to the programming language NXC for the NXT robot and to the programming language C for the Wallaby robot.

B. Construction of the NXT-robot

The first robot the team constructed was a simple line follower consisting of the Lego NXT kits parts generation 2. The kits components used were, two motors, one light sensor, the NXT controller and a few common Lego parts. The motors and sensors were connected to the controller by a RJ12 cable and were programmed by connecting a computer via USB-B

```
white
black

//average of black and white
target = (white + black) / 2
targetpower

kp          //constant of P
ki          //constant of I
kd          //constant of D

integral    //tries to correct past errors
error_old   //sums up errors
derivate    //predicts the next error

while true do
  sensorvalue = readSensor
  error = sensorvalue − target
  integral = integral + error
  derivate = error − error_old
  turn = ((kp ∗ error) + (ki ∗ integral)
         + (kd ∗ derivate))

  powerA = targetpower + turn
  powerB = targetpower − turn
  MotorA_power = powerA
  MotorB_power = powerB

  error_old = error
```

Listing 1. Pseudocode for the PID-Controller that was used in the line follower experiment

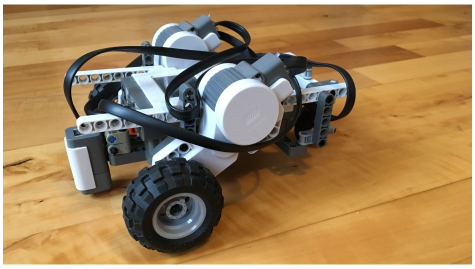

Fig. 3. Picture of the NXT controlled line follower that was used for the experiments

cable. One of the first challenges in the construction was the installation of the robots wheels resulting in serious difficulties in steering curved tracks. In addition, using exclusively the limited number of parts available it was impossible to build a adequate steering robot. The solution was to use three wheels instead of four, by mounting the third wheel in the centre of the rear-part of the robot, as shown in Fig. 3. As a result, the turning speed could be increased and the movements of the robot got fluent. After that the robot was capable of following the predetermined line without major difficulties. On the other hand, the improvement of the steering lowered the stability of the construction, but to an acceptable minimum.

C. Construction of the Wallaby robot

In order to increase the comparability, the Wallaby robot was constructed to match the specifications of the NXT robot as closely as possible using only one light sensor in both constructions. To guarantee the stabilization of the robot, a metal plate was used on which the Wallaby was mounted. The light sensor and the motors were placed in the same positions as visualised in Fig. 4. In place of the back wheel of the NXT the Wallaby robot was constructed using a ball caster wheel. The light sensor equivalent to the one used for the NXT, the so-called TopHat displayed higher resolution by offering a wider range of the return values.

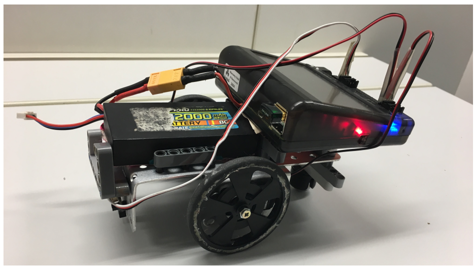

Fig. 4. Picture of the Wallaby controlled line follower that was used for the experiments

IV. Experiments

One of the first problems when it comes to the comparison between the Lego NXT and the KIPR Wallaby is the difference in construction and functionality of the two controllers. Therefore, the first experiment to do was to calibrate the motor of both the NXT and the Wallaby. This formed the foundation for the following experiment.

In order to compare the functionality of the controllers used for the two robots the motor power stated by the programmer was set in ratio to the actual speeds. For this experiment both of the motors had no load attached to it.

A. Motor testing

By counting the revolutions in a certain time, that was measured by a stopwatch integrated in an mobile phone, the RPM (”revolutions per minute”) could be calculated. This was done with a motor for the Wallaby and one for the NXT.

