RoboCupRescue 2009 - Robot League Team AriAnA (Iran)

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Abstract. This paper outlines rescue robots of AriAnA robotics team, the result of our long term research project on high mobility systems. Both robots benefit an innovative locomotion mechanism called Tracked Triangular Wheel which provides the advantages of wheeled, tracked and legged systems together. These robots are equipped with a range of state of the art sensors and hardware. Already our main concern has been making the robots more and more intelligent focusing on reliable navigation, localization and mapping algorithms.

Introduction

AriAnA is the official robotics team of Islamic Azad University of Central Tehran Branch (IAUCTB) and was founded as a basis for a research project on USAR robotics. Our vision is "Aiding human rescue teams in real urban disasters, by providing them intelligent and reliable robotic systems." And our mission is "Building a collaborating team of intelligent search and rescue robots with high mobility."
At primitive steps we designed, manufactured and implemented a novel locomotion mechanism that we call Tracked Triangular Wheel (TTW) [1]. We actually reinvented the wheel to achieve better mobility. By utilizing this new locomotion mechanism, our robot can move on a flat ground as fast as a wheeled system, on the stairs as stable as a tracked one and on the step field just like a legged robot. The first prototype, ARIAN was used in RoboCup 2006 Germany competitions.

We continued development by modifying ARIAN and constructing a new model called META (Fig.1).
Both robots are Tele-Operated systems and use autonomous modules for Simultaneous Localization And Mapping (SLAM) as well as victim detection.

Fig.1. (1) ARIAN at RoboCup 2006 Germany, (2) META

1. Team Members and Their Contributions

• Dr. Hossein Mahbadi	Team leader
• Amir Hossein Soltanzadeh	Mechanical designer, Manager
• Ahmad Chitsazan	Mechanical manufacturer
• Mahdi Emami	Electronics, Hardware
• Mehdi Soltanzadeh	Software engineer, Operator

With special thanks to:

• Dr. Abdollah Baradaran	Advisor
• Azad University of Central Tehran Branch	Sponsor
• Xarrin Advanced Technologies	Technical support
• T. T. Khoozestan Co.	Mechanical manufacturing

2. Operator Station Set-up and Break-Down (10 minutes)

Considering baggage allowance limits of international airlines, we have made a number of portable suitcases for traveling to the competition venue.
Following items are included in our travel package:

- **Main Unit (QTY=2)**
  - Robot main body
- **Operator Control Unit (QTY=1)**
  - Industrial computer
  - Touch screen LCD monitor

- Access point
- Portable printer
- Joystick

- **Equipment Unit (QTY=1)**
    - Battery packs and chargers
    - Mechanical instruments
    - Electronics tools

2.1. At RoboCup competitions

After robot setup at first day, we need two people besides the operator for set-up and break-down procedures.

2.1.1. Operator Station Set-up (10 minutes)

We use a custom designed Operator Control Unit (OCU) for fast set-up and break-down (Fig.2). While two members carry the robots to the arena, the operator brings the OCU to the operator station. When all systems are switched on, an automatic system check is performed under operator's supervision. The whole station set-up process takes less than 10 minutes, with the most time consuming part being sensor warm up.

Fig. 2. (1,2) OCU of AriAnA

2.1.2. Operator Station Break-down (10 minutes)

At the end of each mission, the operator has two specific tasks: stopping the system and delivering generated data in both printed and digital formats while other two members are taking the robots out of the arena. This takes about 5 minutes.

3. Communications

We use an Access Point (AP) which supports 802.11a and 802.11b/g simultaneously; however, our default setting is 5GHz 802.11a CH. 11.
In addition to AP we use a remote joystick and a wireless headset (Table 1).

Table 1. Used communication frequencies

Rescue Robot League		
AriAnA (IRAN)		
Frequency	**Channel/Band**	**Power (mW)**
5.0 GHz - 802.11 a	(selectable)	100 mW
2.4 GHz - Bluetooth	n/a	5 mW
2.4 GHz - Bluetooth	n/a	2 mW

At each mission, both robots keep an eye on network connectivity. When network connectivity is lost for a long period and reconnection attempts fails, the disconnected robot autonomously tries to rollback to a place with network connectivity using its locomotion history. If rollback fails, it begins alarming by sound and flashing light.

4. Control Method and Human-Robot Interface

Our control system consists of the onboard robot control and OCU where most computational tasks are done onboard and the results are transmitted to OCU. We use identical hardware and software control systems on both robots.

