A Novel Track-Drive Mobile Robotic Framework for Conducting Projects on Robotics and Control Systems

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Abstract: This paper presents a novel robotic framework to help students to practically grasp the concepts of Robotics and Control Systems in a laboratory environment. The framework is centered on a robotic rover having two tank-like tracks which permit locomotion on uneven terrains. The sensory system consists of encoders for position feedback while the actuation system comprises of six precise DC motors. To enhance the learning outcomes of students and to permit readily realizaion of applications, developed software library supports three different command levels. The efficacy of the framework has been demonstrated by presenting a list of projects conducted on the framework. In particular, as a case-study, a project titled tether tracking and control of robotic rover has been detailed in the paper with presentation of experimental results. The pilot study indicated that incorporating the framework in robotics laboratory resulted in an efficient methodology of imparting interdisciplinary knowledge to engineering students. Additionally, the framework finds its potential in research of advanced robotic and control algorithms.

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Keywords: Educational robotic platform; Track-drive robot; Robot control; Robotics project; Tether tracking

1. Introduction

Robots, historically originated from science fiction have totally transformed our society. Today, because of their power, intelligence and capabilities, robots are found in almost every sphere of life. Most of these applications demand a robot to be mobile. The concept of a mobile robot is not just limited to a wheel-based platform working on a uniform surface performing a simple task like line tracking. Technological advancements in Mechatronics made it possible to realize mobile robots having sophisticated locomotion ability to operate on rough and loose terrains accomplishing more complex tasks.

Robotics revolution in 21st century has essentially highlighted the importance of up-to-the-mark engineering curriculum. This, on one side, has emphasized updating the theoretical syllabus while on the other hand, has pressed the need to have flexible and highly-capable mobile robotic frameworks in engineering laboratories. These frameworks, when integrated with traditional theory-oriented lecture courses help the students to bridge the gap between theoretical and practical knowledge. This enhances students' motivation and also maintains their interests in regular laboratory sessions as well as in their final projects.

Scientific literature reports numerous mobile robotic platforms that find potential in educational and academic sectors. Gomez et al. presented an open-source low cost educational framework named as Miniskybot [1] that can be fabricated using a 3D printer. The prototype, made from ABS plastic is actuated with two servos and uses a differential drive mechanism. Another modular and expandable mobile robotics framework for academic use has been designed by researchers at Worcester Polytechnic Institute (WPI) [2]. Equipped with a four-wheel powered drive train, the framework is based on ATMega168 controller and uses optical encoders for feedback. Other examples of mobile robotic frameworks that find potential in academics include CubeSystem [3], Micromouse kit [4], Thymio II [5], Hanover framework [6], Curtin platform [7], Khepera robot [8], Lynxmotion Tri-Track Chassis Kit [9] and virtual platforms from Tel Aviv Univ. [10] and Queensland Univ. [11].

Most of these frameworks are wheel based and suffer from limitations in terms of their locomotion capability over non-uniform terrains. They lack flexibility, scalability or modularity. Also, availability of limited commands or functions in the mentioned frameworks put a constraint on the type of control algorithms and strategies that can be tested based on them.

This paper is structured as follows; Section 2 discusses the novelty and features of the framework.

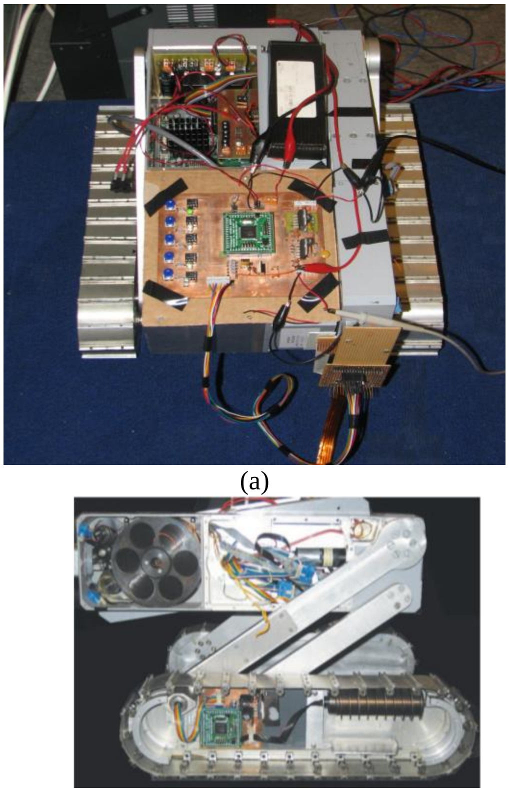
Section 3 mentions in-depth details of the framework while Section 4 lists the projects conducted on the robot with a presentation of a case-study. Results are highlighted in Section 5. Finally Section 6 comments on conclusion and elaborates the potential applications of the framework.

