Spiderino - a low-cost robot for swarm research and educational purposes

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***Abstract*— This paper presents a design for a low-cost research robot based on the small size of the Hexbug Spider toy[1]. Our basic modification replaces the robot head with a 3D-printed adapter, consisting of two parts to provide space for sensors, a larger battery, and a printed circuit board (PCB) with Arduino microcontroller, Wi-Fi module, and motor controller. We address the assembling process of such a robot and the programming using Arduino studio. The presented prototype costs less than 70 Euro, and is suitable for swarm robotic experiments and educational purposes.**

I. Introduction

In the past ten years, swarm robots have gained increasing interest in the research community. Inspired by animals in nature such as ants and bees, swarm robots offer novel approaches such as self-organization, self-learning and self-reassembly [PAPS16] in order to solve complex problems, like moving a large object by a group of robots or distributed sensing [CM15]. Consequently, design and implementation of a swarm robot is still a big challenge where designers have to take into consideration several aspects such as locomotion, actuation, navigation, size, sensors, costs and communication [PAPS16], [PAPS15]. On the other hand electronic components for such a robot have become cheaper, smaller and consume less power consumption than before, which helps to make swarm robots more efficient, lighter in weight and smaller in size [ZSP12]. For example, the Arduino Pro Mini and the Wi-Fi module ESP8266 which are used in Spiderino cost 20 and 5 Euro, respectively. This paper introduces a robot named Spiderino, which is shown in Figure 1.

In research, testing a swarm robot is difficult due to the hardware complexity and cost of robots. Software simulation can be used in order to test swarm behavior, but this is considerably complex and often inaccurate due to the poor modeling of the environment, which calls for a validation with real robots. Our purpose in the next step is to model and simulate swarm behavior using a group of 10 Spiderinos.

On the other hand, the Wi-Fi module is widely used in Internet of Things (IoT) applications, for example, in home energy monitoring [HAA$^+$16], continuously remote monitoring and watching of a solar plant system, as well as on portable devices like mobile phones [JJGY16].

[1]https://www.hexbug.com

Besides the use in swarm robot experiments, where we need a large number of robots at an affordable price, there exists another possibility for using the robot in school education. Here we see the employment of a standalone robot with a group of pupils performing simple programming tasks. A single robot comes with a limited number of functions and sensors which eases the programming interface, second the six-legged locomotion and the spider design are likely to raise interest among children. The low cost of a single robot will correspond to the unfortunately very limited budgets for additional materials in science education in schools.

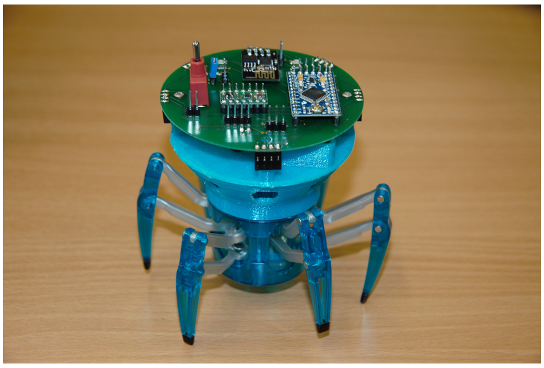

Fig. 1. Spiderino

In general, educational robots [TG10] [Tra10] are not restricted to the requirements for swarm robotics which we identify by the following properties of a robot [EHRZ15]:

- Affordable: The total price of one robot including additional modules should not exceed 100 Euro. The body of the robot can be easily reproduced using a 3D printer.
- Swarm-oriented: The robots will be used in experiments with swarms and the components of the robot should enhance cooperation between robots
- Customizable: The model can be changed in order to meet different requirements, for example, by adding additional sensors.
- Open-platform: All models and blueprints of the robot are freely available information which everyone can use, reproduce or modify.
- Easy to use: Enable simple, user friendly programming of robotic functions.