4.1. Hardware Overview

Hardware of our robots (Fig. 3) consists of these main sections:

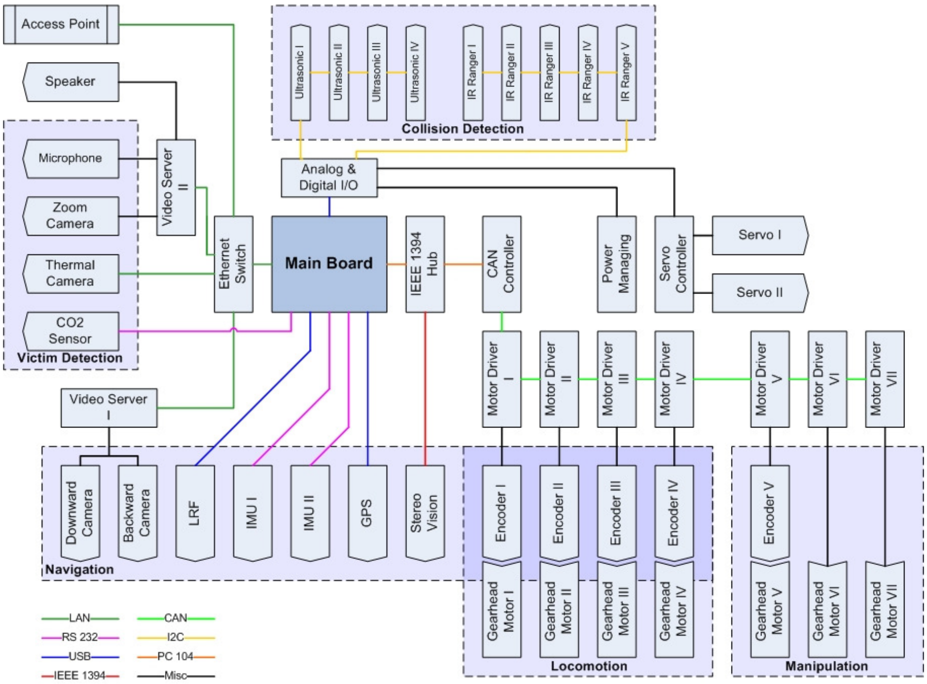

Fig. 3. Hardware block diagram of our robots

- **Main Unit**

Computational system on mobile devices like robots must be compact, rugged, low power, reliable, extendable and easy to handle. PC/104 is an embedded computer standard controlled by the PC/104 consortium which defines both a form factor and computer bus. PC/104 is intended for specialized embedded computing environments where applications depend on reliable data acquisition despite an often extreme environment. We chose PC/104+ hardware to be employed on both robots (Fig. 4). The main unit consists of a motherboard, CAN controller, FireWire (IEEE 1394) card and Analog/Digital IO. Below is the feature list of the main board:

- Pentium 2.0 GHz with 2MB cache
- 2 GB DDR2 RAM, 80 GB SATA2 2.5" Hard Disk
- 4×RS232, 6×USB, 2×LAN ,8×GPIO
- PC 104+, Mini PCI, PCI Slot interfaces
- 204×146 mm, 0.85kg
- +5V and +12V, Max 30W, Suspend 18W
- Suitable temperature, humidity and vibration characteristics

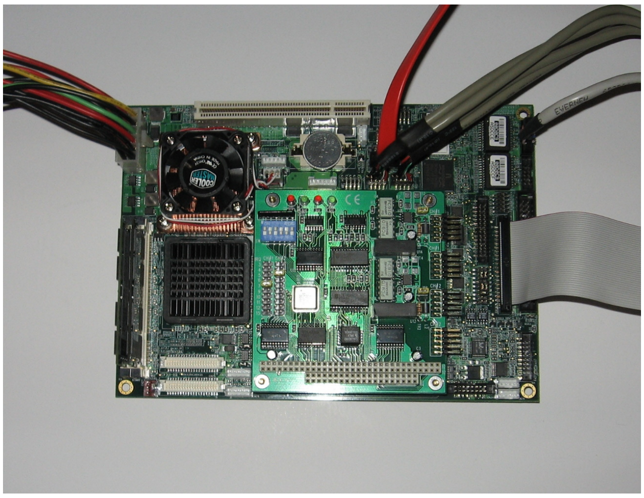

Fig. 4. PC/104+ compatible industrial computer used in our robots

PC/104+ type CAN controller and FireWire cards are used to connect motor drivers and stereo vision module to the main board respectively.
Analog/Digital IO board is microcontroller based and is used to collect sensor data from ultrasonic and IR rangers, also to control power management unit and laser range finder stabilizer servos. This board interfaces with motherboard via USB.

- **Motor Driver**

We are using reliable motor drivers which provide accurate position and velocity controlling for simple DC motors. These drivers are connected to motherboard via CAN bus to reduce wiring inside the robots.

