iHammer GO!

Team Description Materials

Logistical Information

Team Name	iHammer GO!
Organisation	iHammer Robot Technology Center
Country	China
Mentor	Yintao Li, Bin Wu,
Contact	Bin Wu
	Bin Wu's email: 164712168@qq.com Yintao Li's email: kenkuo@foxmail.com
Website	http://blog.sina.com.cn/wuxyxmy

PreFace

iHammer GO! is a small group of Robotics and Information Technology enthusiasts formed in late 2017. It was the first time that we participated in RoboCup2018 RMRL and obtained the 6th place. We won the first place at RoboCup in Sydney, Australian last year. We received many important suggestions from Mr. Sheh and learned a lot from the teams all over the world.

Our robot consisted of a six-wheeled chassis, a robotic arm with 5 degrees of freedom, a Raspberry Pi, an Arduino Mega and 2 cameras. The robot is not only able to effectively complete multiple competition tasks, but also low-cost.

During the past year, our robot has been improved in many aspects. The performance of mechanic system, driving circuit was enhanced. The algorithms and control software were updated for better communication reliability. In the next months, we plan to upgrade the control software for auto-drive mode.

Meanwhile, 2 new members had joined us! Let's go for it!

Latest update on 2020-03-16

Figure 1. iHammer GO! Team

1. Introduction

The iHammer GO! (Figure 1) is a small group of Robotics and Information Technology enthusiasts formed in late 2017 with the intent of creating a robot capable of competing in the 2018 Rapidly Manufactured Rescue League (RMRL) at RoboCup in Montreal, Canada. It was the first time we participated in the RMRL and we obtained the 6th place. We won the first place at RoboCup in Sydney, Australian.

Although we are very young in the RMRL project, we have participated in many other events of the same type, like the RoboCup Junior. The team lead by Xinyang Wu who ranked the first place in Rescue Line of RoboCup Junior 2017 China Open and 2018 China Open, respectively. The team he joined ranked the second place in Rescue Line of RoboCup Junior 2017 in Nagoya, Japan and the first place in RMRC RoboCup 2019 in Sydney, Australian. Although he is still a high school student, he has obtained the professional qualification certificate of software designer recognized by the state. Our robot project was carried out steadily with the support of iHammer Robot Technology Centre in Hefei, China.

Our robot consisted of a six-wheeled chassis, a robotic arm with five degrees of freedom, a Raspberry Pi, an Arduino Mega and 2 cameras. The chassis was driven by six 370 DC deceleration motors. The robotic arm was actuated by four Lobot LX-16AA Serial Servos. The Raspberry acted as a host computer, and the Arduino Mega acted as a slave computer. These two cameras were used to collect images. As a result, the robot was cost-effective to complete the competition task.

The core members of the iHammer GO! participated in the RoboCup RMRL in Montreal, Canada and Sydney, Australian. Since we learned about the RMRL competition in 2017, we were attracted by its characteristics. Robots in RMRC were different from robots in RoboCup Rescue Line greatly, many kinds of robots could be found in this game, such as the wheeled, the tracked, and other amazing types of robots we had not seen before. The 3D printing technology and open source technology were widely used in the design and production of these robots.

Figure 2. Robot of iHammer GO!

Through observations of the performance of robots in the RoboCup RMRL, we found that in the game, some robots could not move any more when their wheels turned too fast. The problem was caused by the wheels in a suspended state rather than by the lack of power. The key to solve the problem is to make the wheels contact with the ground effectively. Therefore, an elastic suspension system was used to our robot. Under the action of the damping springs, the wheels could contact with the ground as much as possible so that the robot could own enough driving force to get rid of the trouble. By this way, the ability of the robot to pass the complex terrain was greatly improved.

We also found the tracked robot with an auxiliary mechanical arm was one of the most effective solutions. It has good passability in various complex terrains. However, the energy consumption and manufacturing cost of the tracked robot were too high. Because the wheeled robot could move fast in most terrain, and have advantages in speed, energy, working time and cost, we finally chose wheeled robots as a competition solution.

2. System Description

Our six-wheeled rescue robot was composed of a wheeled chassis, a robotic arm and a vehicle electronic device.

2.1. Wheeled chassis

The wheeled chassis consisted of 3D printing parts, such as frame, suspension, wheel, chassis and so on. It had six wheels driven by six large torque motors. Different from four-wheel drive robots, the six-wheel robot could provide enough gripping force to pass complex terrain.

Frame

The frame was made up of two 3D printing parts linked by screws and three brackets fixing suspension system, shown in Figure 3. The frame has been modified three times to lower the height of vehicle. It is very important to improve the ability to pass in earthquake site where there are many unexpected obstacles.

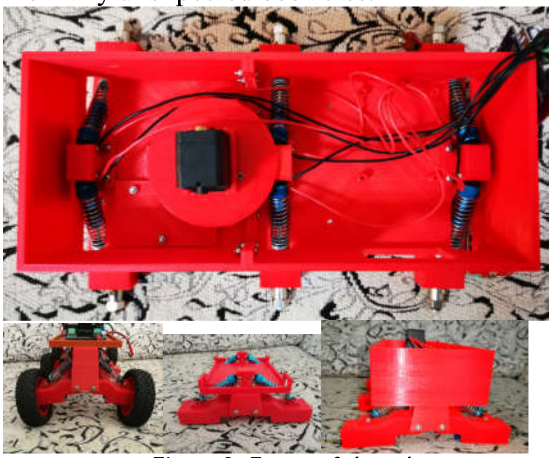


Figure 3. Frame of the robot

Suspension

The independent suspension was adopt in the robot design. Each side of the wheel was individually connected with the frame through the elastic damping suspension, and wheels on both sides could move independently. The wheels could contact with the ground to provide enough gripping force in the complex terrain. So the ability of the robot passing through in the seismic regions was improved.

Figure 4. Suspension bracket of the robot

The suspension bracket was made by a 3D printer, shown in Figure 4. The suspension bracket was connected to the frame through the bearings and anti-loose nuts to ensure the reliable function of the suspension system.

Figure 5. 734 shock absorber of the robot

The 734 shock absorber of a model racing car composed of a spring and a hydraulic damping shock absorber was adopted to act as the elastic damping damper. As a result, it could help the robot adapt to different environment.