2. Framework Novelty and Features

Looking on the above mentioned literature (Section 1), it is evident that the presented framework is a novel platform having following features:

- Locomotion: Tank-like tracks. The weight distribution is more even and slippage is less as compared to the wheels.
- Basis: Does not exist ‘virtually’. It is a hardware based framework employing a fabricated prototype.
- Design theme: Highly modular and inherently flexible design.
- Applications: For academic, educational and research purpose.

The overall framework consisting of robot mechanics and associated electronics is illustrated in Figure 1 while important features of the robot are listed in Table 1.



(a)

(b)

Figure 1. Framework robot (a) Top view (b) Side view

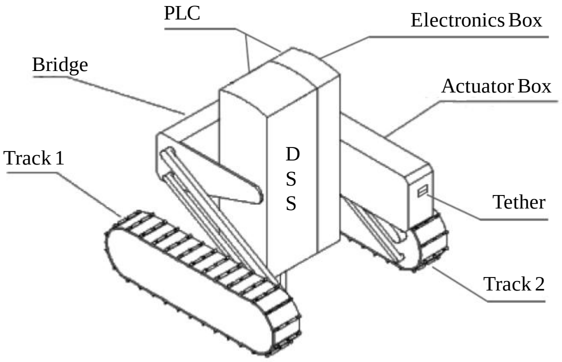
Table1. Framework features

Parameters	Feature	Description
Physical	Locomotion	Tank-like tracks
	Speed	20mm/sec (max.)
Sensing	Position	Motor encoders
	Tether	IR
Actuation	6 DC motors	2 for Traction 2 for Payload Cab 2 for Tether
Modules	Subsystems	Control Locomotion Power Auxiliary Drilling & Sampling

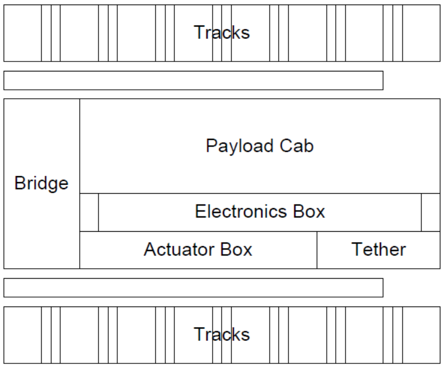
3. Framework Description

The mechanical structure, hardware and software architectures of the framework are detailed below.

Mechanical Structure: The mechanics of the robot has been designed keeping in view structural stability issues. The tracks in the robot look more or less like that of military tanks, but there is also the side covers to protect the motion motors and batteries from dust. Track bodies have been fabricated from steel and Aluminum. The tracks can be moved in different directions and this motion causes the turn of the whole body. The core of the robot is the central PayLoad Cab (PLC) which accommodates the control electronics (see sub-section ‘Control SS’) and the Drilling and Sampling Subsystem (DSS) [12]. The PLC has 2 Degree Of Freedom (DOF) motion i.e. it can be lifted up/down and can be tilted in a rotary position. There are two equipment compartments in the robot. A bridge couples various components of the system. Figure 2a and 2b presents the mechanical structure [13] and block diagram of the robot respectively.



(a)



(b)

Figure 2. Robot (a) Structure (b) Block diagram (top view)

Hardware Architecture: The whole robotic framework can be divided into several SubSystems (SS). Figure 3 illustrates various SS. Main SS include Locomotion, Control and Tether. The Control SS does all the computing and the communication. It also contains all the needed controllers. The Power SS provides energy for the whole framework. The rest of the SS include actuators that are controlled and sensors that give feedback about the current state of the system.

