Distributed Control System for Rover Prototype

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Abstract- **For interplanetary exploration, Rovers are required. This project involves building one such rover with 'Walk and Roll' capability. The first generation of Walk and Roll Rover has wheel on limbed being developed to implement effective control system. This rover has total 12 DoF to be controlled in real-time and needs to deal with information of multiple sensors such as encoders and hall sensors. This vehicle concept is capable of efficient rolling mobility on moderate terrain.**

Index Terms- **Rover, Distributed control, multi-axis control.**

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1. INTRODUCTION

ISRO want to make six limbed walk and roll rover. It has better mobility than conventional wheeled rover. Minimum three legs are required to stand on wheel. So three limbed rover is designed. Many rovers for planetary exploration such as Sojourner, MER, Curiosity have been developed.

A rover generally has multi degree of freedom to be servo actuated and should

Deal with information from multiple sensors, which require quick computing capabilities. Control system must be compact and light so the overall mass of rover become reduces and can place in spacecraft [1]. Therefore the performance and architecture of control system designed for the Rover are crucial problems.

The walk and roll rover is capable of moving rapidly and efficiently over rolling terrain at speed of at least 10 km/h, that is 100 times faster than wheel rover.

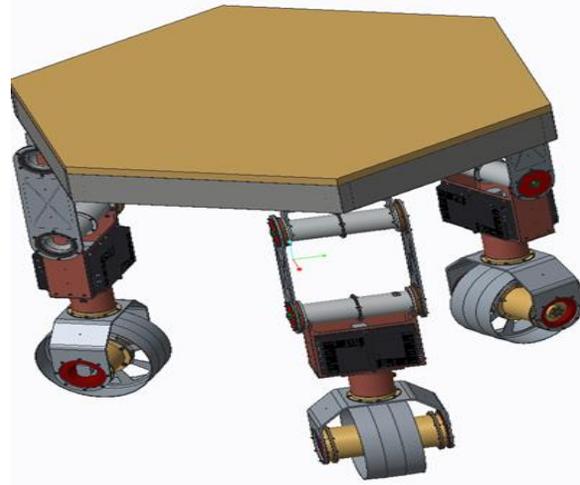This robotic vehicle uses wheels on legs to accommodate wide range of terrain.

Figure 1: Three Limbed Rover

2. OVERVIEW

Three limbed with three degree of freedom vehicle as shown in fig 1 comprise a robotic network that is highly modular and reusable, providing substantial margins, redundancy and configurability. This vehicle was built from commercial-grade components that have analogs that can be flight qualified for the planet environment. Rover has a flexible platform designed to serve multiple roles like transportation and exploration. It is intended to be remotely operated by user. First version of Walk and a Roll Rover made by ISRO has three legs attached to a hexagonal chassis at equidistance. Each leg of Rover has pitch joint, pitch joint, ankle joint from top respectively, resulting in 12 degrees of kinematic freedom. At the end of each leg is a multi-purpose wheel. Operators use laptops to monitor and control Rover. Each joint of rover made up of BLDC motor attached with Incremental encoder and planetary gear. Holding brake is attached with each joint.

This vehicle is able to climb over vertical steps with a height of 50% to 70% of the staved length of the vehicle. The main advantage of the wheel-on-leg configuration for high mobility is that, unlike a conventional vehicle, it does not require thrust from some wheels to generate the traction needed by other wheels to climb obstacles. Instead, each wheel can be lifted by its leg and set on or over an obstacle, like a foot.

The major parts of Walk and Roll rover are three Wheel-on-Leg assemblies which include distributed sensing, computation, and control electronics, a hexagonal frame, and a power generation and storage system.

Each wheel drive actuator needs a very powerful motor to sustain the 10-km/h speed required for acceptable real-time collaboration with astronauts. Each wheel of the Rover breadboard vehicles is equipped with a -1.9 horsepower motor, delivering 1755 N peak rim thrust (527 N continuous) at 10 km/h rim speed. The brakes on each wheel are sized for the worst case thrust loads. The static stability will continuously be monitored to prevent overturning the rover. At higher speeds dynamic stability will need to be evaluated as well [3]. Distributed motor control is used on Rover. This stems from the need to be architecturally-similar to future flight systems, which are expected to be based on a flight motor control module that will survive the extreme thermal environment of planetary missions. By distributing the controllers out to each motor, only power and serial data busses need to be routed out the legs. This avoids the very heavy and complex wiring harness containing thousands of wire. The main problem with using centralized motor control is the extreme risk of intermittent failure in the complex wiring harness late in system integration before launch [2]. If an intermittent fault is discovered late in the integration process, it is essentially infeasible to de-integrate a harness with thousands of wires from the vehicle, re-integrate a spare harness, and adequately validate full functionality in a short time. In the flight version, dual-redundant power and serial data buses interconnect the flight-like motor controllers, so that no single fault can disable the system. Each leg would have such redundant buses.

The hexagonal frame provides the attachment points for the leg assemblies. The batteries are mounted to this frame, as are the docking adaptors for each face of the hexagon. The electronics that controls Rover are also mounted on the inside of the frame. In the flight system, the electronics will be packaged inside multilayer insulation and will use low thermal conductivity titanium mechanical supports that allow the battery/electronic module to stay warm at night or while in shadow with very little heating power.

