ECE 445

SENIOR DESIGN LABORATORY

PROPOSAL

A Transformer

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1. Introduction

1.1 Problem:

In some cases or scenarios, locations or areas are inaccessible to human, such as narrow pipes and crevices in collapsed buildings, so we need adaptive robotics to reach that area instead of us and do some of the work for us. The robotics that we will introduce and build is Modular Self-Reconfigurable Robotics (MSRR), which are able to connect to each other and change their configuration in order to create new robots or structures.

With its features, MSRR can be used in many scenarios, like space exploration, disaster response, undersea inspection, education, entertainment and art. For example, It can be used for space exploration missions, where they can reconfigure themselves to adapt to different tasks and environments, and they can also repair themselves and replace damaged modules. In disaster scenarios, MSRR can adapt to changing environments or narrow and complex landform, help with search and rescue missions. In the undersea scenarios, MSRR can also work and help with inspection or building piers and tunnels. The other aspect application of MSRR is education, entertainment and art. Because MSRR can be assembled and reassembled to create different configurations, it can be programmed to create interactive artworks and installations.

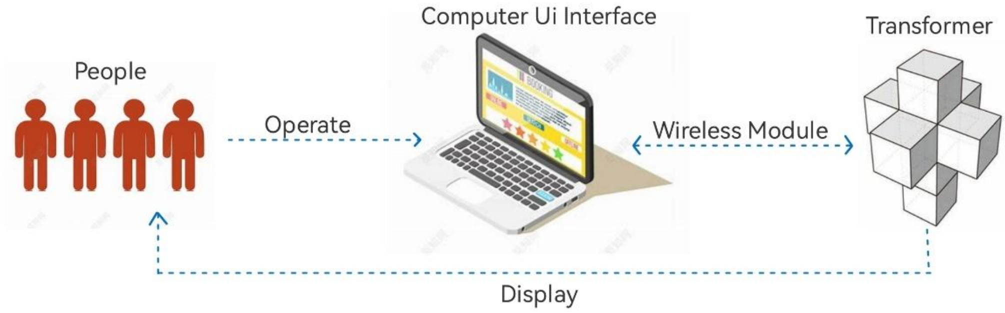
1.2 Solution:

We are aiming to build a modular block system with self-reconfigurable features. Our solution will include easier lighter devices, fluent transformation and easy-to-operate interface. It’s an innovation in the field of MSRR, especially in education, entertainment and art. More concisely, we will use electromagnet to control the mechanism of block robotics. Different block robots are controlled by a central host computer through wireless signals. MCU in block robots receive signals from wireless module and control the circuit to apply positive or negative current to the electromagnet to control the rotation or suspension of the block entity.

A 3D printed cube and 12 metal sticks on the edges. Metal sticks on the edge serve as hinges to attach different cubes during the rotation. When the joint surfaces of the two blocks need to be changed, the hinges form a tight connection between them, allowing the blocks to flip over smoothly without falling apart. The wireless module transmits command signal from host computer to block robots. After the signal is received at the remote side, MCU in block robots will process this signal and convert it to control signals on its ports. Electrical circuits will get input signal from an MCU port, then use it to control the state or polarity of 6 electromagnets on the block surface or 8 electromagnets on the corner which have 5v voltage and 3kg force. The change of polarity of electromagnet is used to complete the rotation and deformation of the robot.

When the modular block robotics come into application, we can also install different modules on different block, but they are further study and exploration which are not included in this project.

