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Tether Tracking and Control of ROSA Robotic Rover

Jamshed Iqbal[1,2]
[1]University of Genova
Italian Institute of Technology
Genova, Italy
jamshed.iqbal@iit.it

Seppo Heikkilä[2], Aarne Halme[2]
[2]Automation Technology Laboratory
Helsinki University of Technology
Espoo, Finland

***Abstract*— Mars is currently the centre of interest for space exploration. Tremendous efforts are still in progress to find clues of existence of life on Mars. Rovers are major sources of information of Mars. This paper focuses on a robotic roving vehicle RObot for Scientific Applications (ROSA) having its initiative of European Space Agency (ESA). ROSA being a tethered rover makes possible to reduce the weight/size of rover because power is delivered through tether. Additionally, tether provides communication lines between the lander and the rover. Tethered robots require complex control system. This paper presents a specialized tracking system for rover's 40 m tether. The proposed system is capable of tether tracking within resolution of ±6 cm. The same strategy can also be used in other tethered robots for rescue, security, underwater, mines hunting and cleaning petroleum tanks after minor modifications.**

***Keywords*— Tether control, robotic vehicle, Mars exploration, ROSA**

I. INTRODUCTION

A tether can be as simple as a rope and as sophisticated as cabling for under-water submersibles which provides air, power and communication links with the surface. In robotics, the word 'tethered robot system' generally has been used for describing mobile robots restricted by power supply and/or data communication cabling [1]. A fundamental tool of tethering for many practical applications is a winch system for reeling in/out the tether. Tethering systems typically consist of the tether and components that stack the tether and winding/unwinding the tether.

Tethers have been used in many areas including ground, under-water and aero-space environments. Over the last decade, mobile robots have demonstrated the ability to operate in severe environments and perform hazardous tasks. A number of these tasks require tethered robot systems. Tethers have been used for helping robot locomotion on steep slopes. Some other recent studies on cable crane robotics, autonomous cable winding and unwinding, space robotics, rope interfaces, casting manipulators and cable driven robots also use tethers to some extent. Although a lot of applications using tether have been encountered but tether manipulation and control has not been much focused in literature.

RObot for Scientific Applications (ROSA) is a tethered robotic rover intended for planetary operations. During operation, the rover ejects from lander, goes to point as guided by lander camera, drills and collects planetary soil samples and finally returns back to the lander following the tether. Figure 1 shows a typical lander-rover scenario. Tether is also depicted in figure.

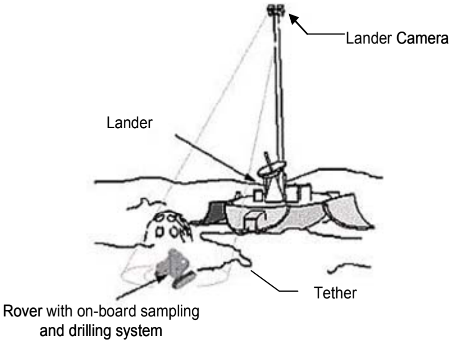

Figure 1. Typical lander-rover system

ROSA has two tracks, which make it capable of operating in difficult terrains. The tracks are actuated with independently controlled DC-motors. The actuators with corresponding equipment are located inside the tracks. Figure 2 shows overview of these details. The whole system has been divided into several subsystems (SS). Main subsystems include locomotion SS, tether SS, control SS, power SS, auxiliary SS and processor unit. The payload part of the rover can be tilted full 360 degrees in order to allow the drilling in all angles [2].