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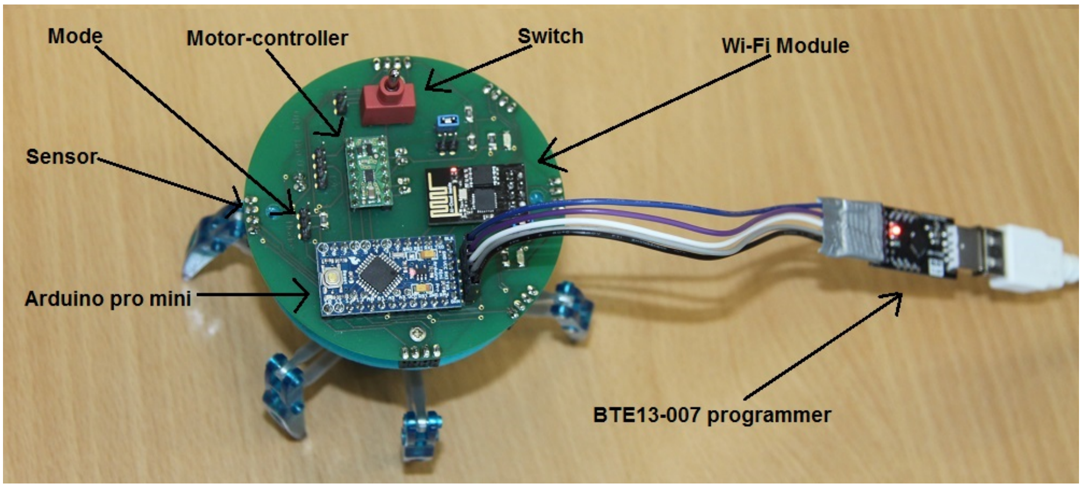

Fig. 2. Connecting BTE13-007 to the PCB

Robot	Cost ($)	Motion	Speed (cm/s)	Autonomy (h)
Colias [AMZY14]	41	wheel	35	1-3
Jasmine [KTKS09]	100	wheel	N/A	1-2
Kilobot [RAN12]	120	vibration	1	3-24
Kobot [TGC+07]	800	wheel	N/A	10
E-puck [MBR+09]	840	wheel	13	1-10

TABLE I
COMPARISON OF SOME ROBOTS FOR SWARM APPLICATIONS

The current prototype, Spiderino, is an improved version of [EHRZ15]. The main improvements are: new 3D-printed adapter, adding a Wi-Fi module and a customized PCB. This paper presents the new prototype and it is organized as follows: Reviewing the state of art is addressed in the related work section. Hardware design of Spiderino and the basic software tasks, 3D adapter printed properties, and the modifications to a Hexbug Spider are addressed in Sections III, IV, and V, respectively. Measurements of power consumption, walking speed and its modes are explained in Section VI. Finally, the paper concludes in Section VII and gives an outlook.

II. Related work

Robots designed for swarm applications are not a new topic [Ker11], [CS05], and this chapter describes some existing solutions. The Hexbug spider has been used before in [LPR14], in order to develop a low cost cooperative robotics platform. Table I provides an overview of existing swarm robotics platforms. Next, the most important pros and cons of the existing platforms are highlighted.

Table I contains a column showing the cost of the robots. This characteristic is subject to variation, because the price can be considerably different depending on changing price policies of vendors. Another problem is connected to the fact that some robots were manufactured in great numbers but only once and it is nearly impossible to buy them today (e.g., Jasmine [KTKS09]). The cost for existing robots present on the market can also vary depending on suppliers and financial regulations between countries (custom duties, VAT). Although the costs do not provide a clear way to compare the robots, it is possible to use relative comparison for robots' costs. For example, the E-puck robot [MBR+09] has the highest price and is 20 times more expensive than the Colias robot [AMZY14]. Thus, the price of the E-puck robot makes real experiments in the domain of swarm robotics quite expensive.