- **Video Server**

Two robust video servers are employed in each robot to convert analog videos to MPEG4 format and stream them over LAN.

- **Power Supply and Management**

Results of practical tests indicate that average power consumption of each robot is approximately 300Wh. 12x4000mAh Polymer Li-Ion cells are packed to build a 24V-8000mAh (192Wh) battery pack with capacity to deliver an 1880W high-drain discharge. With this pack robots are expected to handle 40 min. missions.
We have built a power management unit with multiple digitally controlled outputs. Voltage and current of each output can be digitally adjusted. This unit is connected to main board via D/A IO controller which enables the operator to monitor power consumption of individual devices besides remaining battery power.
We are working on direct LAN access to power management unit to switch devices on/off in emergency cases. The other hardware components are discussed in the next sections.

4.2. Software Overview

We use Player/Stage framework for robot control. Sensor reading and ranging based SLAM modules run onboard in robots and GUI also player server run on OCU as our human robot interface.

4.2.1. Player robotic server

Player is a device server that provides a powerful, flexible interface to a variety of sensors and actuators. Because Player uses a TCP socket-based client/server model, robot control programs can be written in any programming language and can execute on any computer with network connectivity to the robot. In addition, Player supports multiple concurrent client connections to devices, creating new possibilities for distributed and collaborative sensing and control [2].

4.2.2. Human-Robot Interface (HRI)

Design of HRI directly affects operator's ability to fulfill a task. It also affects her/his ability to understand the current situations, make decisions and provide high level commands to the robotic system [3].
As a key point in developing an effective, efficient, usable, and deployable interface, we need to appreciate the operator needs and requirements as well as the way of presenting them to her/him [4]. The previous experiences besides observing the GUI of First Person Shooter (FPS) video games were very useful in this regard. In developing our GUI, we've heeded the following concepts [5]:

- Awareness of the robots surroundings: *how accurately the user can describe the robot's local environment*
- Awareness of robots status: *knowledge about the state of robot itself, such as its power level, orientation, attitude, or the position of its camera relative to the front of the robot*

Fig. 5 illustrates our main GUI which is designed for multi-robot control.

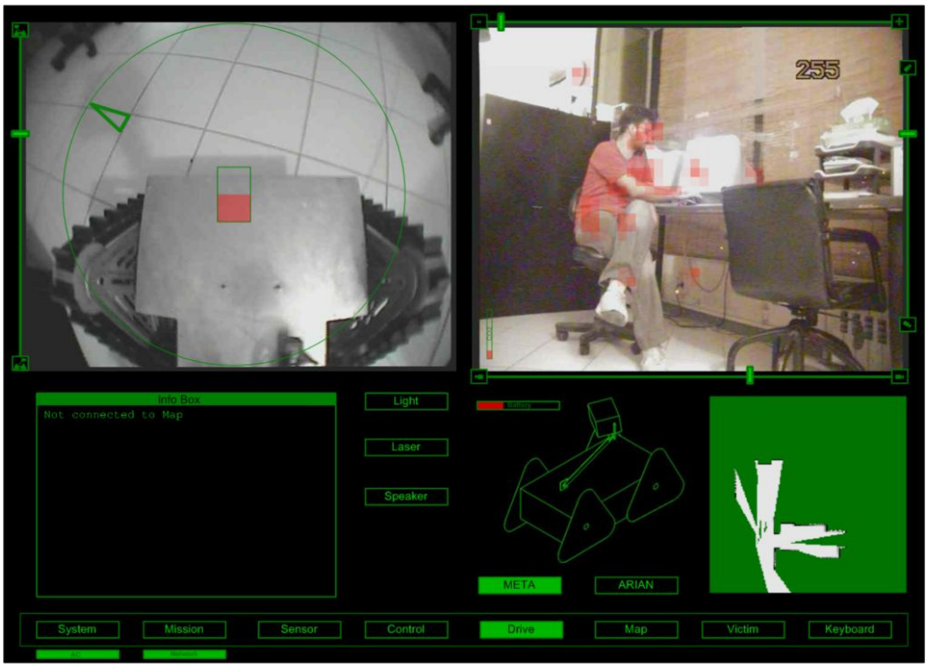

Fig. 5. GUI of AriAnA

We have three cameras installed on robots' arm. Top left image is from downward-looking wide angle camera overlaid by robot heading indicators. Top right image is from PTZ camera overlaid by thermal image. This automatically switches to backward camera, when robot is moving backward.
Info box, robot 3d rendering and last updated map of active robot besides remaining battery power are displayed below the camera images.
OCU has a touch screen LCD thus operator can open other GUI screens by touching buttons in main screen.