Figure 6. Wheel of the robot

Wheel

The wheel were made up of a tire, hub and axis adapter, as shown in Figure 6. Rubber tire (86 mm in diameter) was used. With these wheels, the robot could pass complex terrain effectively. The hub was a 3D printing part designed by ourselves. Inspired by the Martian car, we designed the shape of the hub using 10 graceful spiral spokes.

Figure 7. axis adapter

Axis Adapter

The axis adapter was used to connect the wheel and the motor output axis. The axis adapter used on a smart car was metal six-angle axis adapter, which was about 2 cm in length.

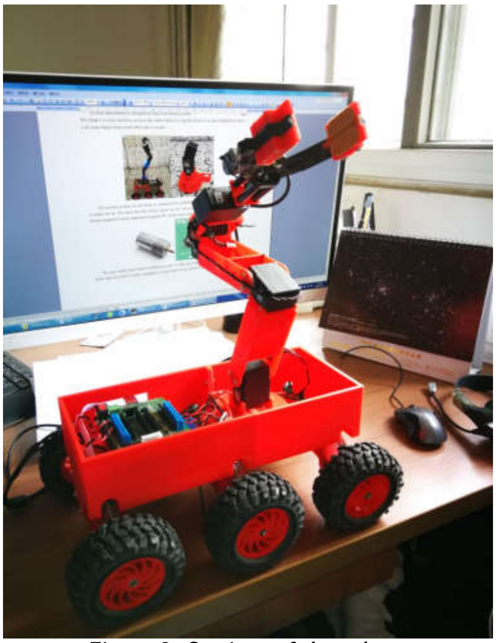


Figure 8. Carriage of the robot

Carriage

The carriage was at the top of the frame as installation platform for the robot arm and the vehicle electronic device as shown in Figure 8. The carriage was too big to print with our Ultimaker2 3D printer. Therefore, the carriage was made up of two parts. A slot was adopted to joint two parts together for improving the bonding strengths of the two parts.

2.2. Robot Arm

The robotic arm was designed referring to Open Academic Robot Kit: 5 Degree of Freedom robot arm using Dynamixel AX-12A servos. Instead of expensive Dynamixel series servos, Lobot LX-16A servo was adopted to reduce the price. The technical parameters of this servo was similar to the Dynamixel AX-12A servo, while its price is only 1/3 of Dynamixel series.

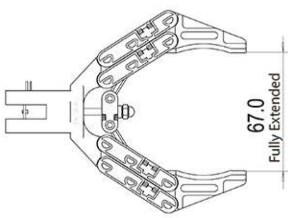


Figure 9. gripper of the robot

Gripper

A gripper is used to hold things, shown in Figure 9. The gripper is a Makeblock part purchased from Web-supermarket. It has a parallel quadrilateral structure. We are developing a 3D-printable manipulator of the robot car, which will greatly reduce the weight of the manipulator and improve its performance.

Figure 10. Arm rotator of the robot

Arm rotator

A robot arm rotator is designed to add a freedom of robot arm, shown in Figure 10. It is very useful to recover the robot when it is upside-down. It is also helpful for robot to perform task with the robot arm. We have designed a mechanical arm rotating platform with a motor reducer of a toy excavator, shown in Figure 11.

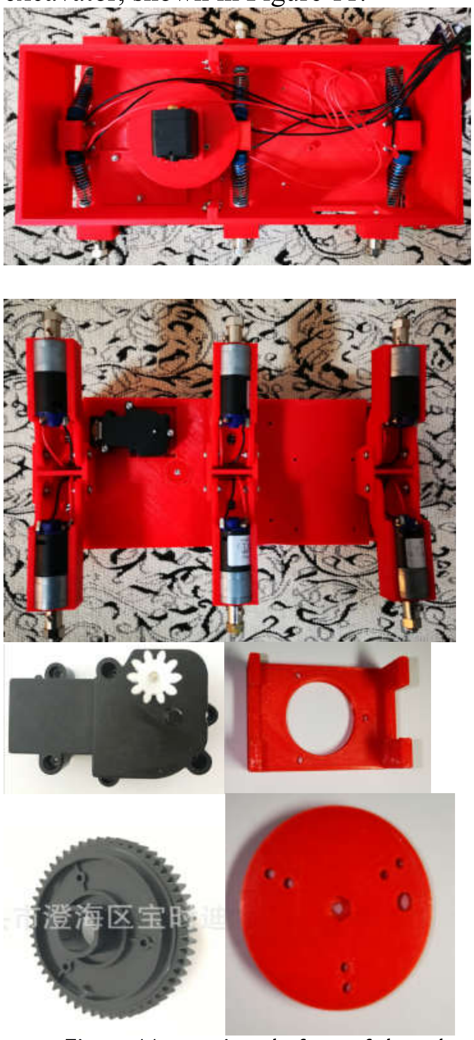


Figure 11. rotating platform of the robot arm

Camera

A camera is installed on the top of the manipulator to observe the working state of the manipulator. It can also observe the terrain around the robot using the flexible motion characteristics of the manipulator in a large range. The camera is mounted on a 9g steering gear and can rotate 1 to adjust the field of view from left to right.

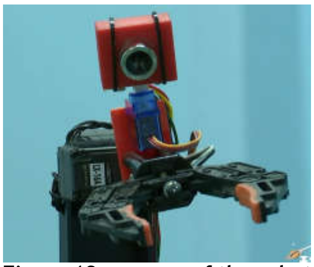


Figure 12. camera of the robot

3D software

OpenSCAD is software we used to design 3D components. It is a free software and available for Linux/UNIX, MS Windows and Mac OS X. Different form most free software for creating 3D models, OpenSCAD uses a programming language to create 3D models. Designer could control the modelling process completely and easily change any step in the modelling process or make designs that are defined by configurable parameters.

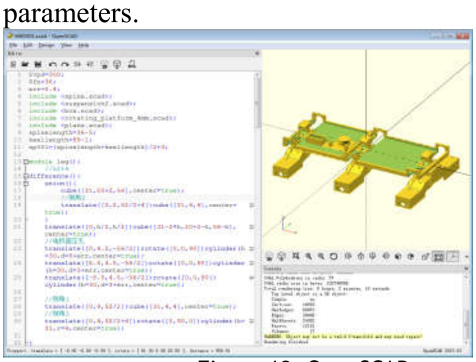


Figure 13. OpenSCAD

2.3. Vehicle Electronic Device

Figure 14. Motor

Motor

The motion system of the robot consisted of 6 modified 370 gear motors. The gearbox using the original 370 motor's gearbox, the motor used the high speed DC motor. Its working voltage was 12 V, with 350 mA rated current. Besides, the original speed was 17000 rpm with 500 rpm output shaft speed, and the rated torque is 5 kg· cm. Compared with the servo, the DC gear motor is cheaper and more powerful, which was more suitable for the robot to move in complex road conditions.