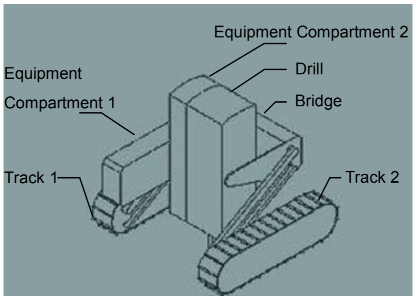

Figure 2. ROSA

II. ROSA TETHER

Selection of tether parameters is very critical for proper operation of tether subsystem. The length of the tether cables should be sufficient to cover the minimum total accumulated travel distance. The selection of the cable was made according to the wide operating temperature range (from -73°C to 260°C) of the Kapton [3]. Also the very thin structure was considered

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as an advantage when making the selection. Especially when rewinding the tether, flat structure of the Kapton is very practical. The tether has five circuits in it: two for the power supply and three for the serial link. A slip ring is used as a rotating joint between the reel and the body of the payload cab. Table I summarizes typical characteristics of ROSA tether.

TABLE I. TETHER CHARACTERSTICS

Feature	Description
Length	40 m
Width	1.5 cm
Material	Kapton
Color	Yellowish Orange
Composition	5 sub wires

III. TETHER SUBSYSTEM

The main computer is controlling tether reel with two small motors: reel motor and feed motor. Both of these motors are Maxon 1.2-W DC gear motors with precious metal brushes. The feed motor is used to control the rewinding and unwinding speed of the tether. The reel motor has two operational modes. When unwinding the tether, the reel motor operates as an electrical spring and provides a constant resistance to keep the tether tensioned. When rewinding the reel motor operates with full power to rewind the tether as tight as possible. Figure 3 shows tether subsystem.

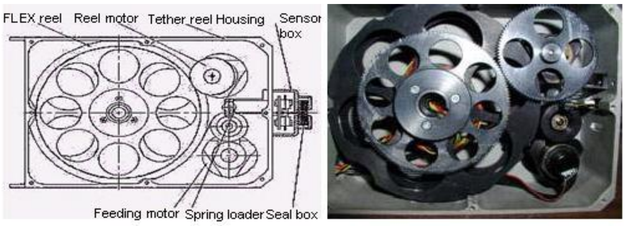


Figure 3. ROSA tether subsystem

IV. TETHER TRACKING SENSOR

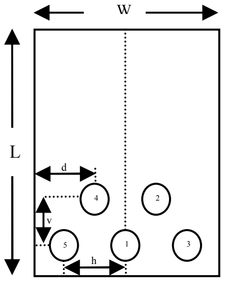
Tether can be tracked by systems based on proximity sensors or tactile sensors. Moreover vision based imaging system based on the camera can also be used by a robot to follow the tether. Hence possible candidate strategies could be based on vision, ultrasound, IR or whiskers. Ultrasonic sensor has not been used because of low pressure on Mars surface. Operation and performance of whisker is highly dependent on mounting of sensor relative to object under detection. In ROSA, the object under detection (tether) is highly flexible. It can bend at any angle from any position in front of rover. Secondly, the width and thickness of tether is significantly small, so it made tether tracking cumbersome by direct mechanical contact using whiskers. Because of these factors and geometrical dimensional considerations, the idea of using whisker sensors for tracking ROSA tether was no more considered. Vision based system imposes high processing requirements for micro-rover and need for an onboard camera. IR sensors are quite simple and robust but they suffer with the interference from ambient light. This is the key problem in IR sensor operation. Secondly, IR sensor works perfectly and gives best results if the reflected surface is either black (perfect absorber) or white (perfect reflector). These challenges need to be addressed while developing a system based on these sensors. Though challenging but IR sensor has been considered as suitable option for tether tracking in ROSA.

V. TETHER TRACKING SYSTEM

Tether tracking system consists of front-end sensing system, Data & Control Handling Hardware (DCHH) and Central Command & Control Hardware (CCCH).

A. Front-end Sensing System:

A black coloured two-fold prototype assembly has been designed for tracking the tether tracking. The upper fold has five holes on it corresponding to five IR sensors. The lower fold is just a flat piece. Tether is passed through this assembly. The thickness of sensor assembly is 2 mm. This allows the freely winding and unwinding of tether inside the assembly. Figure 4 shows front-end assembly.