5. Map generation/printing

We are using a Rao-Blackwellized Particle Filtering algorithm [6] as a real time FastSLAM [7]. This algorithm uses IMU corrected LRF data as well as odometery for 2D mapping. Entire SLAM algorithm runs on-board individually on each robot and the resulted Occupancy Grid map is transmitted to OCU periodically during the missions (Fig. 6). Operator can edit the map to add elements like victim information or label locations to help human rescuers to identify them. At the time being we don't actually do multi-robot mapping and at the end of each mission the OCU do a post processing to merge the generated map of each robot to prepare final report. Finally a 2D map with user additions is printed.

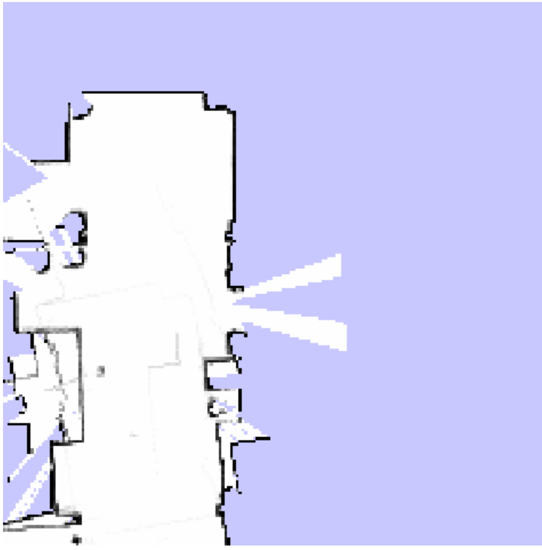

Fig. 6. A sample generated map by ARIAN while people waking around it

6. Sensors for Navigation and Localization

As stated before, both robots are tele-operated with identical hardware components and sensors. Like most tele-operated mobile robots, our main navigation sensor is camera. In addition to the cameras, the robots are equipped with these sensors for navigation and localization (Fig. 7):

- Laser Range Finder (QTY=1): *indoor*
- Optical shaft encoder (QTY=4): *indoor/outdoor*
- IMU (QTY=2): *indoor/outdoor*
- Stereo Vision module (QTY=1): *indoor/outdoor*
- GPS (QTY=1): *outdoor*
- Ultrasonic ranger (QTY=4): *indoor*
- IR ranger (QTY=5): *indoor*

Data of these sensors is also used as a basis for critical collision detection and avoidance. If a collision is detected, avoidance gets higher priority than user command. Collision avoidance feature can be turned on/off by operator, so in cases like step fields you can turn off this feature to try your chance.

Fig. 7. Navigation sensors of both robots

It should be mentioned that we have developed a servomechanism to electromechanically stabilize LRF using one of two IMUs on each robot similar to the method utilized by team "RESKO" at RoboCup 2007 U.S. (Fig. 8). Additionally, we are working on a Stereo Vision based visual odometery to be replaced with traditional odometery.

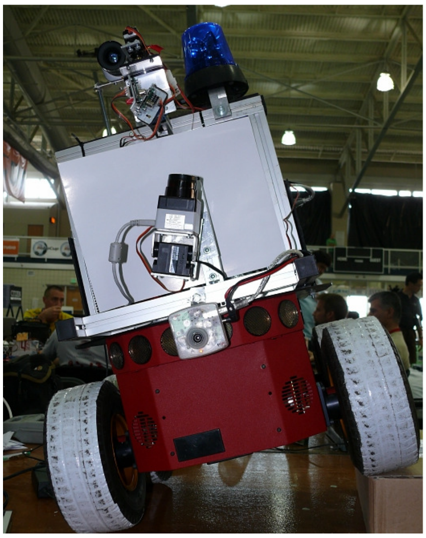
Fig. 8. The robot of team RESKO at RC07 RRL

7. Sensors for Victim Identification

We have constructed a manipulator to hold all victim detection sensors. These sensors are packed in a pan/tilting end effecter called Victim Detection Package (VDP). The VDP equipped with these sensors are used for victim detection (Fig. 9):