1.3 Visual aid:

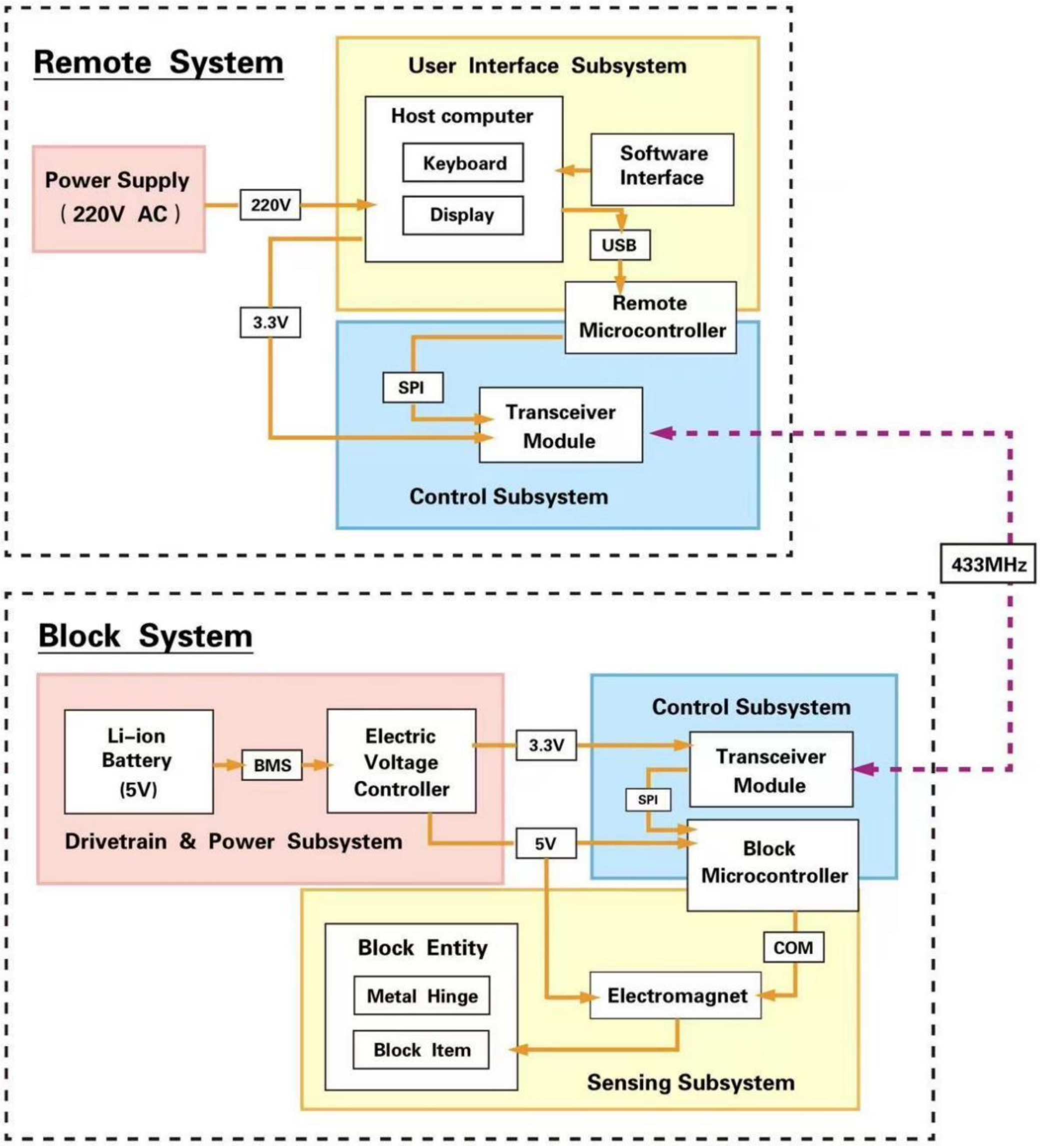


1.4 High-level requirements list:

1. Compact and portable: The control units within each mechanical entity are compact, capable of integrating wireless modules, control circuits and electromagnets, and each mechanical entity is smaller than $216cm^3$($6cm$ * $6cm$ * $6cm$) in size and lighter than 1kg.
2. Flexibility: Each mechanical entity can achieve a 90° flip and a 180° flip in four directions (Front, back, left and right).
3. Separability: At least three mechanical entities can be controlled by the control system, and these mechanical entities are not affected by each other.
4. User-friendliness: The computer control interface is clear and concise so that users can clearly operate the transformer.

2. Design

2.1 Block Diagram



2.

2.2 Subsystem Overview

Remote System: We use a computer as the remote side system. The user sends command through the user interface, then the transmit signal should be sent to the block side through a wireless control module. The computer and wireless control module are connected by a serial port module which encodes the command.

- User Interface Subsystem: Software user interface on the computer. The user can order the state or operation that the block system performs.

- Control Subsystem: Wireless control system, 433MHz or 2.4GHz. The Transmitter should control more than ten receivers on the blocks.

- Remote Micro Controller: A serial port module which connects the computer and the wireless control module. TTL serial port module connects the computer with USB and the wireless module with COM.