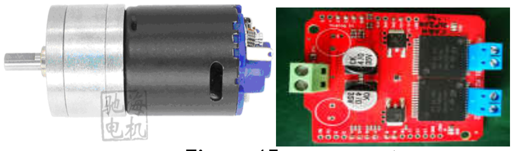


Figure 15. a new motor

After three time upgrade, we found a new motor from the Internet. It has same installation size as the 370 motor we adopted previously, but it can provide greater torque and the price is not expensive. On the other hand, it also causes some problems to upgrade the motor. For example, the current consumed by the motor increased to 2.7A, and the motor driver we adopted before (TB6612, 1.5A for each channel) cannot supply such a large current. We have upgraded a more powerful motor driver. Finally, Monster Motor Shield VNH2SP30 is chosen by us.

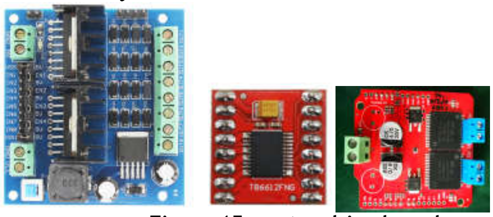


Figure 15. motor drive board

The design of motor drive board is very important for the mobility of the robot. We have designed three versions of the motor drive board schematic successively. Initially, we used two L298N dual drive boards, which occupy a large space and have limited driving capacity. Later, we used TB6612, which has high efficiency and small size. We used four TB6612, and abandoned the design of a PCB. Next, because we need to replace better motors and drive more current, we adopted the Monster Motor Shield VNH2SP30 and planned to design a new PCB. The module has Arduino compatible pins and can be directly used as an extension board for Arduino. In order to drive all six motors, three motors on each side are connected in parallel as the load of the driver.

Figure 16. servo motor

Servo

Lobot Serial Bus Servo LX-16A (Figure 16) was adopted as servo, which is mainly used for the robotic arm. The technical parameters were similar to Dynamixel AX-12A, but its price was only 1/3 of Dynamixel AX-12A, which greatly reduced the manufacturing cost of the robot. It is in line with the race concept of Rapidly Manufactured Robot Challenge.

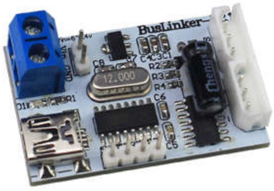


Figure 17. servo bus adapter board

Servo Bus Adapter Board

Lobot Serial Bus Servo used a half-duplex serial bus, while the Arduino slave computer only provided a full-duplex serial bus. Therefore, we use an adapter board that is compatible with serial bus servos, shown in Figure 17. By this way, the communication mode of the servo is switched to the full-duplex mode.

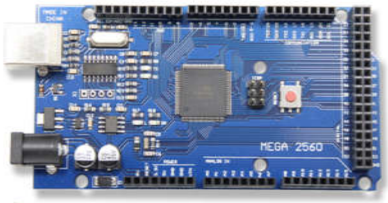


Figure 18. Arduino Mega 2560

Arduino

As a slave computer of the robot system, Arduino Mega 2560 was used for the motion control. The Arduino received the commands of the Raspberry Pi host computer through the serial bus. Then the arduino controlled the motor rotation direction through the digital I/O ports, and used Pulse Width Modulation (PWM) to regulate the motor power. Through the serial bus, the Arduino sent commands to servos of the robotic arm, and obtained the states of servos and reported states to the host computer regular. Therefore, it could achieve the operation of the robot arm effectively.

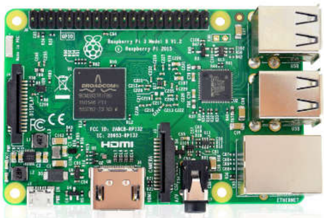


Figure 19. Raspberry Pi 3B

Raspberry Pi

Raspberry Pi 3B was used as the host computer of the robot, responsible for network communication and video transmission and processing. The Raspberry Pi 3B communicated with the Arduino slave computer using a serial bus and communicated with a computer using the 802.11n 5.8GHz WiFi module in a server-client mode, transmitting camera images and receiving control information. Raspberry Pi 3B also provided four USB 2.0 ports for connecting cameras which monitored the environment around the robot.

Arduino expansion board

Arduino expansion board is a circuit board which connects the Arduino with motor driver, Servo bus adapter board Raspberry Pi port and other interface of robot. We use bread board and wire to develop Arduino expansion board at first, but it took too much time and the reliability of the bread board is low. Altium Designer is the software that we used for design PCB. Altium Designer is an integrated electronic product development system launched by Altium Company, the original Protel software developer. The software can help designer easily design schematic diagram, circuit simulation, PCB drawing and editing. The schematic diagram and PCB design of Arduino expansion board are shown in Figures 20 , 21 and 22.