B. Line following

Precision is one of the most important things in robot construction. Therefore it was interesting to find out which controller was able to follow precise movements. At first, a rectangular track with rounded corners was set up using black tape, with an width of 0.59”, on a white table. This was the experimental figure the line followers were to trace, as illustrated in Fig 5 Panel A. Both robots were to follow the track for 3 laps and data acquisition was performed as follows. A camera was installed in a position allowing to track the ArUco tags placed on top of the robots, thereby following the robots movements on the experimental figure. ArUco markers are synthetic square markers which are often used in augmented reality or robotics applications. The camera was connected to a Laptop which recorded the movements of the line followers. The OpenCV ArUco library [5, 6] in combination with python was used. The system was able to periodically detect the current coordinates of the robot. These

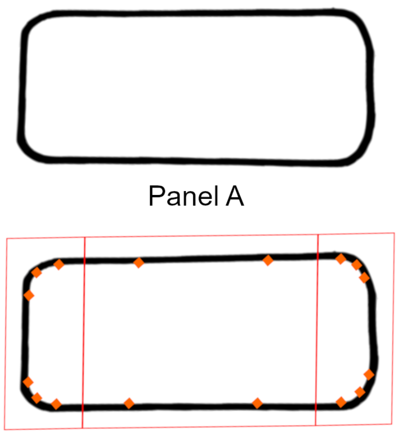

Fig. 5. Panel A depicts the plain track not subdivided in sections and without measuring points. Panel B additionally shows the sections and positions of the measuring points used to calculate the deviation

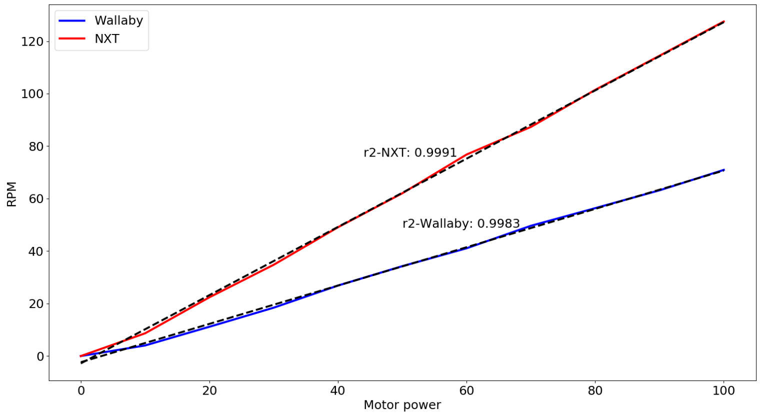

Fig. 6. Diagram of the power to speed ratio, representing the motor power (in percent) comparing the Lego NXT (red) and the KIPR Wallaby (blue). Additionally the linear regression (dashed black line) and the coefficient of determination (r^2) of the measured data is displayed

coordinates were inserted on a coordinate system using the python library matplotlib [7] which illustrated the movements of the robot.

In order to quantify the results the rectangular track was subdivided in 2 major sections, the straight middle section as well as the curves as shown Fig. 5 Panel B. In the middle section 4 measuring points were placed and the deviation from the inner border of the tape was calculated for each point. Analogous data acquisition was performed in order to detect the precision of the robots in the curved sections using 3 measuring points representing the beginning, the vertex and the endpoint of the 4 curves, in total 12 points. The results are given as the mean deviation for all measuring points in each section.

V. Results

A. Construction

The NXT robot was easier to build because it only consisted of Lego parts. The Wallaby, however, was mainly built of metal parts which are a lot more difficult to handle. However the design of the Wallaby controlled robot was unambiguous because it consisted of way less parts. The light sensors were placed on the same position on the robot although the one on the Lego NXT was easier to mount.

B. Programming

The languages C and NXC are very similar, mainly because the NXT syntax is based on C. However, C is more advanced and complex. NXC is often used for programming NXT robots. According to that, the language is less complicated and ideal for beginners. The most important commands and functions are already integrated and therefore it has a high fault tolerance.

C. Power to speed ratio

The numerical results of the motor testing experiments are shown in Tab. I., listing the RPM values for each robot at specific motor power given in 10% intervals, ranging from 10% to 100%. To illustrate this, the results have been plotted as a graph as shown in Fig. 6. At each percent step the motor of the NXT robot shows higher RPM values compared to the Wallaby robot. When comparing r^2 of both graphs it is noticeable that the power to speed ratio of the NXT increases with less deviation than the one of the Wallaby. Also, the linear regression indicates that both graphs are relatively linear, except for the values below 10% where it differs slightly.