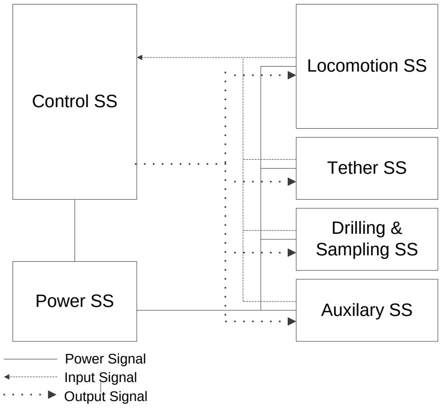


Figure 3. Subsystems of the robot

<u>Locomotion SS</u>: The locomotion SS is responsible for movements of the robot. These include the actual locomotion movements and the articulation of the PLC. To permit the first kind of motion, both tracks of the robot are actuated with independently controlled DC-motors. The actuators with their associated electronics reside inside the tracks as can be seen in Figure 4. For articulation of the PLC, two motors corresponding to its 2 DOF have been used. These include a motor for lifting and another motor for pitching the PLC. Figure 5 illustrates the block diagram of locomotion SS while Table 2 presents the specifications of the motors used in locomotion [14].

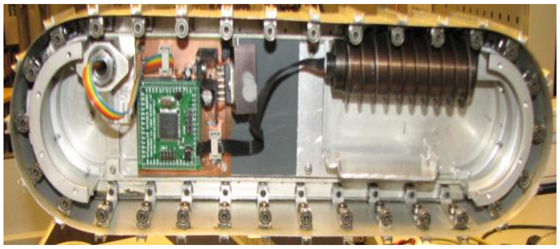


Figure 4. Side view of the robot

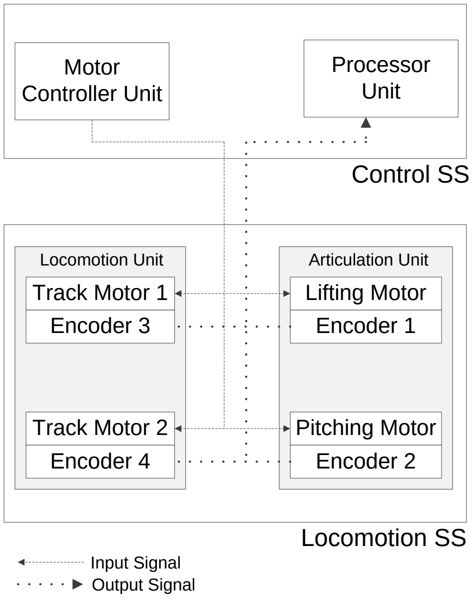


Figure 5. Locomotion SS

Table 2. Locomotion motors specifications

Characteristics	Motor for		
	Traction	PLC lifting	PLC Pitching
Type	Maxon 110164	Maxon 110164	Maxon 110140
Diameter	22mm	22mm	22mm
Brush type	Graphite	Graphite	Precious metal
Power rating	6W	6W	3.5W
No load speed	10500	10500	6520
No load current	23.7mA	23.7mA	4.33mA
Starting current	1100mA	1100mA	411mA
Attached igital encoder	Magnetic 16cpt	Magnetic 16cpt	100cpt
Planetary gearhead	84:1	231:1	53:1

<u>Tether SS</u>: A tether is a cord or a cable that connects a robot to some other robot or to a power/communication unit. The framework robot has a 40m long, 1.5cm wide tether made up of Kapton. The tether has 5 sub-wires in it which can be used to supply power to the robot or for communication or

remote-control purposes. The tether mechanism consists of reel and feed motors for winding and unwinding the tether. Figure 6 shows tether SS while tether motors are featured in Table 3.