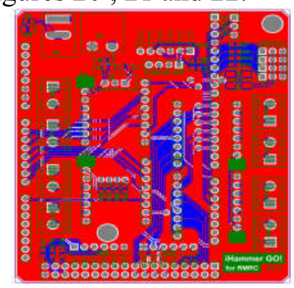


Figure 20. PCB design of Arduino expansion board

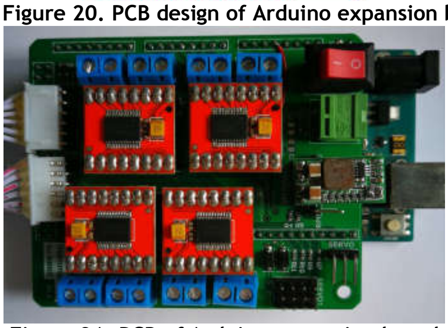


Figure 21. PCB of Arduino expansion board

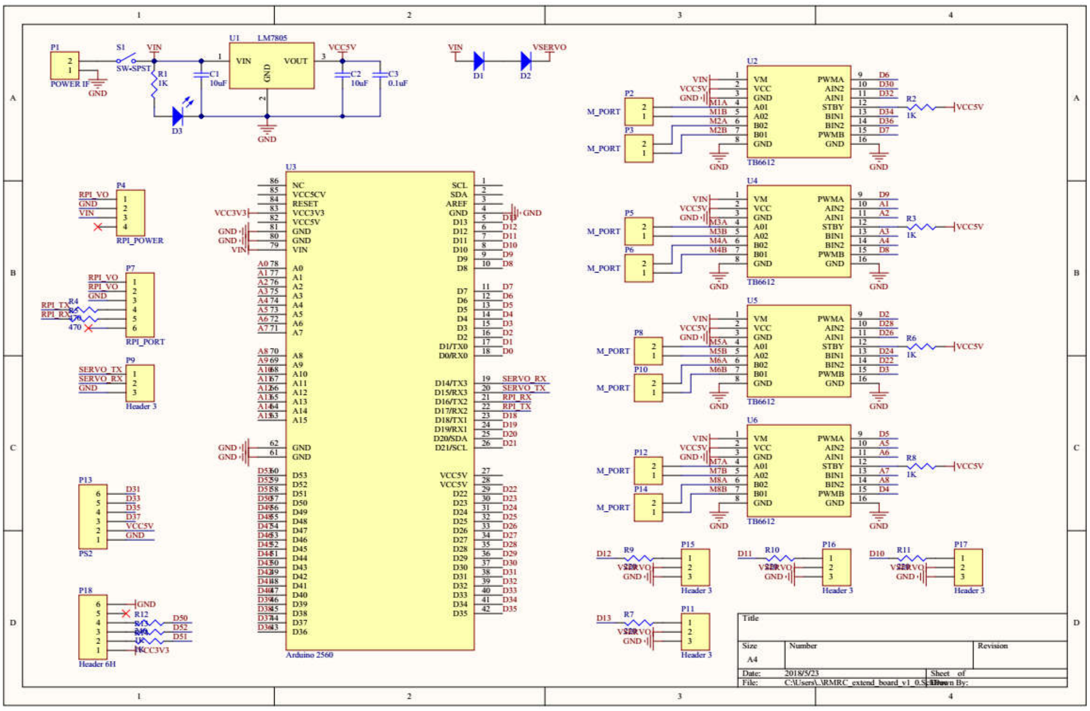
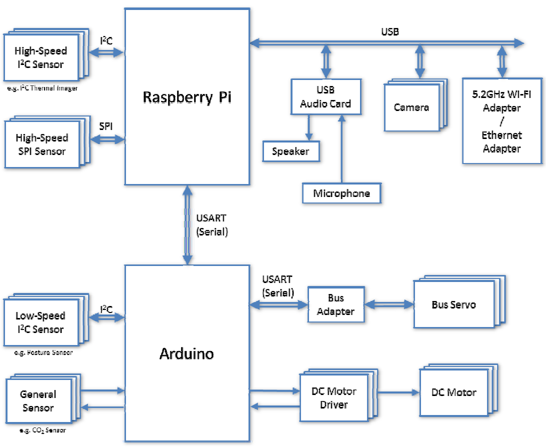


Figure 22. Schematic diagram of Arduino expansion board

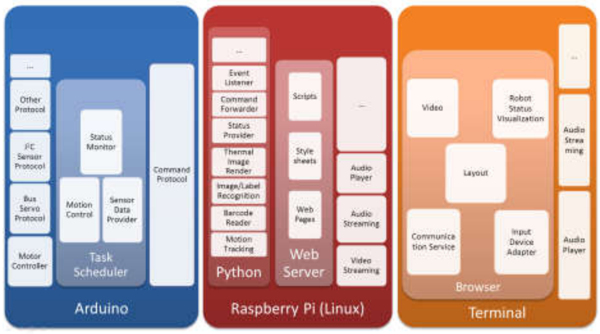
3. Software

3.1. Architecture

Upper-lower machine structure is adopted on the robot side. There is a variety of sensors which have a large difference in communicating and data rate in the system, as well as several kinds of actuators. Normally, both the number and the type of GPIO pins provided by the Raspberry Pi are not enough to manage them. So we've divided them into two classes: high-speed devices, such as camera and infrared thermal imager, and low-speed devices, such as gas sensor and motor. Low-speed devices are handled by the Arduino, and some high-level and resource-consuming processing is assigned to the Raspberry Pi.



Between the robot and the operator control unit, we used Browser/Server model to simplify the development and reduce dependency on a certain platform in some degree. Procedures on the Raspberry Pi are designed as services, preparing for future integration into ROS.



3.2. Robot

Arduino

Object-oriented programming was used to optimize the program structure. Our serial servo had no communication library yet, so we had to design it by ourselves. We reviewed the relevant information and completed the communication library. A communication protocol between the Arduino and the Raspberry Pi was developed to standardize the communication data between the Arduino and Raspberry Pi.

The program on the slave computer was mainly composed of following modules:

Slave.ino was the main program of Arduino. It was used to execute the commands sent by the Raspberry Pi host computer, such as controlling the movement of the robot and the operation of the robotic arm and monitoring the state of servos of the robotic arm.

Car6WD.cpp was the abstraction of the robot motion system, which was used to control the specific operation of each motor.

SerialServo.cpp was the abstraction of the serial bus servo, which was used to send and receive servo command data frames, and provide a practical servo command method.

CommandReceiver.cpp was instructions processing tool used to receive commands from the Raspberry Pi host computer and parsing the contents.

pins.h was the Arduino pin definition file for managing Arduino port resources.

Raspberry Pi

The official operating system of Raspberry Pi 3B was *Raspbain Linux*. Python 3.4.2 was used to carry Python Serial library and Python *Bottle* open source server framework acting as the interface to communicate with the Arduino slave computer. Apache2 open source server and Bootstrap open source web framework were used as our human interface website. mjpg-streamer open source application was used to transmit camera videos.

The structure of programs on Raspberry Pi was as follows:

Folder *html* was the hosting human interface website, scripts, and Bootstrap web framework.

Folder *mjpg-streamer* was the Video Stream transmitting program working directory.

Folder *python* were Stores Python scripts for communication with the Arduino slave computer.

Folder *shell_script* stored the Raspbain Linux startup script, and was used to start and stop the host computer programs automatically.

3.3. Human-Robot Interface

Bootstrap open source web framework was used to speed up the development process and reduce the design difficulty of human-robot interface.

We found a program environment is very suit for our robot programming. It is "Eclipse C++ IDE for Arduino". Eclipse is a free, powerful, and full-featured development environment that can be set up to work with AVR and Arduino. The follow is some useful link for this excellent IDE including a tutor movie.