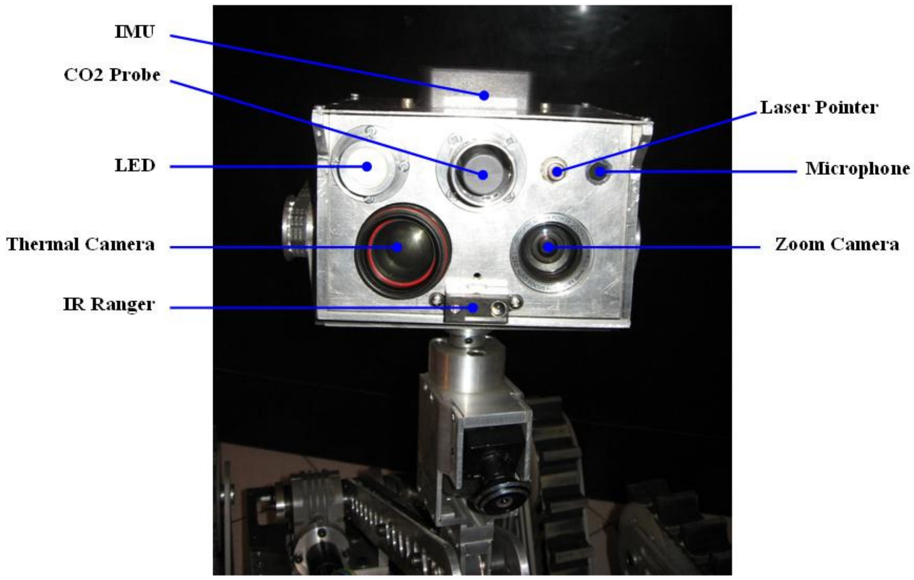

Fig. 9. VDP

- **260x zoom camera (26x optical)**

This camera provides fine images of environment even in almost absolute darkness.

- **Thermal Imaging Camera**

This compact, lightweight and low cost thermal camera is employed to precisely monitor surrounding heat sources. To make its stream more meaningful to the operator, the output is filtered to human body temperature and calibrated with respect to the zoom camera then it is mixed with streams from zoom camera (Fig. 10). This technique was introduced by team “CASualy” at RoboCup 2005 Japan [8].

- **CO2 Sensor**

We’ve equipped both robots with CO2 sensors to sense the exhaled CO2 from victims. They have a response time of about 20 sec. which is common in most CO2 sensors.

- **Microphone**

A sensitive microphone and small speaker is used to have a bi-directional communication between operator and victim.

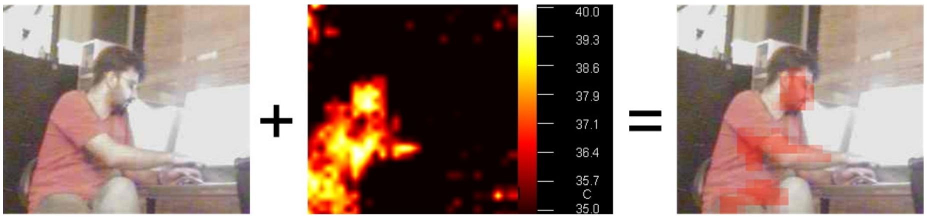

Fig. 10. Blending streams of zoom and thermal cameras

8. Robot Locomotion

As it was mentioned, our robots both benefit an extraordinary differential steering locomotion system called TTW. The base idea of TTW came from "Space Cat" [9] which itself has a close similarity to J. Flory's stair climbing vehicle [10] (Fig. 11).

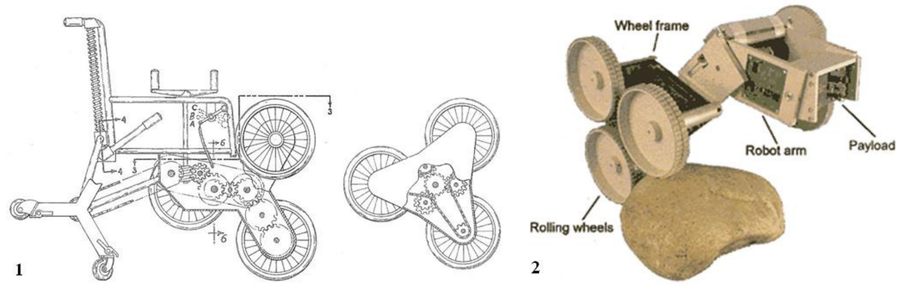

Fig. 11. (1) Flory's stair climbing vehicle, (2) Space Cat

8.1. Concept of TTW mechanism

A TTW consists of a track traveling on triangular path and the path itself can semi-actively rotate around its center of shape (which is approximately located on its center of gravity[1]). This combination provides the system three types of locomotion (Fig. 12):

- Continuous movement: *(tracks traveling), suitable for flat grounds*
- Discrete movement: *(triangular frames rotation), for rough terrains*
- Combined movement: *(both tracks and triangular frames action), for ultra-rough terrains*

[1] Since the TTW is not actually a homogeneous body [11], Center of Gravity (CG) of TTW has a little shift from its Center of Shape.