Symbol	Description (cm)
L	5.7
W	6.0
h	1.8
v	1.3
d	1.7
Hole Dia	0.8

Figure 4. Front end mechanics

The assembly is mounted perpendicular to tether-rover joint point. At this point, sensors in sensor assembly electronics are looking through the holes to see which sensor(s) detect presence of tether beneath them. This information of sensors status is then fed to the Data & Control Handling Hardware (DCHH).

B. Data & Control Handling Hardware (DCHH)

DCHH is the core hardware of tether tracking system. It provides real time control over tether motors, signal processing & analog to digital conversion of sensor data from front-end. The motor controller is based on Atmel AT90CAN128. Block diagram of DCHH is shown in figure 5.

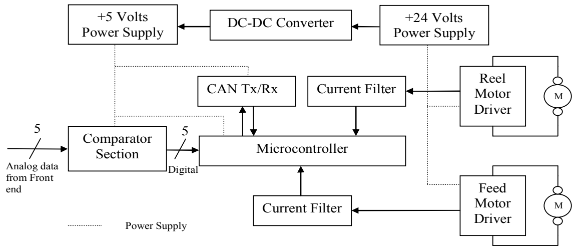


Figure 5. DCHH block diagram

C. Central Command & Control Unit (C^3U)

C^3U is main hardware of ROSA. It consists of On-Board Computer (OBC), PC104 CAN interface card, DC-DC converter, and distributor circuit. A Pentium III equivalent single board system (Ampro ReadyBoard 710) has been selected as an OBC. It is high performance, low cost and easy interface system, used for high volume, compact embedded applications that need high performance, high-speed I/O and low power applications. Block diagram of C^{3}U is shown in figure 6 whereas overall communication architecture is presented in figure 7.

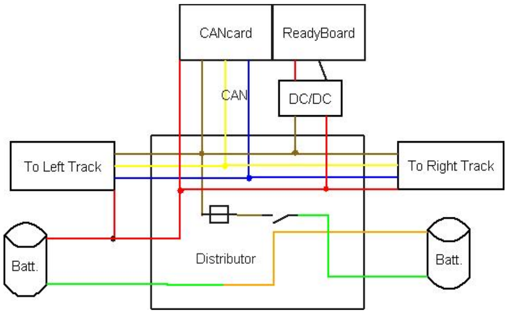


Figure 6. C^{3}U block diagram

Remote terminal simulates ground station. WLAN connection has been set up for communication between remote work station and C^{3}U. Except for front-end hardware, communication between all other entities in the system is done using CAN protocol.

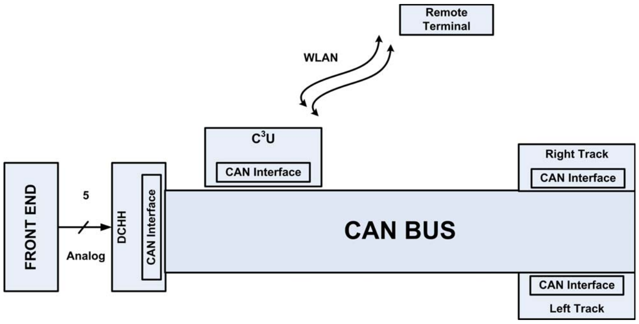


Figure 7. Communication architecture

Messages on CAN are identified by assigning unique ID to each message. The idea is that when using multiple motor controllers on the same bus, only the root microcontroller ID (MCID) has to be changed for each controller. Message IDs are then derived from the MCID to preserve symmetry.

VI. SOFTWARE

Tether tracking software has been developed by keeping existing wheel motor control software as an example. The software on C^{3}U has been organized in well defined structure. After initialization, device is first opened followed by CAN reset. The control has possibility to exit if either of these steps is not successful. The control then prompts for one of three MCIDs. Finally it prompts for number/alphabet corresponding to low level command. These options are summarized in table II.

