Misaka: Versatile swarm robotics platform for swarm user interface development

ABSTRACT

This paper introduces a versatile swarm robotics platform for distributed algorithm visualization, also an extendable open-source open-hardware platform for developing tabletop tangible swarm interfaces. We provide two different versions of Misaka: the commercial version and the explorer version. The commercial version is Swarm robots for distributed algorithm development, while the explorer version, which is an open-source PCB, gives users more freedom to develop their own swarm interface for specific purposes. Bluetooth 5.1 provides us with high-bandwidth communication, as well as a new method of positioning Misaka. We will integrate it into Misaka when we get the commercial model.

CCS CONCEPTS

• **Human-centered computing** → **Systems and tools for interaction design**; • **Hardware** → *PCB design and layout*.

KEYWORDS

Swarm, tangible interface, hardware platform, Human-Robot Interaction

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1 INTRODUCTION

The name of our platform, Misaka, comes from "Misaka Network" in the light novel, manga, and anime series, A Certain Magical Index, and its side-story mangas and anime series, A Certain Scientific Railgun and A Certain Scientific Accelerator. The Misaka Network is a brainwave network formed between the Sisters. The Sisters are Mikoto Misaka's 20,000 clones, who can share their thoughts and memories within their communication network. Misaka Network is actually a strongly-connected distributed network. One of our platform's typical applications is verifying distributed algorithms in a decentralized network, so we choose Misaka to be our product's name.

We design two different versions of Misaka: the commercial version and the explorer version.

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The commercial version is Swarm robots, equipped with onmi-wheels and stepper motors, and can move holonomic and precisely. Distributed algorithms researchers can utilize it as a fully decentralized hardware platform to test newly raised algorithms, also a visualization platform of all kinds of consensus algorithms. Furthermore, teachers can use it as a great tool to visualize dynamic multiple scatterplots and to explain theories to their students.

The explorer version is for those researchers who want to develop tabletop swarm robots of their own. This version is a single PCB, which integrates almost all functionalities needed to develop any kind of swarm interface for many purposes.

Both versions have the ability to add suitable extensions to it. We also provide models adding function to it, such as computer vision, wifi, machine learning algorithms, etc.

2 BACKGROUD AND RELATED WORK

There are many tangible swarm robots such as Zooids[3] and Cellulo[5]. But none of them is both compact and omnidirectional.

We learn from user experiments that most users (especially children) are used to pressing and push Misaka to move it on the surface, which prevents us from using the differential steering used by Zooids[3] or e-puck[4]. We can only use magnetic drive technology similar to Cellulo[5] or omnidirectional wheels used by WolfBot[1].

After trying, we found that the speed of the magnetic drive motor has a great relationship with the magnetic strength of the magnetic ring, the remaining battery power, the friction between the magnetic ring and the shaft, and other uncontrollable factors. It is impossible to map the wheel speed of the car with the motor PWM. The time-variant mapping relationship between duty cycles made it difficult to control the direction and speed of the car, and this idea was finally abandoned.

The omnidirectional wheel used by WolfBot is directly connected to the motor, which makes the chassis occupy a large area. In the end, we used a 1.5-inch onmi wheel and a miniature reflex stepper motor (the worm in the reduction gear changes the transmission direction by 180 degrees) to minimize the system, shown in Fig 1.

3 INTERACTION DESIGN

3.1 Distributed algorithms test and visualization

Distributed algorithm verification is mostly carried out in a pure software environment of a single device, such as Matlab simulation, which lacks a general hardware platform to test the feasibility of these algorithms in actual communication scenarios.