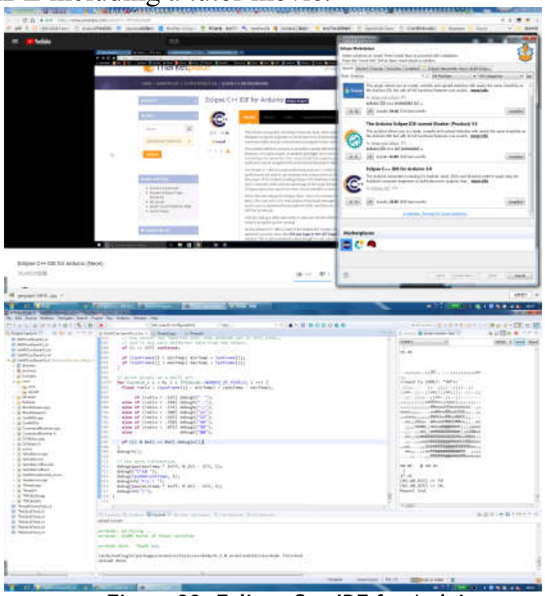


Figure 23. Eclipse C++ IDE for Arduino

3.4. Image recognition

In RMRC competition, image recognition is a very important function of rescue robots. We understand that these tasks can not be achieved without machine vision support, and OpenCV is the more commonly used library.

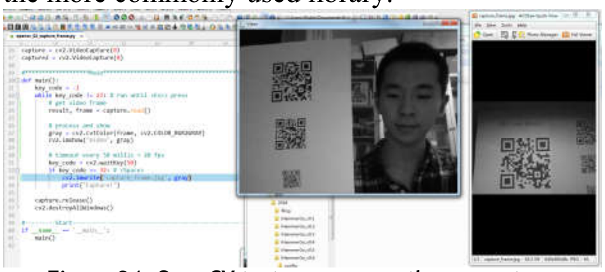


Figure 24. OpenCV test program on the computer.

We have adopted mjpg-streamer to provide webcam video streaming. So we thought, can we combine these two powerful libraries and use OpenCV to process the video stream that is input to mjpg-streamer? If it is possible, the recognition results will be drawn directly in the video image, which solve the trouble of re-generating the video stream. We discovered that mjpg-streamer has such a function by chance.

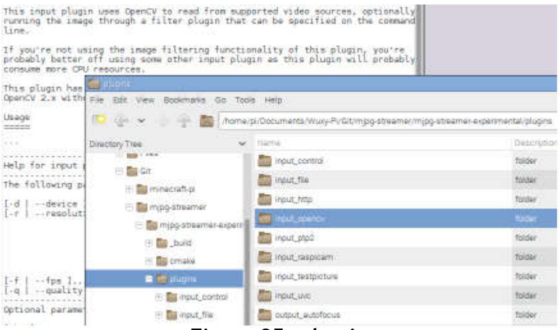


Figure 25. plug-in

This plug-in provides a "filter" and provides a Python interface for editing the video frame.

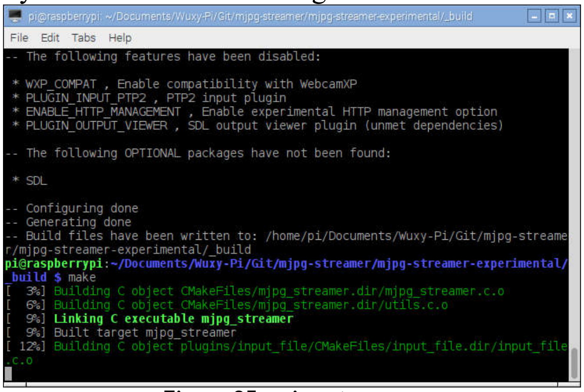


Figure 25. mjpg-streamer

To enable this plug-in, we need to recompile mjpg-streamer. But we seem to be too happy. When recompiling mjpg-streamer, cmake warned that we could not find libopencv-videoio, and compile error. After searching for more than an hour, we finally found the problem.

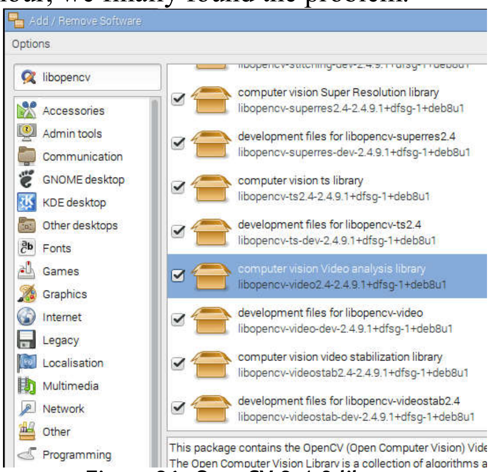


Figure 26. OpenCV 2.4.9 library

Raspbain Linux's Debian software library only contains OpenCV 2.4.9, while mjpg-streamer requires OpenCV version above 3.1.0. It looks like we need to compile the latest version of OpenCV.

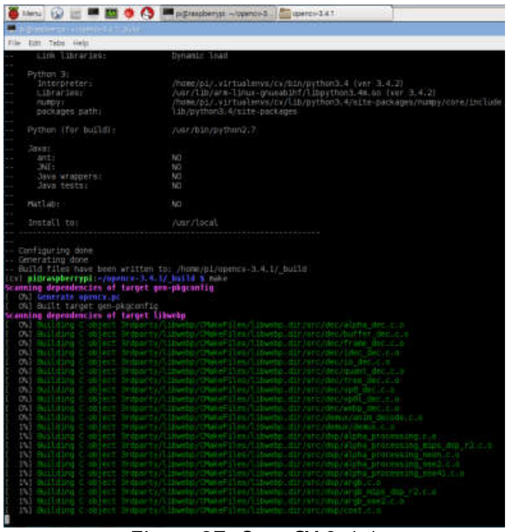
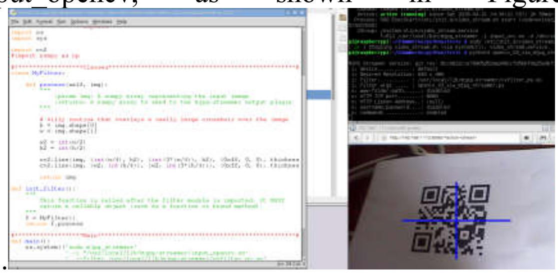


Figure 27. OpenCV 3.4.1

According to the online guidance, we spent 2 hours in downloading and compiling OpenCV 3.4.1. The problem has been solved. We wrote a simple program to test the mjpg-streamer plug-in input_opencv, as shown in Figure



28.