TABLE II. USER INTERFACE

Option	Description
1	Set Speed
2	Get Speed
3	Get Current
4	Get Ticks
5	Set Acceleration
6	Set PWM
s	Get Sensors Status
q	Quit

Figure 8 shows flow chart of software. All the ‘Get’ commands are combined. Similarly all the ‘Set’ commands are shown as one branch for simplicity although all of these commands have unique message IDs.

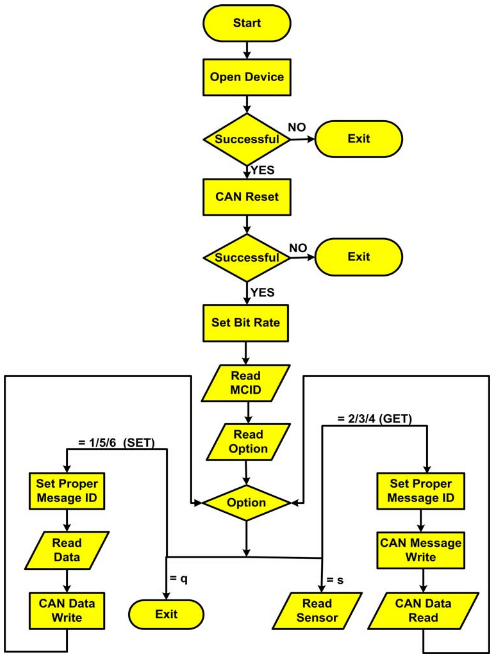


Figure 8. Structure of C^{3}U code

After the initialization, the microcontroller starts an infinite main loop. This loop only checks if there are any new messages in the message buffer and handles the message specific requests. All the other actions are executed by interrupts. Signal flow diagram of microcontroller code is shown in figure 9.

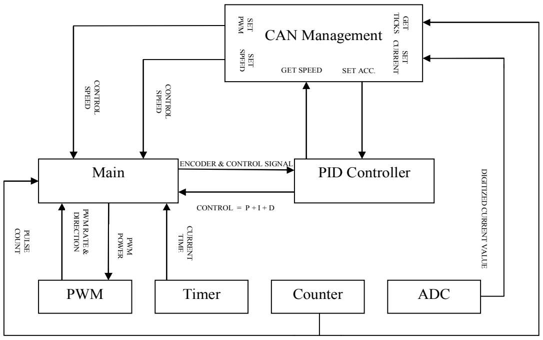


Figure 9. Signal flow diagram of microcontroller code

When microcontroller gets these low level commands from C^{3}U via CAN, it needs to activate proper software sections to execute command. These software sections include timer, counter, ADC, PWM, CAN management and PID controller etc. Motors can be commanded by two options: Raw PWM values or by setting PID controller parameters.

VII. TESTING AND RESULTS

During final testing phase, tether has been spread in different patterns on test platform. A wooden carpeted block has been used as test platform. The rover is then commanded from ground station to move and follow the tether. Figure 10 shows ROSA during testing phase.

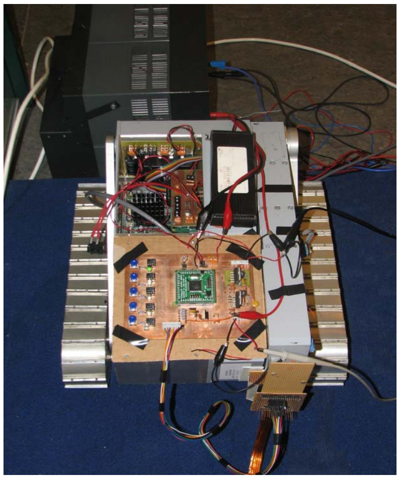
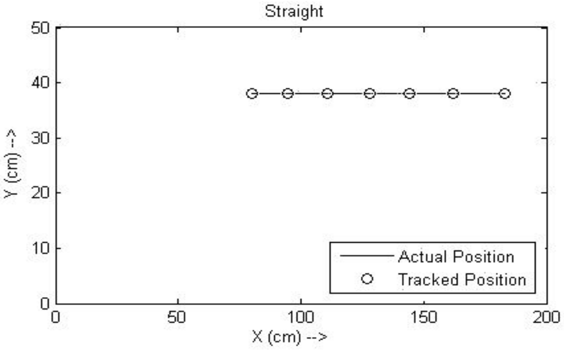
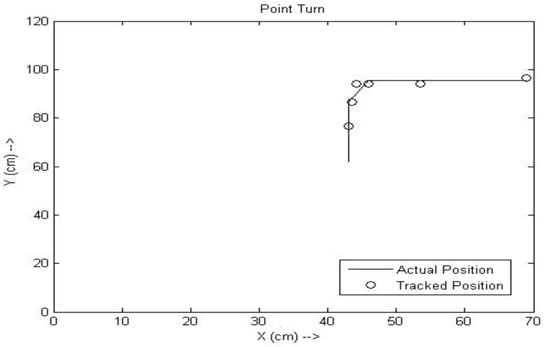