Most of the newly proposed algorithms are verified in a pure software environment of a single device, without considering the communication delays in the actual hardware environment, data packet order, and poor communication connections. The ZigBee chip which is used in our platform is widely used in the Internet of

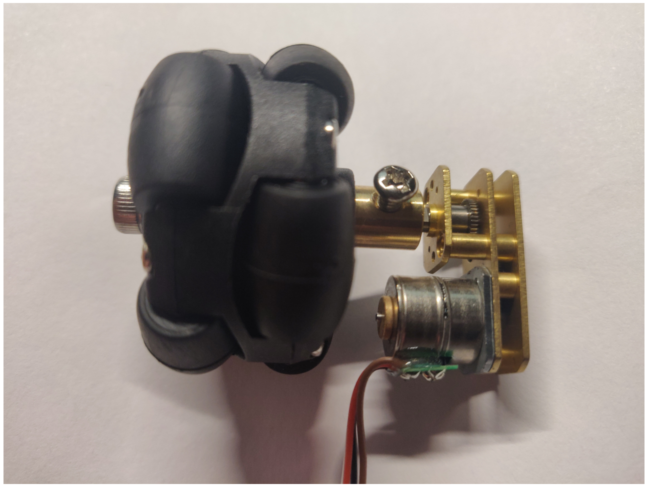

Figure 1: Stepper motor used in Misaka

Things systems, and can well simulate the hardware communication environment.

This platform makes a completely decentralized test environment possible. At the same time, since this is a convenient visual development tool, it makes interactive code writing/testing/display possible. Distributed algorithm developers can use our decentralized platform to test the feasibility of the hardware and get interactive code writing, testing, and display experience.

For example, when we develop a consensus algorithm, we can manipulate its iteration process using the Misaka platform, shown in Fig 2.

3.2 Teaching application

Some concepts are difficult to understand, so you can use a swarm interface to do interactive and interesting teaching.

For example, a swarm system can be used to describe a scatter plot with multi-dimensional variables, etc.

4 HARDWARE DESIGN

To make our hardware more universal, we design two different versions of Misaka: the commercial version and the explorer version.

4.1 Commercial version

The commercial version aims at HRI applications, as well as algorithms development and visualization scenarios. It is a small custom-made robot as shown in Figfig:CommercialVersion.

The commercial version consists of a 3D printed frame, custom-designed PCB, battery, omni-directional wheels, and micro stepper motors.

The frame is printed using PLA(Polylactic Acid). It is carefully designed to fit the motors, wheels, and the PCB. The 3D Model of it is shown in Fig 4, and the CAD detail is shown in Fig 5.

Its dimensions are 100 mm in diameter and 50 mm in height. Each robot is powered by a 450mAh 2S 7.4V LiPo battery. Most of the power in the robots are consumed by the motors. The current draw of each robot is approximately 100 mA when the motors are stalled and 800 mA during typical use. Thus, with a 450 mAh battery, robots are capable of moving for half an hour and can work even longer with BLE(Bluetooth Low Energy).