Figure 28. The image of the camera is processed by OpenCV, and the blue crossing is added to the center.

Figure 29. MLX90640 infrared thermal imager

Infrared thermal imager

MLX90640 infrared thermal imager sensor module is adopted in our robot to detect object. This module IR Proximity Sensor has 32*24 Temperature Lattice Sensor. It is much better than the 16*16 sensor which we use last year.

4. Experiments and tests

4.1. Basic motion test

A series of basic tests were carried out, such as forward motion, backward motion, steering motion, passing through obstacles, robot control, video image transmission, remote control operation, battery life, and maximum communication range. These tests were completed successfully and verified the performance of the robot.

4.2. Field test

Our robot was tested in a variety of environments, such as grassland, sandy land, demolition building sites, and large cobblestone beaches, verifying that the robot had strong ability to pass these complex terrains. The robot performed well because a six-wheeled elastic suspension system was adopted. The robot could contact effectively with the ground and get rid of the trouble in time when it is tilted at a large angle.

Figure 30. test field

Our test field has 9 different terrain lanes and is configured into a maze that can be navigated in sequence. Some kind of test has been carried out in this field. The robot can pass these terrains without too much difficulty. some new challenges has been added in this year's RMRC. We need to upgrade our arena and retest whether our robots can accomplish these tasks.

Figure 30. test field

4.3. Experiences of RoboCup

The core members of the iHammer GO! participated in the 2018 RoboCup RMRL in Montreal, 2019 RoboCup RMRC in Sydney, and 2017 RCJ Rescue Line competition in Nagoya, Japan. We have focused the competition for a long time and communicated with the players in RMRL. We have learned a lot of information about RMRL competition, and took many videos of participating robots and teams. This information was very helpful for us to join RMRL competition. It was the first time we participated in the RMRL and we obtained the 6th place. We won the first place at RoboCup in Sydney, Australian. We think the following points will help improve our robot performance

1. A good mechanical structure design is adopted. The six wheel system with independent suspension has excellent performance. The rubber tire has strong grip. Six motors are evenly installed in the lower part of the robot, which reduces the center of gravity of the system to the greatest extent, ensures the stability of the robot in the rugged and inclined state, and six deceleration motors provide sufficient driving capacity. These designs make our robot pass through all terrain obstacles with high speed.

2. Reliable circuits and control systems have been developed, which have never failed in the whole process of the competition. The performance is perfect, so that we can focus on competition, without the troubleshooting and emergency maintenance of the robot.

3. Our robot is designed completely based on mature components, so it has a high cost performance. The price of components and parts needed to purchase robots online is so low. We have enough spare parts. There are three spare robots we brought to Sydney, and a large number of spare parts. Even though we don't have special financial support, we don't need to worry about the production cost at all. The extremely low cost guarantees the continuous development and performance improvement of our robots.

4. Excellent team organization and training. Compared with Montreal in 2018, this is the second time for us to participate in RMRC. We have reorganized the team; reasonably allocated the labour division of the team members, trained the operators in the specific obstacle field, and gave full play to the technical advantages of the

rescue robot we designed.

5. Reasonable competition strategy is adopted in the competition. We found that the score of two-dimensional code recognition is higher. We take the advantages of camera installed in the front of the robot arm, and can identify the smallest two-dimensional code by moving close. We give up several terrains that we can get through, and use the saved time for the recognition more two-dimensional code. We have also planned a reasonable competition route. By turning back and detouring, we try to arrange two high-risk terrains in the last stage, so as to ensure that even if there is a mistake, there will be enough high scores in the first half of the competition. In fact, this happens in the final.

Figure 34. a reasonable planned competition route in the RMRC final of RoboCup2019

RMRL is a very well-designed new competition program that could attract more robot lovers to participate in the R&D of robot projects. It is hoped that RMRL will expand its publicity after the competition and make a significant contribution to the development of RoboCup.

We also made two different types of robots to test their passing ability on the test field. One was a wheeled robot with four longitudinal independent suspensions as shown in Figure 31 It was similar to the structure of our competing scheme, but the installation direction of the suspension was different. Field tests showed that the robot also had a strong obstacle-surmounting ability. The other was a miniature tracked robot with 3D printing driven by N20 micro-motor, as shown in Figure 32. Although small robots were small in size and difficult to climb obstacles higher than themselves, they were lighter in weight, had higher power density and more agile in action. They could penetrate small holes and drill through holes under obstacles. In some special rescue scenarios, they had unique advantages. Small robots and micro robots were low cost and could be manufactured rapidly and collaborate as a robotic swarm. It is expected to become a hot research.


Figure 31. wheeled robot

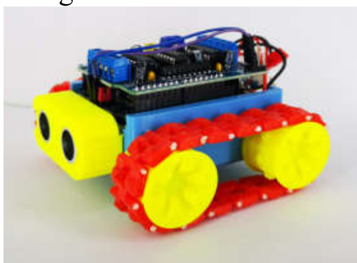


Figure 32. tracked robot

We also made a lot of other robots for robot competition and robot education. They are also made mainly by 3D print. Although it is not used in RMRC competition, we still learned a lot of knowledge and experience in the process of designing and making these robots. More importantly, we enjoyed the happiness brought by robot.

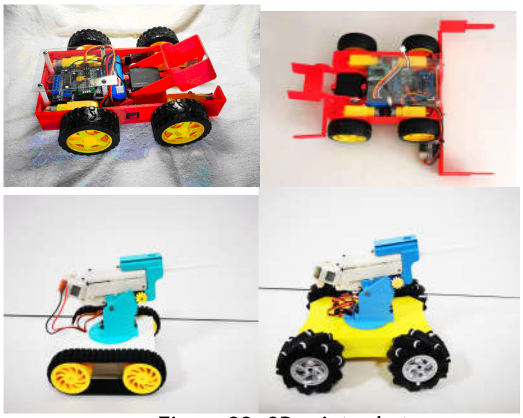


Figure 33. 3D print robot

5. Conclusion

We have presented a solution to improve the survivability of rescue robots on the complex terrain. A series of modifications were made in last year:

1. Mechanical system of the robot is redesigned. Some parts is modified, which had problems in the competition. For example, the thickness of suspension bracket is increased. The weight of the car body is decreased, further reduced the centre of gravity, and improved the stability of the robot.