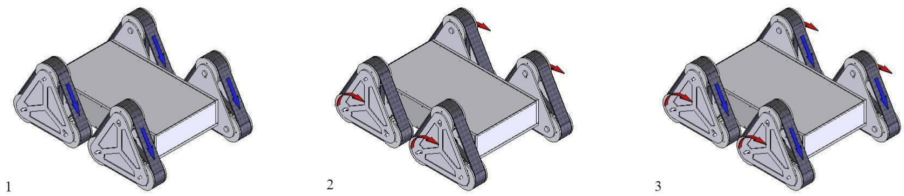

Fig. 12. (1) Continuous, (2) Discrete and (3) Combined locomotion provided by TTW

For optimizing the weight and size of system, each side tracks are driven by just one DC servo motor. Therefore, these tracks (both right tracks and both left ones) are synchronous. There is the same matter behind front and rear triangular frames where the front frames are synchronous, so are the rear ones (Fig. 13).

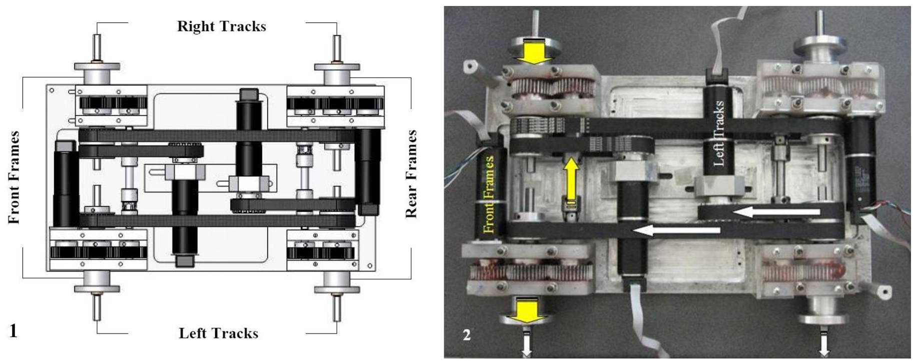

Fig. 13. (1,2) Power transmission system of ARIAN (V1)

To increase the mobility of system without increasing the complexity of its control process, we prepared surface adaptation capability which consists of two different categories (Fig. 14):

- **Lateral Adaptation**

From a kinematical viewpoint, the joint between triangular frames and main body of our robots is semi-active which can be adapted to contact surface passively or be controlled actively. The passive mode is used to mechanically maximize the contact surface in any situation.

- **Axial Adaptation**

Left frames in contrast with right ones at front or rear of the main body may have phase shift up to 20 degrees for decreasing bumping effect. This is a useful feature at uneven environments like step fields where mechanical dampers are not useful because of low velocity of the system [12].

Fig. 14. (1) Lateral and (2) Axial adaptation

One of the characteristics of tracked vehicles is their high friction force which may be advantage or disadvantage depending on situations. For example, it causes their higher traction force, but the efficiency of tracked systems significantly reduces in turning movements as a result of grater contact surface in comparison with wheeled ones. We managed this problem using the active state of semi-active joint between frames and main body. It provides the following configurations (Fig.15):

- Positive configuration *(suitable for ramps)*
- Negative configuration *(horizontal surfaces)*
- Trans configuration *(unknown areas)*

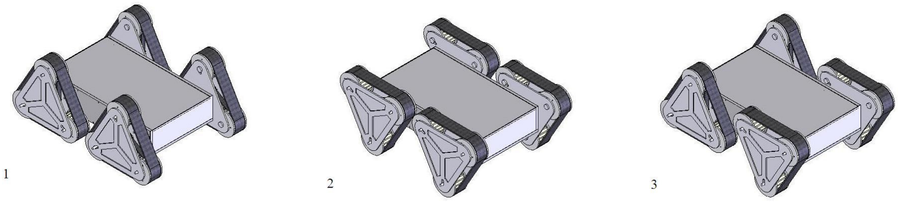

Fig. 15. (1) Positive, (2) Negative and (3) Trans configurations

8.2. Mechanical Specifications

- **ARIAN**

ARIAN uses simple TTW mechanism which was discussed briefly at previous sections. Table 2 and Fig. 16 outline its mechanical specifications.