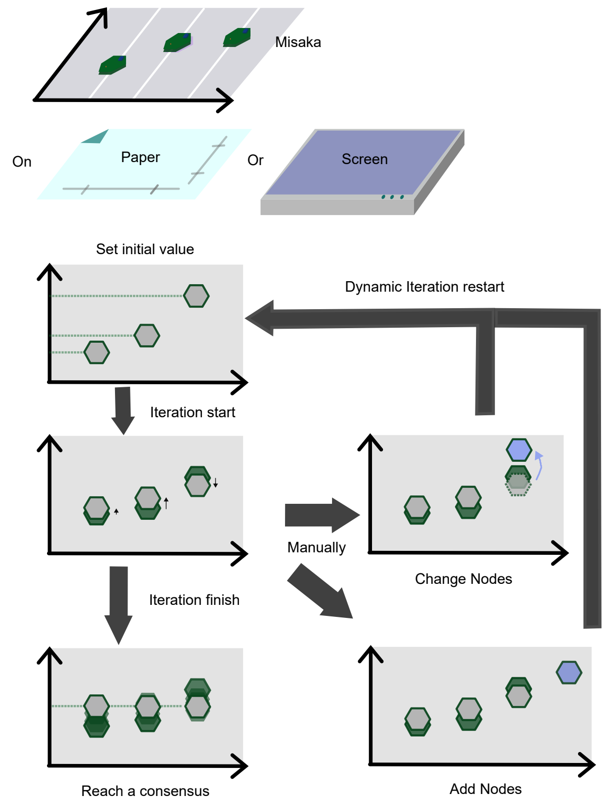

Figure 2: Dynamic Iteration

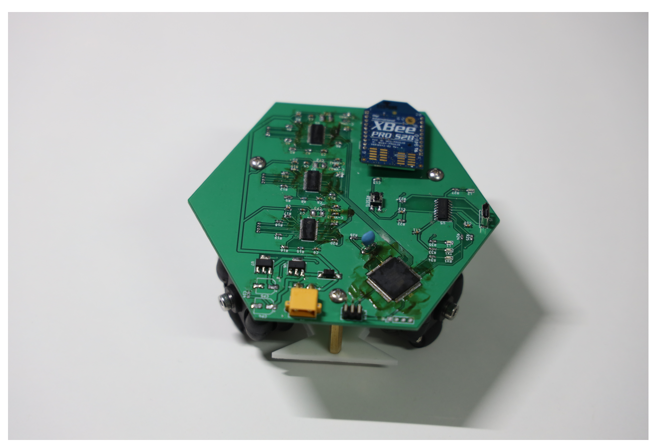

Figure 3: The commercial version

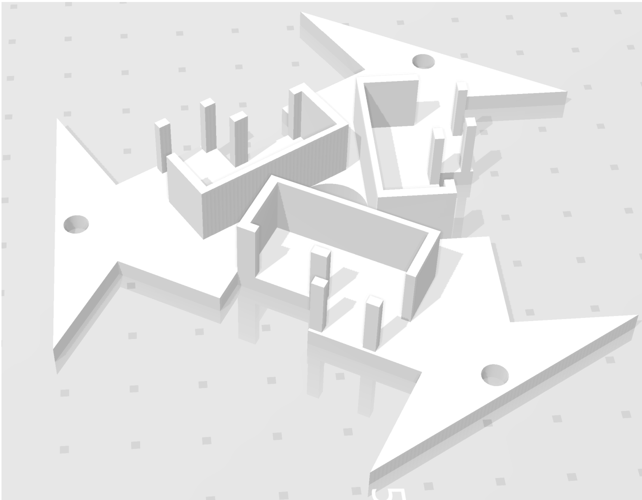

Figure 4: 3D Model of the Frame

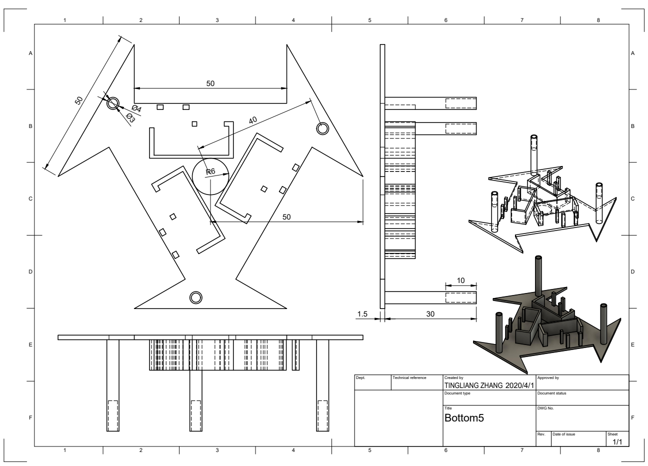

Figure 5: the CAD of the Frame

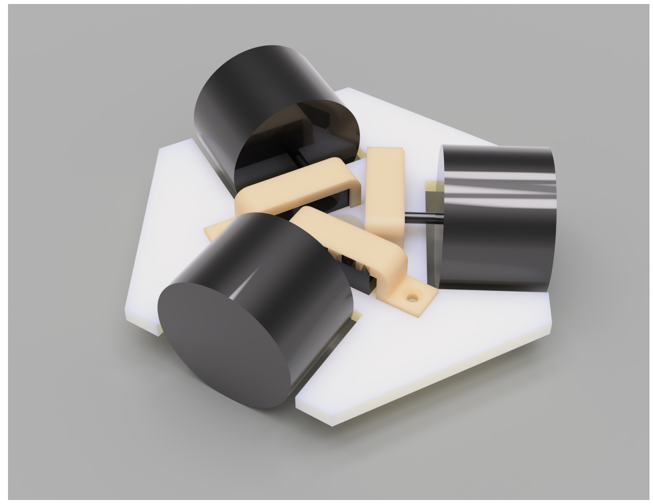

Figure 6: Chassis render

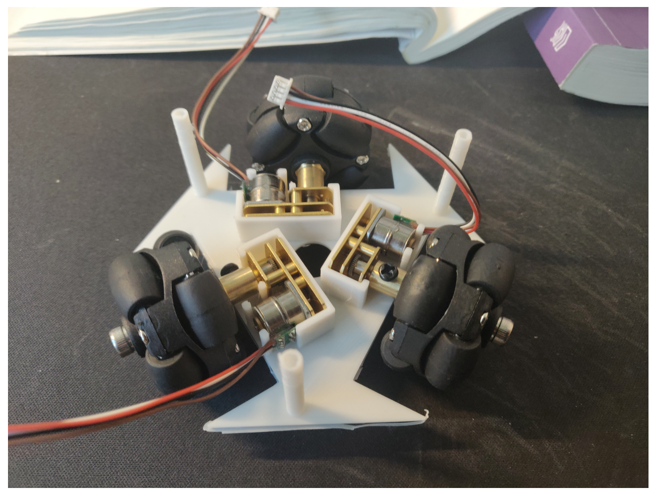

Figure 7: The holonomic chassis

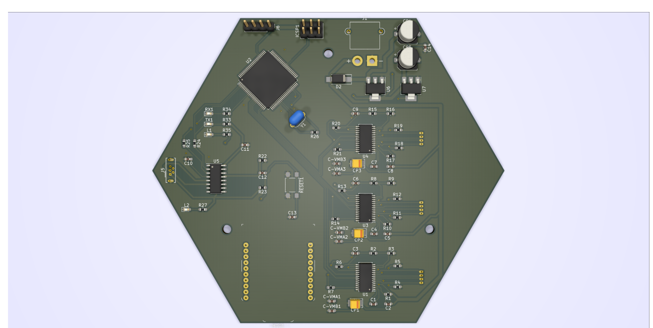

Figure 8: The commercial version PCB

Three 38-mm-diameter omni-directional wheels are driven by micro stepper motors to precisely control the rotation angle of each wheel. To drive the robot, a motor driver chip (DRV8825) and three 2-phase 4-wire Stepper Gear Motor are used. With this combination, the robot has a maximum speed of approximately 20 cm/s. The holonomic system allows robots to move precisely and can easily respond to user interaction. The shape of the holonomic chassis is shown in Fig 6, and the real picture of it is shown in Fig 7.