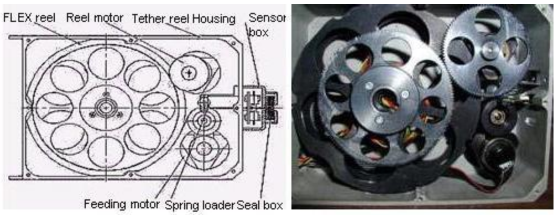


Figure 6. Tether SS

Table 3. Tether motors specifications

Characteristics	Tether Motors
Motor type	Maxon 167170
Motor diameter	20mm
Brush type	Precious metal
Supply voltage	12VDC
Assigned power rating	1.2W
No load speed	12800
Stall torque	72.7mNm
No load current	15.97mA
Starting current	153mA
Ma. continuous current	108mA
Attached encoder	Dig. magnetic 16cpt
Internal gear	55.1:1
Motor control	Variable speed

Control SS: This SS can be considered as the brain or central unit of the robot because it controls all the actions and processes all the input signals. It acts as an interface between the software and the actuators and the sensors. According to these signals, the control SS produces the required low-level functions. The SS is further divided into four separate units, Command and Control Unit (C^3U), motor controller unit, optional encoder signal converting unit and output controller unit. These units are shown in the Figure 7.

C^3U consists of On-Board Computer (OBC), DC-DC converter, PC104 CAN interface card and Distributor circuit. Block diagram of C^3U interfaced with components responsible for the robot mobility is shown in Figure 8. A Pentium III equivalent single board system (Ampro ReadyBoard 710) has been selected as an OBC. It is low cost, high performance and easy to interface system, used for compact embedded applications requiring high performance, high-speed I/O and low power applications.

The communication among various system components of the framework is based on Controller Area Network (CAN) interface. CAN is a broadcast, differential serial bus standard for connecting electronic control units. Overall communication scheme is illustrated in Figure 9.

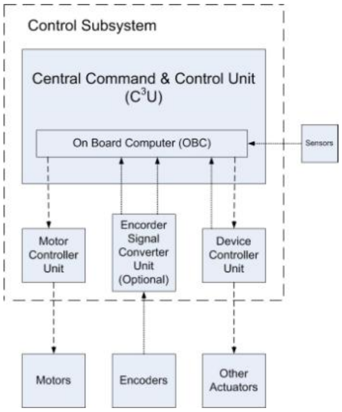


Figure 7. Control SS

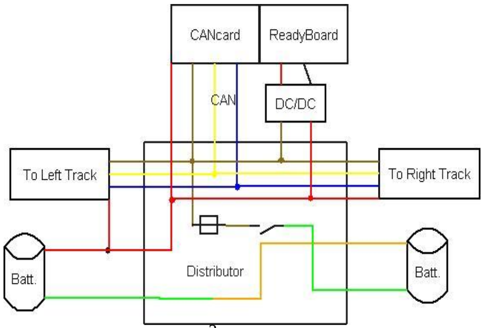


Figure 8. C^3U block diagram

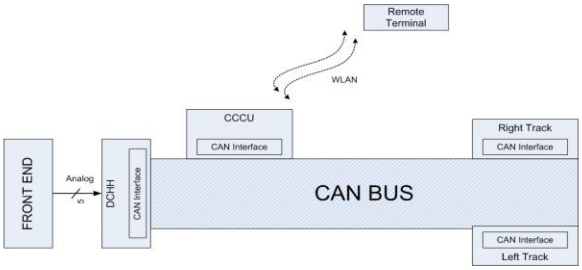


Figure 9. Communication scheme

Software Architecture: To address the requirements of beginner as well as advanced users, the developed commands library supports three different levels of command including:

- High Level Commands: Top level commands have been developed to control the mobility system and tether tracking system. e.g. drive, turn, wind & unwind tether etc
- Medium Level Commands: These commands give more control over the mobility system and tether tracking system. e.g. wind tether by 60 cm.
- Low Level Commands: This level include commands for reading sensor values, setting different parameters like speed, acceleration, raw Pulse Width

Modulation (PWM), Proportional Integral Derivative (PID) values and getting different parameters like speed, ticks, current etc

Figure 10 further elaborates the command levels where Data and Command Handling Hardware (DCHH) is for tracking the tether (Section 4).