Most of the robots for swarm applications use a differential drive motion model where two wheels are placed on the sides of a robot. This system usually has a simple design and it is easy to control. Unfortunately, the authors of this paper have faced the problem with E-puck robots using the differential drive model when they could not move on the surface that was not completely straight. The Kilobot robot uses vibration for its motion [RAN12]. This approach does not allow the robot to be controlled precisely and the effort to calibrate the trajectory is quite high. The Kilobot robot requires a completely flat surface.

Charging a robot's battery may increase the human effort for required experiments. Robots for swarm applications should be able to work for some hours so an experiment can be completed without recharging the robots. The autonomy of the robots mentioned in Table I gives an indication for this, but depend on the number of modules used in an experiment. Kilobot and E-puck robots provide easy ways of charging.

III. PCB and electronic components

The main board of the Spiderino is a circular-shaped two-sided PCB with a diameter of 80 mm. The board has sockets for the Arduino, the motor driver PCB, and a Wi-Fi module.

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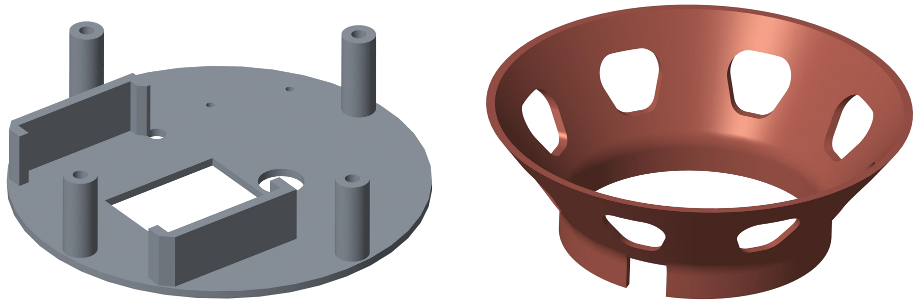

Fig. 3. Parts for adapter between locomotion system and PCB

For user interaction, the board features an on/off/charge switch, two light-emitting diodes (LEDs) and two jumpers for mode selection. It further contains connectors for battery, motors, and 6 four-pin interfaces for sensors.

Regarding the basic electronic elements, we used an Arduino Pro Mini with an ATmega processor (3.3V, 8 MHz), a ESP8266 Wi-Fi module, and a POLOLU-Motor-DRV-DRV8835 to control the two motors of the Hexbug Spider.

The Arduino Pro Mini has a number of facilities for communicating with the ESP8266. The Arduino Pro Mini provides serial communication, which is available on digital pins 0 (RX) and 1 (TX). The baud rate in ESP8266 should be 9600 because Arduino Pro Mini with 8 Mhz processor does not work correctly with high baud rate like 115200 or 57600.

We used a BTE13-007 as programmer for Arduino Pro Mini. It has a USB connector which maps itself as a COM port. In addition, on the PCB we added a connector for serial programming of the Arduino Pro Mini. BTE13-007 has to be connected to the PCB, which can be achieved with a five-wire connector as shown in Figure 2.

The correct COM port, the Arduino microcontroller type and the programmer should be selected correctly in Arduino Studio in order to program the Arduino board. As a first test, we have programmed the Arduino with basic functions in order to make Spiderino walk forward or backward, turn right or left, switch on/off some LEDs, plus the possibility of detecting 3 different modes set by a jumper on the PCB.

The Wi-Fi module can be also programmed using Arduino Studio. It is a low-cost WiFi module suitable for adding WiFi functionality to an existing microcontroller project via a UART serial connection[2]. It can work in three modes: ESP8266 Basic Mode, WiFi ESP8266 Layer mode, and TCP Layer mode that is used when we use an internet connection [WP16]. In order to test the Wi-Fi module, we ensured AT commands are received correctly, for example, we enable the Wi-Fi module to act as both a Station and an Access Point using AT+CWMODE=3 command.