The commercial version's main circuit board is shown in Fig 8. The main processors onboard is an AVR microcontroller (Microchip ATmega2560-16AU) that combines 86 general-purpose I/O lines, 32 general purpose working registers, PWM, 4 USARTs, 16-channel 10-bit A/D converter, and a JTAG interface for on-chip debugging. ATmega2560 manages most logic computation.

Eight independently WS2812B LED on PCB illuminated in full RGB using are wrapped inside the 3D printed enclosure to provide the robot's state display as well as full color indicating, shown in Fig 9.

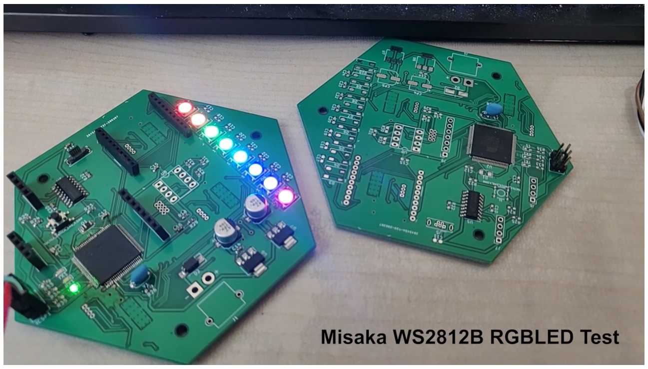

Figure 9: The RGB LED

Now robots communicate with each other using the Digi XBee module. XBee supports mesh networking which can be decentralized. We can use this feature to develop and test distributed algorithms that are also decentralized.