2. In the circuit system design, motor driver was modified to supply more power for six motors.

This could help the robot improve the ability of obstacle surmounting.

3. We learned ROS robot operating system, and made a four-wheel differential robot with lidar. We are familiar with motion control, slam and motion planning by making this robot. Next, we hope to apply SLAM technology to our rescue robot。

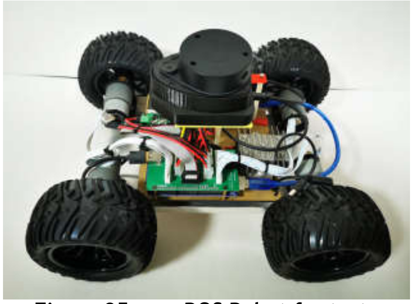


Figure 35. our ROS Robot for test

We have taken part in the RMRC twice, from the 6th place of Montreal to first place in Sydney. It's a pity that our robots is still less powerful compare to robot of team TUPAC. But our robots have higher cost performance ratio. We hope to have the TUPAC performance as much as possible with our low-cost advantage. We hope to do better in this year's competition.

Through participating in the RMRC competition, we learned more knowledge and ability of designing and manufacturing robots. Without the RMRC competition, our robot might not have the power to go through such a complex terrain, equipped with so many degrees of freedom robots arm and complex image processing capabilities. It is the RMRC challenges that promote us to design and manufacture so much powerful robots and promote our abilities continuously. This is really the charm of the robot competition. Through the robot competition, we also met robot enthusiasts from all over the world. Besides, the extraordinary works in the competition endow us with new idea for our next robot. We enjoy every happy time brought by the RMRC competition.

iHammer GO! Team

6. References

RoboCup Federation 2017, RoboCup 2017, viewed 9 September 2016
https://www.robocup2017.org/eng/index.html

Sheh, R 2015, The Open Academic Robot Kit, viewed 30 July 2017
http://oarkit.intelligentrobots.org/home/

Taobao.com 2017, 85mm轮胎 海绵内胆 智能小车轮子 两轮自平衡小车轮胎, viewed 2017.8.17
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=535888025527&_u=gc4kdee545

Taobao.com 2017, L298N电机驱动板模块 步进电机 智能车 机器人 Arduino, viewed 2017.8.12
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=548690276558&_u=gc4kdeb51d

ROBOTIS Inc 2016, Dynamixel AX-12A, viewed 24 September 2017
http://support.robotis.com/en/product/actuator/dynamixel/ax_series/dxl_ax_actuator.htm

Taobao.com 2017, 6WD搜救平台 智能车底盘 减震 越野 攀爬 , viewed 2017.8.10
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=541672590664&_u=gc4kde61bf

Taobao.com 2017, 金属轴套 不锈钢 卡位套 2/3/4/5mm DIY模型拼装, viewed 2017.9.11
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=548690276558&_u=gc4kdeb51d

Taobao.com 2017, 304不锈钢锁紧螺母\防松螺帽\尼龙\防滑M3M4M5M6M8M10M12自锁螺丝, 2017.9.11
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=550725648996&_u=gc4kde747c

Taobao.com 2017, 带边轴承 滚珠轴承 四驱车轴承 电机法兰轴承, viewed 2017.9.12
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=524554891761&_u=gc4kde9dd0

Taobao.com 2017, 25GA370直流减速电机减速马达 低速电机大扭矩慢速电机, viewed 2017.9.13
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=532926274616&_u=gc4kde540a

Taobao.com 2017, 环奇734配件 金属前避震器M0520 金属后避震器M0521, viewed 2017.9.23
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=19894110383&_u=gc4kde1fe6

Taobao.com 2017, L298N电机驱动模块 四路电机驱动 智能小车驱动电机模块, viewed 2017.9.25
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=555113216638&_u=gc4kde0643

Tmall.com, 304不锈钢沉头螺丝 GB819平头十字螺丝钉 M3 M4 M5, viewed 2017.11.26
https://detail.tmall.com/item.htm?id=529652825301&spm=a1z09.2.0.0.4b9f2e8dt936By&_u=gc4kde4605

Taobao.com 2017, 串行总线舵机/智能串口双轴数字舵机LX-16A/机器人大扭力高精度, viewed 2017.12.25
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=545718863797&_u=gc4kdea220

Taobao.com 2017, 3D打印机耗材PLA/ABS/UM2 Ultimaker2专用直径2.85mm厂家直销现货, viewed 2017.12.1
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=542610706183&_u=gc4kde9342

Taobao.com 2016, 爱上Raspberry Pi 入门套件 树莓派3套件 Rasp3代套件, viewed 2016.8.14
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=20113802083&_u=gc4kdee9ec

Taobao.com 2017, 狮子遥控模型动力锂电池2S 7.4v 3S 11.1v

2200mah25c30C, viewed 2017.8.10
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.67002e8dYcw7XC&id=36115004697&_u=gc4kde6f22
Taobao.com 2017, 7*9CM双面喷锡 FR4 1.6厚 2.54间距 万能板 pcb 线路板, viewed 2017.10.23
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.67002e8dYcw7XC&id=555012065682&_u=gc4kdebd15
Taobao.com 2018, PS2手柄转电脑PC/PS3转换器 转接头 USB接口, viewed 2018.3.5
https://item.taobao.com/item.htm?spm=a1z09.2.0.0.4b9f2e8dt936By&id=3549303854&_u=gc4kdedace
Github 2018, CopyThreads: A lightweight threading library, viewed 2018.1.29
https://github.com/jensh/CopyThreads
Github 2018, SARTRobot, viewed 2018.2.6
https://github.com/SFXRescue/SARTRobot
树莓派实验室 2018, 树莓派上MJPG-streamer的安装过程, viewed 2018.2.4
http://shumeipai.nxez.com/2017/05/14/raspberry-pi-mjpg-streamer-installation.html
Bootstrap中文网 2018, 起步 · Bootstrap v3 中文文档, viewed 2018.2.12
https://v3.bootcss.com/getting-started/
Apache Software Foundation 2018, mod_userdir - Apache HTTP Server Version 2.4, viewed 2018.2.8
http://httpd.apache.org/docs/2.4/mod/mod_userdir.html
Marcel Hellkamp 2018, Bottle: Python Web Framework, viewed 2018.1.24
http://www.bottlepy.org/docs/dev/
CSDN 2018, 树莓派3B 设置通用（UART）串口的方法, viewed 2018.1.3
http://blog.csdn.net/berryfish/article/details/60147631
MakerBot Industries 2018, Open Academic Robot Kit: 5 Degree of Freedom robot arm using Dynamixel AX-12A servos, viewed 2018.1.4
https://www.thingiverse.com/thing:368804
Marius Kintel 2017, OpenSCAD - The Programmers Solid 3D CAD Modeller, viewed 2017.3.25
http://www.openscad.org/index.html
菜鸟教程 2018, HTML 教程, viewed 2018.1.5
http://www.runoob.com/html/html-tutorial.html
Arduino.cc 2017, Arduino style guide, viewed 2017.12.17
https://www.arduino.cc/en/Reference/StyleGuide
CSDN Blog 2018, 给树莓派安装VNC server并设置自启动, viewed 2018.1.1
http://blog.csdn.net/rocklee/article/details/50358942
Reference: How to install OpenCV 3 on Raspbian Jessie
https://www.pyimagesearch.com/2015/10/26/how-to-install-opencv-3-on-raspbian-jessie
Arduino Playground - Eclipse
https://playground.arduino.cc/Code/Eclipse
Eclipse C++ IDE for Arduino (Neon) - YouTube
https://www.youtube.com/watch?v=TtPvkPpAx0E