[2]https://wiki.microduino.cc/index.php/File:ESP8266/WiFi_Module_Quick_Start_Guide_v_1.0.4.pdf

IV. 3D ADAPTER

The challenge was to design a lightweight and compact adapter for the Spiderino. Many requirements had to be met with regard to weight, center of gravity and dimensions. The following components had to be accommodated or attached to the adapter:

- Printed circuit board
- LiPo battery

The selection of the 3D printing process was easy to make because the 3D-design is not too complex. It fell on the Fused Deposition Modeling (FDM) procedure. There were some requirements when selecting the 3D printing material. It should be as light as possible, flexible and easy to print. In addition, the price should not be too high to allow the production of larger quantities. After a few tests the selection fell on the following two filaments:

- PETG Filament is an extra tough 3D-print material. This is an extremely high strength filament and can achieve very sturdy and strong prints. The recommended printer temperature is around 230° to 260°C.
- PLA is biodegradable and is the most environmentally friendly 3D printing material which is currently suitable.

During the testing of a previous prototype, there were some changes to be made for the following problems:

- Due to the height and the center of gravity, some problems arose with the stability of the robot. In several test runs, the robot had a slight tendency to turn in one direction. Due to the height of the intermediate plate with the battery, the center of gravity is higher than in the original robot.
- The arrangement of the sensors was not perfect. The robot needs 3 sensor positions for orientation at the front. In the first prototype, however, these were spread evenly over the entire landing.
- The position of the battery was critical. The battery was not isolated on the outside, there were touches with the PCB causing short circuits.

In the current version of the robot, the emphasis was placed on avoiding these problems and ideal placement of components. In addition, the weight of the assembly was reduced. The mounting of the sensors has been solved without 3D-printed parts to ensure high flexibility in sensor

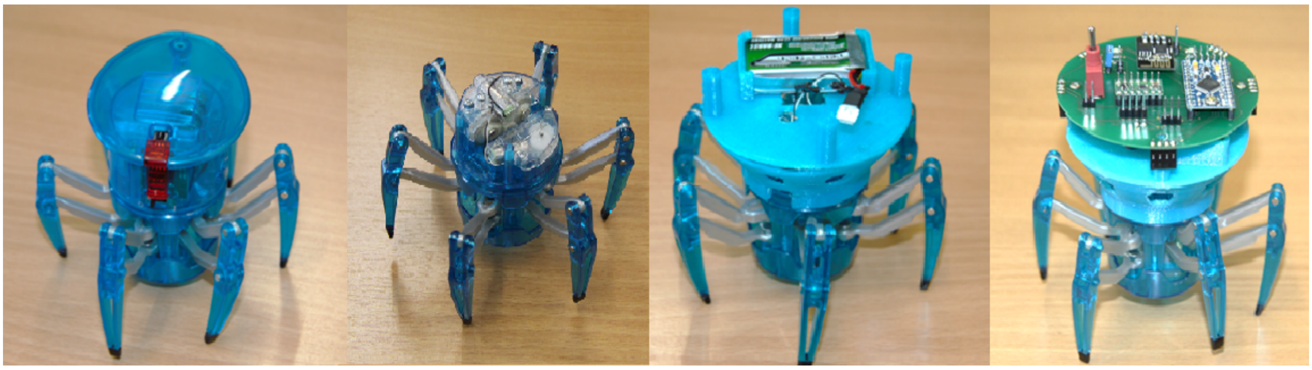

Fig. 4. Replacing the Hexbug Spiders head with a 3D printed adapter and a PCB

configuration. The position of the battery has also been adjusted to shift the center of gravity more to the center. The final cost for the current version is around 2 Euro and the printing time is 4 hours.

V. Robot Assembling

The main modification starts with partly disassembling the original robot. The head of the spider needs to be removed in order to get access to the motors. As a replacement of the head, 3D-printed adapter parts are attached to the robot. The proposed robot design consists of the locomotion system of a Hexbug Spider where we have attached the 3D-printed adapter. The physical parameters derive mainly from the Hexbug Spider which has six legs. The mechanics provide a coordinated movement for all six legs to move the robot. To change the direction, the robot has to turn its head.