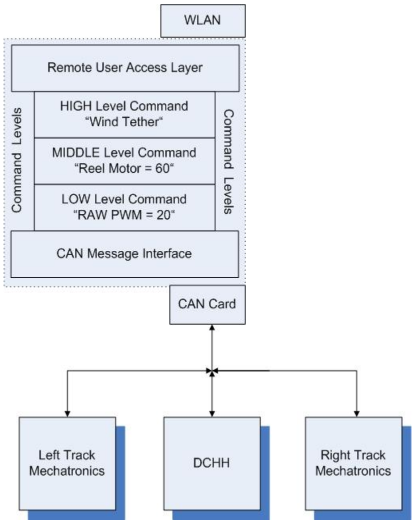


Figure 10. Command level structure

Each message on CAN has been assigned a unique ID. This permits multiple controllers having unique microcontroller IDs (MCID) to operate on the same bus. MCID is then used to derive message IDs for symmetry. For example, motor controllers with IDs of 0x20 and 0x40 receive PWM ratio instructions with message IDs of 0x2E and 0x4E respectively. Thus the last number tells the type of the instruction and the second (and third, when used) tells which motor controller should receive the message. Table 4 lists important message IDs that have been provided to readily use the framework. N is a specific MCID.

Table4. CAN messages in framework

Message	D	Description
STOPALL	x10	Stops all motors, global for all motor controllers
STATUS	x14	Status message from a controller
COMMAND	xN1	Command in data block (START, STOP)
SPEED	xN3	Speed request for the PID controller
GET_SPEED	xN4	Get motors current speed
ENCODER	xN5	Set encoder ticks reading
GET_TICKS	xN6	Get encoder ticks reading
GET_CURRENT	xN7	Get motor current
GET_SENSOR	xN8	Get IR Sensor Values
PID	xNA	Set PID parameters
ACC	xNC	Set acceleration
RAW	xNE	Set raw PWM ratio (PID controller off)
ECHO	xNF	Request echo

4. Projects Conducted on Framework

Exploiting the framework capabilities, numerous Research & Development (R&D) projects have been executed on the developed prototype. The conducted projects are on undergraduate level as well as on graduate level. Table 5 lists graduate final projects conducted on the framework.

Table 5. Projects list

Project	Title	Reference
P1	Tether tracking and control of ROSA robotic rover	[15,16]
P2	Design and implementation of a stereo vision based navigation system for the micro-RoSA-2 Mars rover	[17]
P3	Autonomous navigation system for MRoSA2 with focus on mobility and localization	[18]
P4	Effective localization and tracking utilizing stereo vision for planetary micro-rover ROSA	[19]

The framework having tank-like tracks is an ideal candidate for space exploration projects because of rough and non-uniform terrain there. As a case study, the project P1 is detailed here, which deals with tether control of the robot. This research project finds its motivation in a typical space system (Figure 11) consisting of a lander and a robotic rover. The robot is connected to the lander with a tether that serves the purpose of power delivery and communication. Following its landing on a planetary surface, the lander directs and navigates the robot to the location from where soils samples need to be collected. The robot, after samples collection, returns back to the lander by tracking the tether.

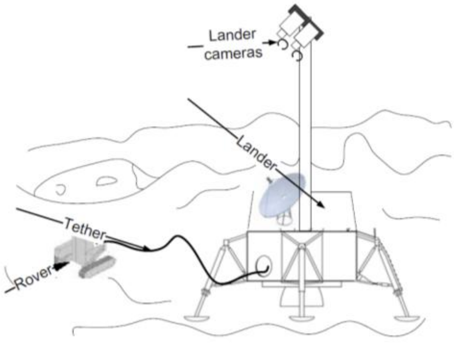


Figure 11. A typical operational scenario for planetary exploration

The proposed tether tracking system for the robot consists of front-end sensors and Data and Control Handling Hardware (DCHH). An array of five IR sensors (HOA2498) detects the position of tether passing beneath it. The analog data from the sensors is then compared with a calibrated threshold to estimate the direction of the tether. The digital output of comparators is then fed to DCHH. DCHH performs the key features of (i) CAN TX/RX interface (ii) Processing of sensor data (iii) Motor control for reel and feed motors. The hardware is comprised of microcontroller, CAN transceiver, regulator, current filtering circuit and motor driver H-Bridge. Based on the comparators output, the microcontroller in DCHH (AT90CAN128) performs two tasks: it directs OBC to move the robot in the direction of tether. Secondly, it directly controls the reel and feed motors through drivers (LMD18200). Figure 12 shows the block diagram of DCHH while the fabricated hardware is illustrated in Figure 13.

Corresponding results of experimental trials on tether tracking are presented in Section 5.