Users can modify the robot for their applications by designing custom modules that attach to its core module or adding powerful chips and development boards to achieve more functions, such as computer vision, wifi, machine learning algorithms, etc. Currently its compatible extensions are shown in Fig 10. For example, in order to give Misaka Linux development environment and capabilities of testing machine learning algorithms, we add Nvidia Jetson Nano to Misaka core through UART for high-level control and image processing. And to connect them with Bluetooth and wifi, we add ESP32 modules which also interact with Misaka through serial communication.[7]

Figure 10: Currently compatible extensions

4.2 Explorer version

For those researchers who want to develop distributed algorithms or tabletop swarm robots of their own, we provide an open-source PCB.

It supports four kinds of different communication protocols, and integrates easy-to-use programmer and debug connector. To drive the stepper motor and DC motor, we have Powerstep01 on board with necessary components. To extend its function, we provide a universal interface which can communicate with other development board such as Nvidia Jetson NANO.

All functionalities onboard are shown below:

- Mega2560-16AU main MCU
- ATMega16U2 USB-UART
- USB Type C port
- PowerStep stepper motor and DC motor drive
- 9 x WS2812B RGB-LED full-color light display
- Downward looking infrared camera with dot paper for positioning
- XBee3, the main Mesh network communication
- Espressif ESP32, provides WiFi 5, Bluetooth, BLE communication
- CP2102. We can burn programs through the USB Type C port
- External battery power supply
- USB port power supply
- Buck DC-DC and impulse back pressure overvoltage and overcurrent protection
- Programmable pins for testing
- Support UART, I2C, SPI communication protocol expansion interface

The PCB 3D model is shown in Fig 11, After SMT, the PCB is shown in Fig 12.

5 FUTURE RTLS WITH BLUETOOTH 5.1

Real-time location systems (RTLS) are used to track and identify the location of objects in real-time using "Nodes" or "tags" attached to, or embedded in, the objects tracked, and "Readers" that receive and process the wireless signals from these tags to determine their locations.[2]

The Bluetooth SIG presented Bluetooth 5.1 in January 2019. With Angle of Arrival (AoA) and Angle of Departure (AoD) which are used for location and tracking of devices, we can simply use BLE 5.1 as both communication and positioning methods.

Those techniques require one of the two communicating devices to have an array of multiple antennae, with the antenna array included in the receiving device when the AoA method is used and in the transmitting device when using AoD, as shown in Fig 13.[6]

With Bluetooth 5.1, we are able to track Misaka with a small margin of location error, as low as 10cm. The accuracy will be enough for many swarm applications.

6 CONCLUSION

We present Misaka, a versatile swarm robotics platform for swarm user interface development.

In summary, our contributions are:

- The smallest omnidirectional open-source swarm platform.
- A set of scenarios to illustrate the possibilities offered by Misaka
- A common platform for any algorithm visualization, and other interactive swarm user interfaces

Furthermore, as benefits, Misaka:

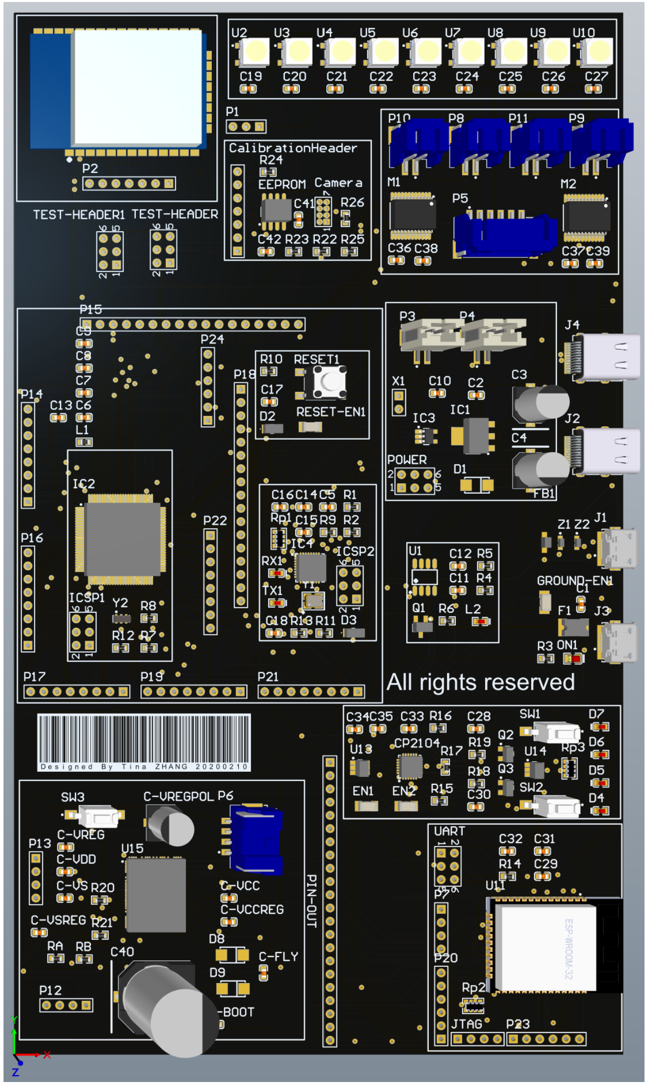

Figure 11: 3D model

- are modular, can be extended with powerful platforms.
- can simulate decentralized communication scenarios.
- are small enough to coexist in large numbers
- are relatively cost-effective: about 30 USD each now, down to $10 if mass manufactured.

We hope that this paper and Misaka open-source platform will spur more research and creativity in the swarm user interface.

All necessary material and documentation for implementing Misaka can be found at Github.

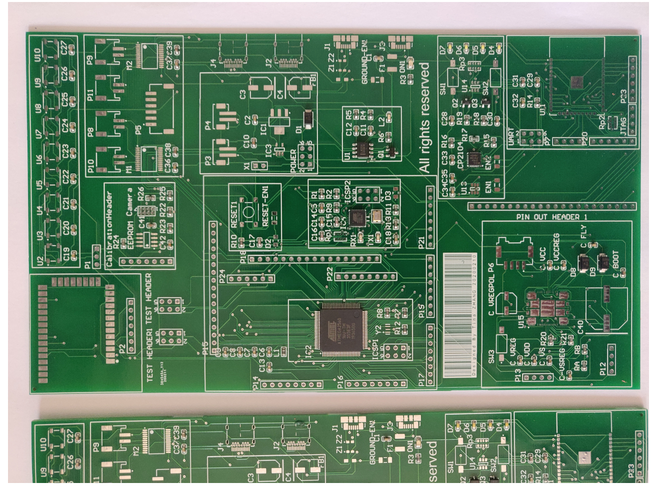

Figure 12: PCB after SMT

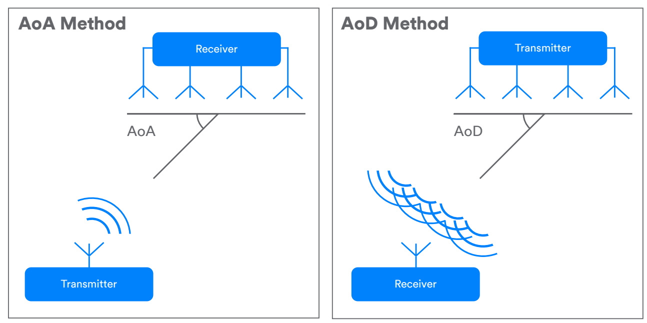

Figure 13: Angle of Arrival (AoA) and Angle of Departure (AoD)

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