Block System: The block system is combined with electrical subsystem, mechanical subsystem and control subsystem. Transceiver module receives signal and Micro Controller decode the signal and control the voltage applied to electromagnet through circuit. The electromagnet can drive the block to move, rotate or suspend.

- Drivetrain & Power subsystem: 5V Li-ion Battery and electric voltage controller. The voltage controller should distribute forward or reverse voltage to the electromagnet to control the polarity of it based on the control signal sent by the Micro Controller.

- Control Subsystem: Transceiver module receives wireless signal from the Remote side and send the signal to the Micro Controller.

- Mechanical Subsystem: A block entity with 6 electromagnets on the surface and 12 hinges on the edge. Blocks are attached through electromagnets. During the rotation, the iron sticks perform as electromagnetic hinges which can enhance the electromagnetic fields and attach the blocks together.

- Block Micro Controller: A nano MCU can decode the signal received from transceiver module. The MCU can decode the transceiver signal and control the voltage and polarity of electromaget

2.3 Subsystem Requirement:

For the Remote system, we have three subsystems, that's Power subsystem, User Interface subsystem and Control subsystem.

i. For the Power subsystem must be able to supply a stable 220 V AC voltage so that the computer can work normally. And the USB interface must be able to supply at least 3.3 V DC voltage to the Remote Microcontroller to make it work normally. And the Transceiver Module has a work voltage at 2V-12V.
ii. For the User Interface subsystem, it must be able to recognize the instructions entered by the user's keyboard, and send it to the Remote Microcontroller by USB interface, and the software must run smoothly.
iii. For the Control subsystem, the Send-Transceiver Module must be able to recognize the instruction from the Remote Microcontroller, and send the control signal at 433 MHz or 2.4 GHz to the right block, we may have ten or more blocks so the Transceiver Module must be able to send the control signal to special block or it must be able to send a special signal that all the blocks can receive.

For the Block system, we also have three subsystem, that’s the Drivetrain & Power subsystem, the Control subsystem and the Sensing Subsystem.

i. For the Drivetrain & Power subsystem, we would like to use a Li-ion Battery, to make the whole system run normally, it must have a stable output voltage of 5 V, and the output current should be 0-2A, and the battery capacity should larger than 5000 mAh to ensure that all the experiments and demonstrations can be carried out properly. BMS is circuit protection device, and it must be able to cut off the circuit when the current is larger than 2 A, and the Electric Voltage Controller must be able to recognize the control signal sent by the microcontroller, to supply a positive or negative voltages to the electromagnet to control the electromagnet's polarity.
ii. For the Control subsystem, the Receive-Transceiver Module must be able to recognize the control signal at 433 MHz or 2.4 GHz, and send the instruction to Microcontroller of the block.
iii. For the Block microcontroller, we use the Aduino-nano, the MCU must be able to decode the instruction send by Microcontroller of the block, and control the voltage and polarity of electromagnet. And it needs a voltage supply of 5 V and a current not lager than 1 A.
iv. And for the block it self, it’s made by 3D-print, and the density of the printed material is $1.24 g/cm^3$, and the thickness of the face should be less than 2 mm, so that the weight of the box itself can less than 150 g, and to decrease the weight, our preliminary determination of the thickness is 1 mm. And we have six electromagnets fixed on its six faces, each electromagnet weighs 25 g, and needs a 5 V voltage supply and current not larger than 0.22A, and each electromagnet can supply a 3 KG magnetic force, we also have 12 hinges on the each edge, the role of the hinges is to enhance the magnetic force between the two different blocks and facilitate rotation, and each hinges is made of iron and weights 0.7 g, with length of 8 cm and diameter of 1.2 mm.

2.4 Tolerance Analysis

In our design, the key point is that our electromagnet is able to attract and move the block in different transforms. We have two configuration of the electromagnet, one is on the surface, one is on the corner. If the power of magnet is enough, we can install the electromagnet on the surface, which is easy to control and we can make the block smaller. Installing the magnet on the corner can give a larger momentum but makes the block larger and harder to control. In our tolerance analysis, we will use mathematical analysis to demonstrate the feasibility of several transforms in our design.