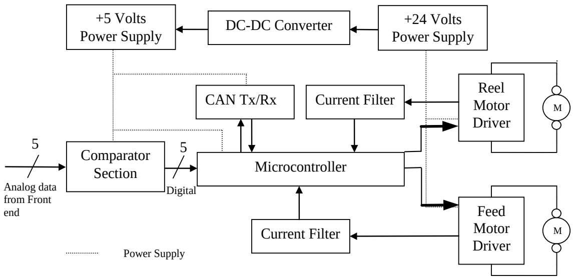


Figure 12. Data and Command Handling Hardware (DCHH) block diagram

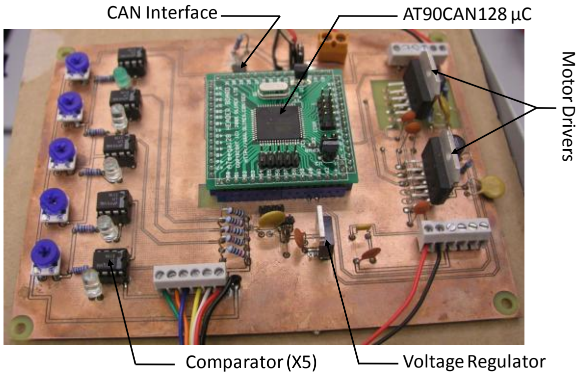


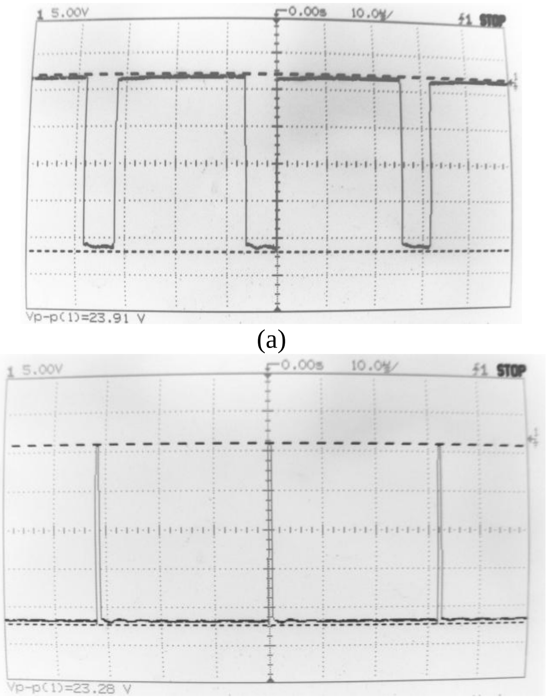
Figure13. DCHH

5. Results

The hardware of both right and left tracks of the framework is symmetrical. Hence results of single (left) track are presented. Figure 14a and b show the results of motor drive signals for PWM inputs of 50 and 250 respectively in an inverted logic. Test results for the framework mobility system have been tabulated in Table 6 where 'Set Speed' is the desired control parameter and 'Get Speed' is the actual data collected from motor encoders.

Results of Tether motors are presented in Figure 15(a) and (b). In the first case, both the reel and feed motors have been subjected to PWM of 100 while in the second case, the PWM of feed motor has been halved. Based on the inverted logic, reducing the PWM increases the duty cycle as illustrated in Figure 15(b). The direction of the motors has been visually observed and polarity of positive and negative PWMs has been confirmed.

Finally, results of the case study presented in Section 4 are aimed at testing the functionality of the tether tracking hardware and to find its accuracy. A wooden carpeted block of 2X1.22 m has been used as a test platform (Figure 16). The tether has been spread in different patterns on the platform. Both sides of the tether track have been taped to indicate the actual position of the tether. The robot is then commanded from the remote terminal to move and follow the tether. A pointer has been attached to the robot to highlight the tracked trajectory.