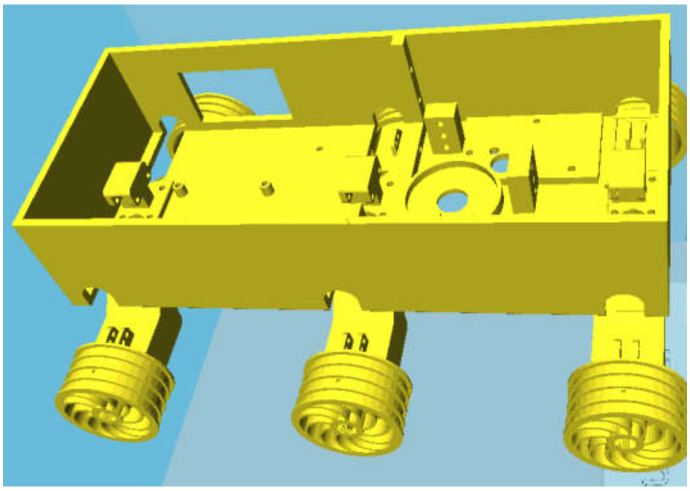
7. Appendix A - Components & Estimated Total Cost

Table 1 - Components & Estimated Total Cost - Robot Only

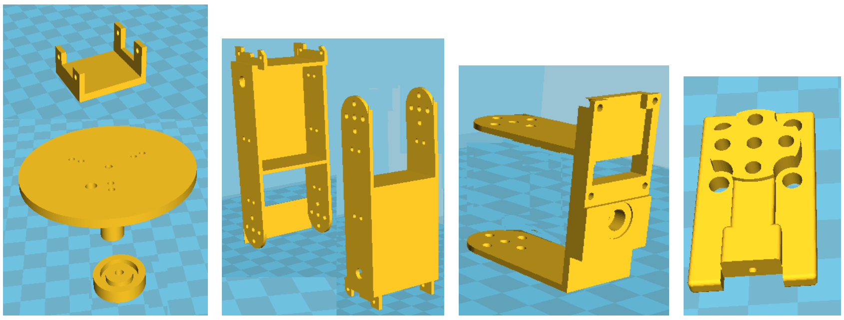
Component	Price (USD)	Quantity	Total (USD)
Wheel Tire	3.17	6	19.00
Axis Coupling	0.32	12	3.80
Bearing	0.47	12	5.70
M3 Bolt and Nut	0.08	60	4.75
Shock Absorber	5.54	6	33.24
370 DC Motor	5.08	6	30.48
TB6612 Driver	3.05	4	12.20
Lobot LX-16A	15.83	5	79.15
Lobot Servo BusLinker v1.2	3.17	1	3.17
Arduino Mega 2560	15.83	1	15.83
Arduino Wiring Board	7.92	1	7.92
Raspberry Pi 3B	33.32	1	33.32
Webcam	7.92	2	15.83
Ultimaker PLA 3D Printer Filament 1kg spool	12.66	1	12.66
2.2 Ah Lithium Polymer Battery	7.92	4	31.66
MLX90640 infrared thermal imager	50.00	1	50.00

Total	366.00

8. Appendix B - Components



3D print components on the 6 wheel car



3D print components on the robot arm

9. Appendix C - List of Software Packages

Table 3 - Software Packages and Dependencies Used

Device or Process	Software Package/s used
Raspberry Pi 3B	Raspbain Linux
	Python 3.4.2
	Apache2
	mjpg-streamer
Web Interface	Apache2 Python: - Bottle
Image Recognition	Python: - OpenCV 3.4.0 - Numpy
Motion Detection	Python: - OpenCV 3.4.0 - opencv_contrib repo - Numpy
QR Code Reading	Python: - pyzbar - zbarlight - PIL

Audio	VideoLAN Manager (VLM) VLC media player
Arduino Mega 2560	Arduino - Servo
Robot Chassis	OpenSCAD

10. Appendix D - List of Hardware

Table 4 - List of Hardware and Chassis Parts

Component	Hardware
Robot Chassis	Design using OpenSCAD.
Robot Wheels	Design using OpenSCAD.
Wheel Tire	86mm
Axis Coupling	Connect wheels to motor axis.
Bearing	Connect suspension to frame.
M3 Bolt and Nut	Connect 3D printed parts.
370 DC Motor	Modified from classical 370 DC Motor.
TB6612 Driver	Motor driver
Lobot LX-16A	Servo for the robot arm.
Lobot Servo BusLinker	Adapter between servos and Arduino.
Arduino Mega 2560	As a lower computer, responsible for controlling robot and sending status of servos to the Raspberry Pi.
Arduino Wiring Board	Design by ourselves.
Raspberry Pi 3B	As an upper computer, central computational device on board the Robot.
Webcam	Camera.
Ultimaker PLA 3D Printer Filament 1kg spool	The 3D printer filament, a type of plastic extruded through a hot nozzle that builds a model by laying subsequent layers on top of each other.
2.2 Ah 2S Lithium Polymer Battery	Powers the entire mobile apparatus.
MLX90640 infrared thermal imager	Provides infrared thermal image.

11. Appendix E - Web and Open Source Presence

Website Blog

http://blog.sina.com.cn/wuxyxmy