At first, we know the Biot-Savart Law and Ampere’s Law:

$$B = \frac{\mu_0}{4\pi}\int_L \frac{I\,dl \times r}{|r|^3} \qquad (1) \qquad F = \int_C I\,dl \times B \qquad (2)$$

So the force between two loop current can be written as:

$$F_{21} = \frac{\mu_0}{4\pi} I_1 I_2 \oint\oint \frac{dl_2 \times (dl_1 \times (r_2 - r_1))}{|r_2 - r_1|^3} \qquad (3)$$

$$F_{12} = \frac{\mu_0}{4\pi} I_2 I_1 \oint\oint \frac{dl_1 \times (dl_2 \times (r_1 - r_2))}{|r_1 - r_2|^3} \qquad (4)$$

Through formula simplification, we can get the following:

$$F_{12} = -\frac{\mu_0}{4\pi} I_2 I_1 \oint\oint \frac{r_1 - r_2}{|r_1 - r_2|^3} dl_1 \cdot dl_2 \qquad (5)$$

For the convenience of calculation, we regard the solenoid as a multiple loops current. For details, we can have a electromagnet with the current of 0.22A and 500 turns, 20mm width and 15mm length. The electromagnet has an iron core and the magnetic force is 3kg when the magnets are attached together. By formula (5) we can assume that the magnetic force of the electromagnet is proportional to the inverse of the square of the distance.

Then we can calculate the coefficient of the magnetic force k, and the corresponding relative permeability μ_r.

$$k = \frac{\mu_r \mu_0}{4\pi} I_2 I_1 \qquad (6)$$

Through calculate the integral when the electromagnets are attached together, integral along the axis of magnets, we can get the coefficient k is equal to 1.132×10^{-5} and the the relative permeability μ_r is equal to 2338.99.

And then we count the weight of the block system and its contents, which consists of block entity, electromagnets, PCB and transceiver, iron sticks, circuits and battery. And the side length *a* of block is about 10cm.

Item	Weight
Block entity	78g
Electromagnets	6*25g
PCB and transceiver	5g

Iron sticks	12*0.7g
Circuits	3g
Battery	100g
Total	344g

According to formula (5) and (6), we can assume that the magnetic force between two magnets is approximately inversely proportional to the square of the distance. That's what we should know in the our project design. When the distance between two magnets is in the level of 5cm, the force between them is about 1/10 with respect to the origin. We can only push the magnet when they are attached together, because the attract force when they are separated alone are very small. So when we design our project, we may have limited operations and transforms. We can make sure that we can do 90 degree transforms, but we need to do experiment and select more powerful electromagnet during our project design process.

3. Ethics and Safety

3.1 Ethics

Protection of Privacy of others:
With its minimized size, MSRR has a promising future to finish various tasks at environments where human cannot easily reach. We should therefore notice the possibility that such a microsized MSRR can be used to complete tasks such as collecting and even steal other's private information without being noticed by a human. According to IEEE Code of Ethics I.1, invasion of other people's privacy is strictly prohibited [1]. Therefore, we must be sure to add related code of conduct that prevents the MSRR from privacy invasion if the MSRR is produced and released in the market. One possible technical solution is to add additional signals that are easy to be noticed, such as alarms and blinks, when the MSRR is collecting information from the environment.

3.2 Safety

Safety issues when assembling MSRR:
First, soldering operations will be very frequent as we will build up our PCBs, test them and refine them for many times. Therefore, frequent use of flux, soldering Iron and other soldering devices might hurt people by high temperature. The operators must stay focused and follow the soldering guidelines.
Second, since our MSRR robot will use a 3D printed shell, we must be careful not to hurt ourselves by its rough edges. To prevent possible injury, one solution is that we can polish the sharp edges with sandpaper and add rounded corners to our shell design.

Possible health issues:

Though the intensity of electromagnetic field generated in our MSRR should not be too large, we should notice that exposure to man-made EMF can have negative effects on health. According to a research conducted by the U.S.Navy in 1984, exposure to unnatural electromagnetic frequencies can cause health problems such as changing hormone levels and cause sterility in male animals [2]. Further experiments need to be conducted if we would like to use microsized MSRR (such as medical robot) to be used in the medical operations.

References

[1] https://www.ieee.org/about/corporate/governance/p7-8.html
[2]https://www.doctorsbeyondmedicine.com/listing/emfs-negative-effects-of-electromagnetic-fields#:~:text=1%20Altered%20cell%20chemistry%202%20Altered%20hormone%20levels,and%20organisms%3B%208%20Caused%20sterility%20in%20male%20animals