Table 2. Mechanical specifications of ARIAN

Weight	28 Kg
Nominal power	540 w
Max continuous velocity	1.1 m/s
Max discrete velocity	1.2 m/s
Max velocity	2.3 m/s
Max passed gradient	0.9 (42 deg)
Max payload (at max gradient)	42 Kg

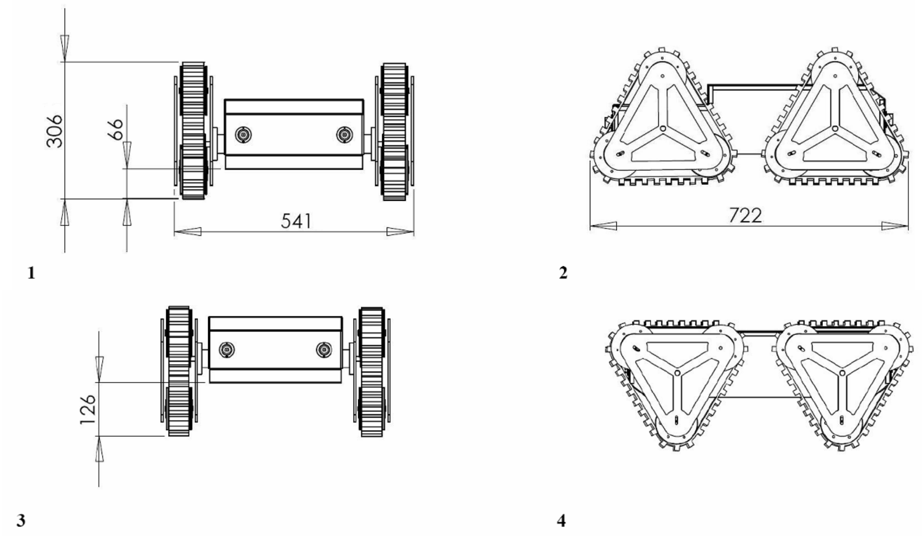

Fig. 16. Dimensions of ARIAN in (1,2) Positive and (3,4) Negative configurations

- **META**

Although META like ARIAN benefits TTW mechanism, it has grate locomotion capabilities in comparison with ARIAN mainly because of its overlapped TTW configuration (Fig. 17).

Fig. 17. (1,2,3) Standing up capability

The followings are mechanical specifications of META:

Table 3. Mechanical features of META

Weight	32 Kg
Nominal power	600 w
Max continuous velocity	1.1 m/s
Max discrete velocity	0.6 m/s
Max velocity	1.7 m/s
Max passed gradient	0.9 (42 deg)
Max payload (at max gradient)	42 Kg

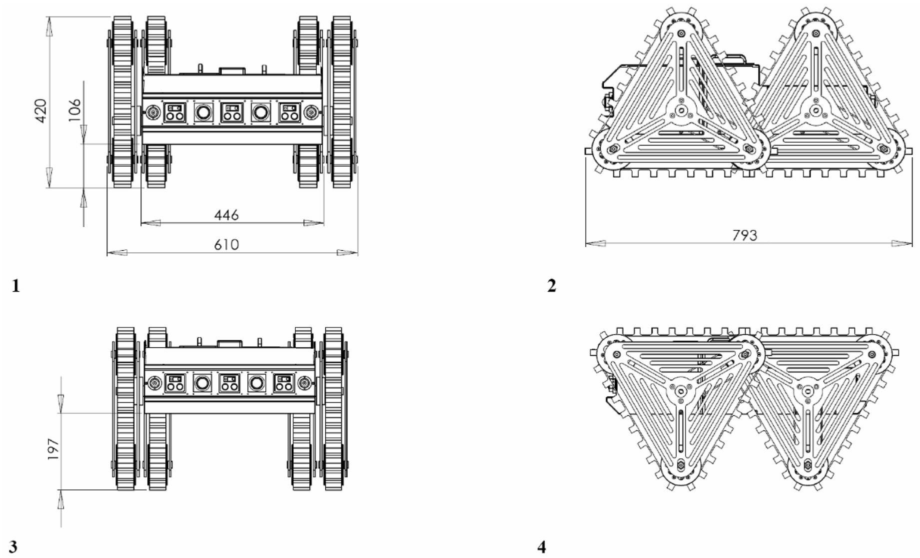

Fig. 18. Dimensions of META in (1,2) Positive and (3,4) Negative configurations

9. Other Mechanisms

- **Manipulator**

As mentioned, we have designed and manufactured a 3DOF manipulator to hold all victim detection sensors (Fig. 19). Its arm actually is a modified four bar linkage which remains elbow perpendicular to the main body. This exceptional feature provides operator the sense of flying over robot. The joints of manipulator are controlled by reliable motor drivers using accurate shaft encoders as well as an IMU located on the top of VDP and its configurations can be pre-stored in software for easy access.