TABLE I
POWER TO SPEED RATIO OF THE NXT AND WALLABY MOTORS

Motor Power	RPM NXT	RPM Wallaby
10%	8.66	4.03
20%	22,39	11.16
30%	34.78	18.43
40%	49.09	26.87
50%	62,03	34.25
60%	76.81	41.08
70%	87.31	49.64
80%	101.44	56.36
90%	114.43	63.16
100%	127.49	70.94

D. Precision in line following

Fig. 7 shows the movements of the robots tracked by the camera, transferred on a coordinate system and overlaid on the actual experimental subject. Panel A of the named figure gives the result for the Lego NXT robot (red), panel B for the KIPR Wallaby (blue) and panel C illustrates the results superimposed for both robots. Tab. II. gives the results quantified, as described in the experimental section. As mentioned

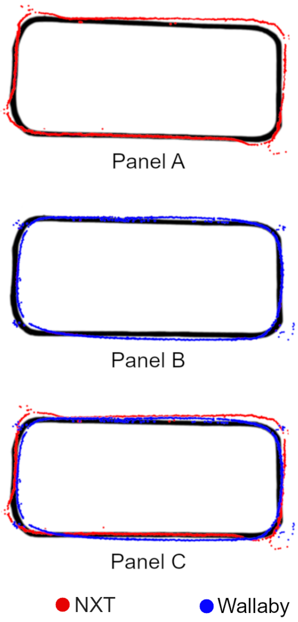

Fig. 7. Depiction of the course of the both robots on the track. Panel A track of the NXT (red) superimposed to the experimental figure, Panel B track of the Wallaby (blue) superimposed to the experimental figure and Panel C superimposition of NXT (red), Wallaby (blue) and experimental figure

TABLE II
MEAN DEVIATION NXT VS WALLABY

NXT	Wallaby
Straight sections	
2.5mm	2.7mm
Curved sections	
3.65mm	**1.27mm**

the mean deviation of the tracked movements from the inner border of the tape were calculated for both robots in the two main sections, straight and curved respectively. As visible for the straight sections both robots showed similar results with a mean deviation of 2.5mm for the Lego NXT and 2.7mm for the KIPR Wallaby. In contrast, in the curved part of the track a mean deviation of 3.65mm was detected for the NXT and 1.27mm for the Wallaby indicating a higher precision for Wallaby. This property my be caused by the use of the ball caster wheel for the wallaby controlled robot which increases the precision of the robot in curves. Furthermore the fact that the accuracy of a robot can be doubled by changing one particular aspect of its construction is interesting.

VI. Conclusion

The results of the experiments indicate that both robotic controllers, the Lego NXT and the KIPR Wallaby respectively, in principle are appropriate for designing, construction and programming a line follower. The experimental data indicate that both controllers used have advantages and disadvantages depending on the requirements the robot has to meet. In addition it strongly depends on the circumstances a robotics team or an individual is currently in, whether in a competitive environment or just for hobby projects. When first learning about robotics in school the NXT is a good option because it is easy to handle both in hardware and software terms. With the special focus on designing and building a ”line follower” with the need for high movement accuracy of the robot the KIPR Wallaby turned out to follow the curved part of the track more precisely in comparison to the NXT. This difference may be explained by the use of a ball caster wheel for constructing the Wallaby controlled robot, which lead to more accurate steering without the disadvantage of instability, as experienced with the NXT, when constructing with three conventional wheels. Therefore it would be interesting to explore whether such a difference would be noticeable when building robots with the same basic construction (differing only in the controller).

On the other hand the results concerning the power to speed ratio indicate an overall higher engine power for the NXT. Furthermore one has to keep in mind that although the line follower experiments were performed under the same light conditions, for comparability reasons the TopHat was left deliberately unshielded. Additional shielding, to prevent falsified data, could offer the possibility to increase the precision of the sensor if necessary. This fact gives the opportunity to develop more sophisticated applications in future work.

However the final decision about which controller system is used strongly depends on the personal preferences and the tasks the robot has to accomplish.

Acknowledgment

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