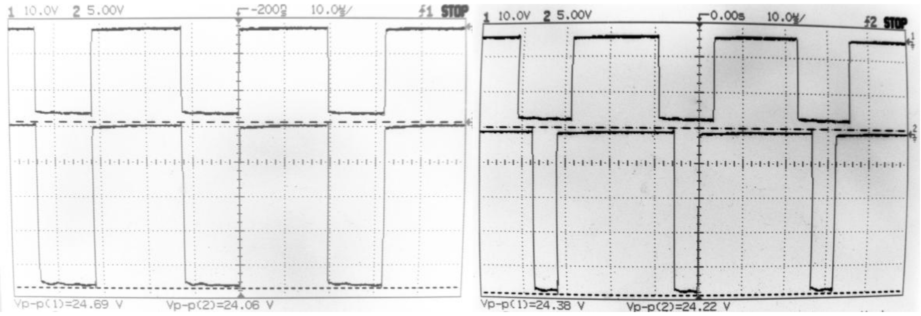
(a)

(b)

Figure 14. Results of left locomotion motor driver when (a) PWM=50 (b) PWM=250

Table 6. Mobility system test results

Direction	Set speed (tps)		Average speed achieved (tps)		Current achieved (mA)	
	Right	Left	Right	Left	Right	Left
Backward	200	200	199	199	73	72
Forward	-200	-200	193	192	75	73
Right	200	-200	206.5	198.5	95	60
Left	-200	200	211.5	202.5	62	92



(a) (b)

Figure 15. Motor driver results when reel motor PWM=100 and (a) Feed motor PWM=100 (b) Feed motor PWM=5

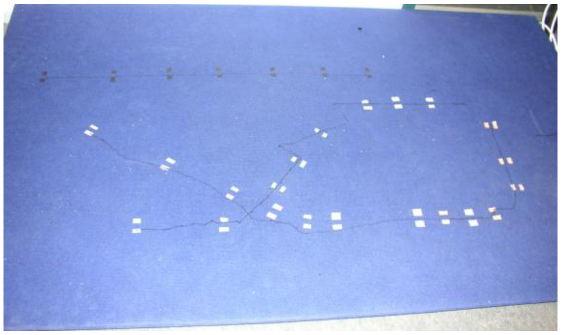
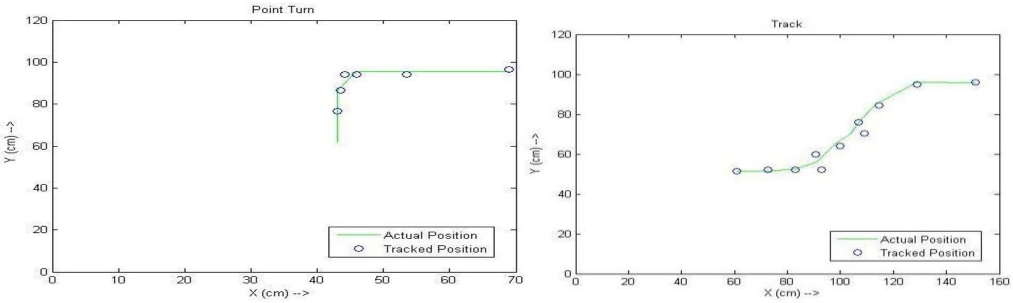


Figure 16. Testing platform



(a) (b)

Figure 17. Tether tracking results in case of a (a) Point turn (b) Track

Tracking results in case of straight positioned tether showed that the robot follows the tether exactly. The straight tether tracking provided an easy way to calibrate the system. Considering trajectories that are more complicated e.g. a point turn and a track, results are presented in Figure 17(a) and (b). The lines show the actual position of the tether whereas circles represent the tracked positions of the robot. These results witnessed that the robot followed the tether even in the vicinity of turn.

6. Conclusion

A robotic framework having tank-like tracks for locomotion has been presented. The framework finds its potential in education, academics, training and research. As a case-study to show the framework capabilities, a Master final thesis conducted using the framework has been detailed. The experimental trials to validate the case study consisted of tracking the tether in various trajectories. Results confirmed that the proposed system has capability to track the tether in close proximity. Some non-linearites have been observed at sharp turns and ends of curve. The tracking resolution is ±6cm. Although implementation of a trivial control algorithm (PID) has been discussed but the framework can be used to realize more sophisticated control strategies like Sliding Mode Control (SMC), Linear Quadratic Regulator (LQR) etc. The presented framework is expected to open avenues of research by implementing and validating advanced algorithms like collision avoidance, trajectory generation, path planning etc.

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