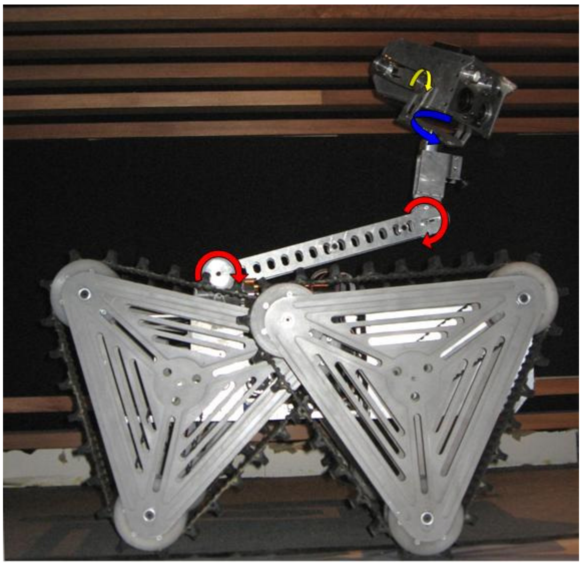

Fig. 19. 3 DOF manipulator on META

10. Team Training for Operation (Human Factors)

As it was mentioned, we have constructed the OCU for developing an intelligent and user friendly HRI system, but still handling our robots is not as straightforward as a car driving. To reach such a valuable goal, we have constructed a test site in our laboratory based on NIST 2005 test arena [13] and we use it to constantly improve HRI quality.

11. Possibility for Practical Application to Real Disaster Site

Iran is one of those countries in the world that is subject to frequent earthquakes, and having a real working rescue robot is of high value for our society. It is a highly motivating goal for us to build such a robot. Although, we've tried to use industry grade standards in our robots, they are not as reliable and cost efficient as rescue dogs yet. We are taking our first steps towards this high goal of rescuing human life.

12. System Cost

Following tables present the approximate cost of our systems.

Table 4. Components of ARIAN

Category	Part Name	Company	QTY	Website
Mechanics	Robot platform	---	1	---
	Gearhead DC motor	Maxon	5	www.maxonmotor.com
	Gearhead DC motor	Buhler	2	www.buehlermotor.com
Control	Motor driver	Maxon	5	www.maxonmotor.com
	Industrial computer	Advantech	1	www.advantech.com
	Video server	Moxa	1	www.moxa.com
Victim detection	Camera (260x)	Zoom	1	www.chaiboon.com
	IR thermometer	Omega	1	www.omega.com
	CO2 sensor	Vaisala	1	www.vaisala.com
	Microphone	---	1	---
Navigation	Camera (wide)	Telecom	1	www.rf-links.com
	IMU	Micro Strain	2	www.microstrain.com
	LRF	Hokuyo	1	www.hokuyo-aut.jp
	Ultrasonic ranger	Devantech	4	www.acroname.com
	IR ranger	Sharp	5	www.acroname.com
Communication	Access point	Proxime	1	www.proxim.com
	Ethernet Switch	DLink	1	www.dlink.com
Other	Battery	Kinetic	12	www.gitabattery.com
	Electronics	---	---	---
		Total Price (US$)		24,600 ±100

Table 5. Components of META

Category	Part Name	Company	QTY	Website
Mechanics	Robot platform	---	1	---
	Gearhead DC motor	Maxon	5	www.maxonmotor.com
	Gearhead DC motor	Buhler	2	www.buehlermotor.com
Control	Motor driver	Maxon	5	www.maxonmotor.com
	Industrial computer	Advantech	1	www.advantech.com
	Video server	Moxa	2	www.moxa.com
Victim detection	Camera (260x)	Zoom	1	www.chaiboon.com
	Thermal Camera	Ann Arbor Sensor sys.	1	www.aas2.com
	CO2 sensor	Vaisala	1	www.vaisala.com
	Microphone	---	1	---

Navigation	Camera (wide)	Telecom	1	www.rf-links.com
	IMU	Micro Strain	2	www.microstrain.com
	LRF	Hokuyo	1	www.hokuyo-aut.jp
	Stereo Vision	Videre	1	www.videredesign.com
	Ultrasonic ranger	Devan-tech	4	www.acroname.com
	IR ranger	Sharp	5	www.acroname.com
Communica-tion	Access point	Proxime	1	www.proxim.com
	Ethernet Switch	DLink	1	www.dlink.com
Other	Battery	Kinetic	12	www.gitabattery.com
	Electronics	---	---	---
		Total price (US$)		65,300 ±100

Table 6. Components of OCU

Category	Part Name	Company	QTY	Website
Hardware	Industrial computer	Advan-tech	1	www.advantech.com
	Touch screen moni-tor	Advan-tech	1	www.advantech.com
	Portable printer	Canon	1	www. canon.com
	Joystick	Logitech	1	www.logitech.com
	Access point	Proxime	1	www.proxim.com
Other	Li-Poly battery	Kinetic	12	www.gitabattery.com
	Electronics	---	---	---
		Total price (US$)		4,200 ±100

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