Figure 10. ROSA during testing

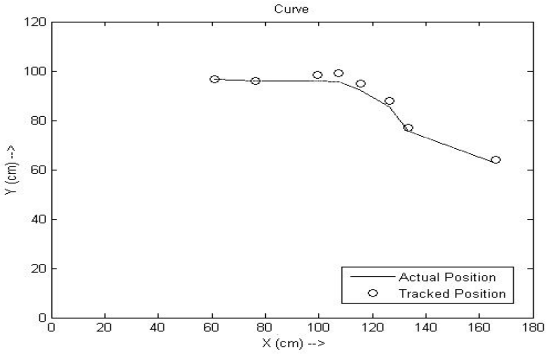
Preliminary results of tether tracking system are presented in figure 11. Lines show actual position of tether whereas circles represent tracked positions of rover. Results of straight tether tracking system show that the rover follows straight path exactly. This was quite an obvious outcome. The straight tether tracking provided an easy way to calibrate the system. Results of point turn and curve show that there are errors associated with tracked line especially in the vicinity of turn. The differences between actual and tracked paths increase if the track has continuous turns. The system automatically evaluates the position of tether and follows it to reduce error until rover reaches finally to the lander.



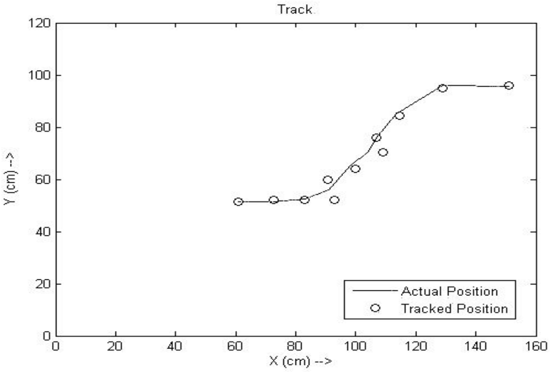
(a) Straight



(b) Point turn



(c) Curve



(d) Track

Figure 11. Results

VIII. CONCLUSION

The presented work is a basis for future research in tethered based robotic vehicles. A concept of tether control system has been proposed. To realize the concept practically, the system has been then developed keeping in view constraints on Mars. Preliminary tests clearly show that the developed system is capable of tracking the tether within resolution of ±6 cm. Because of tether flexibility and low speed of ROSA, this resolution is quite enough for mission achievement. To further increase accuracy of proposed system, the tether tension measurement sensor can be installed at tether-rover join point. This can be simply done by incorporating a force/pressure sensor. The next step is to develop algorithms which eliminate probability of tether entanglement. Considering planetary environment, this entanglement can result from obstacles like rocks or a huge block of soil possibility resulted from storm. Secondly, intelligent path planning is very important in case of tethered rovers because improper path planning might lead to a situation where tether is entangled. The proposed system can be used in wide variety of tethered robotic applications ranging from underwater to space with slight modifications depending upon application scenerio.

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