The Hexbug Spider has a mechanical movement system with six legs and two small electric motors for simultaneous, coordinated movement of the spider legs. One motor is used for rotary motion, the second for forward or backward movement.

The goal of the mechanical design of the robot is to yield mechanical robustness and reliability of the movement, as well as for low energy consumption and low cost of overall design, aiming at light-weight mechanical variants [EHRZ15]. Figure 4 shows the Hexbug Spider before and after the disassembling step.

VI. Spiderino Characteristics

Using Arduino Studio allows us to program the Arduino microcontroller in order to control the two motors of Spiderino and implement the basic functionalities such as walking, turning and lighting the two LEDs. In addition, there is a software library written in C/C++ to control the motor speed and read information from the proximity sensors. This library can be easily imported into Arduino Studio to implement a firmware for Spiderino. We will use it in the current prototype after adding five distance sensors to Spiderino. However, for the test cases, we programmed the Arduino microcontroller with the basic functionalities in order to measure speed and power consumption and to test the mode switch functionality.

A. Spiderino Consumption

The Spiderino prototype has a LiPo battery with a capacity of 750mAh. A simple test program was uploaded that makes Spiderino walk, turn and light two LEDs in order to measure the power consumption. Figure 3 illustrates the measurements for these functionalities. The autonomy of Spiderino is between 4 and 20 hours where it depends on the number of modules used in an experiment. For example, if the bot is only walking on a wood table, the battery could power the Spiderino for 15 hours with an average consumption of 45mA. However, if the bot is walking on a carpet that is not smoothed well, consumption will increase up to 60mA. The bot can move with a speed of 6 cm/sec. One moving cycle of all six legs takes 500 milliseconds. The bot has to turn its head in order to change its direction, a full turn takes 3 seconds.

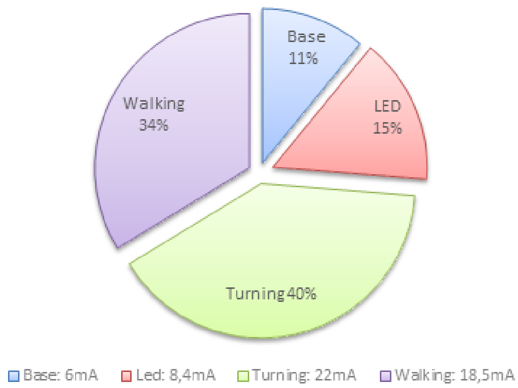

Fig. 5. Power consumption for different functions

The ESP8266 Wi-Fi module has different standard rates for power consumption according to different modes as described in the ESP8266 datasheet. During the communication between Wi-Fi module and Arduino pro mini in order to test the connection, the regulated power consumption was around 70mA. Usually, the module will be in deep sleep mode in order to save power[3].

[3]https://nurdspace.nl/ESP8266

B. Mode Detection

The Arduino Pro Mini platform has an internal pull-up resistor of 20-50 kOhms that can be enabled or disabled to a specific digital pin on Arduino[4]. We used this feature in order to achieve three mode possibilities for a single digital input pin. The designed PCB has a jumper with three pins as shown in Figure 2 providing three switching possibilities which are no jumper, a jumper to the right side or to the left side.

VII. Conclusion and Outlook

In this paper, we have presented the Spiderino prototype, designed for swarm robots and educational purposes. The overall assembly of the final robot is quick and the material costs are low. Spiderino locomotion makes the robot attractive for applications where a two wheel differential drive or using vibration cannot be used.

Additionally, we plan on adding five optical sensors (CNY70) for each Spiderino. Then, we will program and simulate swarm behavior. For that purpose, we will use the FREVO tool [SFE12] which creates an Artificial Neural Network (ANN) using an evolutionary algorithm and a reference simulation.

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