The power system for the Earth test bed vehicles consists of three 120VAC 13A circuits. In the lab these are supplied by wall plugs and extension cords. One of the 120VAC circuits supplies all the commercial computer and related equipment via conventional outlet strips. The other two 120VAC circuits operate current-limited power supplies that supply 12VDC, 24VDC, and 48VDC. In particular, the 48VDC power supplies charge a string of modern high performance lead-acid batteries to supply power surges as possibly needed by the wheel or leg motors.

3. OBJECTIVES

Develop and demonstrate the ATHLETE vehicle, showing power-efficient rolling mobility and walking on extreme terrain.

4. APPROACH AND METHODOLOGY

Rover mechanical system
The Rover vehicle, shown in Figure 1, consists of three identical, three degree of freedom limbs. Attached to the end of each limb is a wheel which can be used for mobility in the form of driving over benign terrain. The rover body is shaped as a hexagon, giving six flat faces that can be used to dock to similar rover vehicles. Each of these mechanical subsystems is discussed in the following sections. The limbs of the rover vehicle consist of three degrees of freedom giving them the ability to be used as both structural links between the wheels and the frame as well as general purpose manipulators. Each of the limbs are identical and are composed of the Hip Pitch, Knee Pitch and Ankle Roll joints as illustrated in Figure 2. At the end of each limb is a powered wheel which is used either for driving or for actuating tools during manipulation tasks.

The center of the hexagon is left open to provide access for the limbs to manipulate payloads on the top deck by moving the limbs through the center of

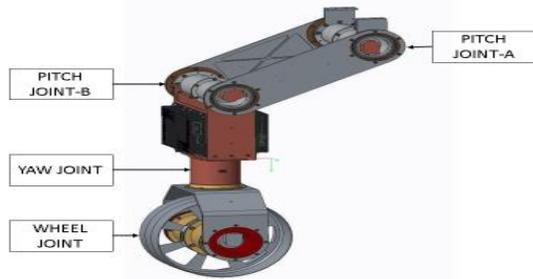the hex frame. Attached to two of the interior faces are battery housings.

Figure 2: Single limb of Rover

Attached to a third interior face is the main CPU for the vehicle. The flat exterior faces of the frame are used for docking of multiple vehicles together.

Rover electronics

The rover Software Development Models are controlled by a commercial Central Processing Units (CPUs). These processors operate on a compact PCI bus using a commercial enclosure having a redundant power supply. An RS-422 serial interface is used to communicate with distributed motor controllers.

The servo control boards were selected based on their functional similarity to an extreme environment motor controller that will allow the motor controllers to be placed on the extremities of rover vehicle with little or no thermal protection. All motors are brushless, so as to be similar to any flight system. A small custom printed-wiring board was developed for motor support (analog I/0, brake control, etc.)

An 802.11 A/G wireless access point/ client allow commands and data to be exchanged with a control station implemented in a bus (used for field operations). Power supplies include 480W 12V logic supply, 800W 24V brake supplies, and multiple 500W 48V primary motor bus supplies. The 48V supplies charge a stack of sealed lead-acid batteries. Batteries voltage and temperature are continuously monitored.

Rover Software

The rover software runs on PowerPC processors. It is used as the main system CPU, handling most aspects of the system, including system control and mobility. In order to support a future transition to flight, the software was designed on the model of a real flight system. This model includes breaking the software

into modules, where the modules handle such areas as system initialization, timer services, commands, telemetry, motor control, higher-level mobility, and navigation. Modules are themselves broken into "objects," each of which encapsulates a very limited area of responsibility. Objects are implemented as hierarchical state machines, are loosely coupled, and communicate with each other using asynchronous messages to request services and deliver data [4]. The rover design uses a C++ base class from which all actual objects inherit. The base class binds together a state machine and a message queue. Multiple objects can share the same queue, allowing them to run in the same task context [5]. Support software outside any object reads the queue and dispatches messages to the appropriate objects for processing.

Motion control software

The current command set for initiating vehicle motion consists of four different classes of commands: joint-space, Cartesian motion of one or more legs, Cartesian motion of the body keeping the wheels planted, and driving maneuvers. Joint-space commanding allows an arbitrary set of joints to be run to prescribed angles - either relative to current joint angles, or to absolute angles. Motion is coordinated in that all specified motors are started simultaneously, with their peak velocities scaled so that goal angles are nominally reached simultaneously. A fault on any motor in the set halts all motors in the set. It is interesting to note that it would be rare for a single failed motor to disable the vehicle because of the large degree of redundancy in the system design. In the unlikely event that an actuator fails in a pose that disables the vehicle, adjacent limbs can make us of tools to amputate the failed limb.

Cartesian commands for moving the legs specify a goal position and orientation for the wheel fork of each leg to be moved. Position and orientation are linearly interpolated at intermediate via points, to give straight-line translation and smooth re-orientation. Motion from one via point to the next is done in joint-space, and advancement to the next goal via point is done when all joints angles are sufficiently close to the current goal. The tolerances are set to allow advancement while the legs are still moving, to avoid stopping at each intermediate position. If multiple legs are moved in the same

command, their motions are coordinated to start and nominally end at the same time (even if one leg is to physically translate more than another). The entire trajectory is pre computed before any motion is done, and motion is not started if any part of the trajectory is unreachable [7].

Cartesian commands for the body allow a new body position and orientation to be specified. Intermediate via points are computed to allow the body to translate in a straight line and change orientation smoothly. The positions and orientations of each wheel fork is computed at these via points, to remain fixed in the global frame [6]. One application would be doing fine body repositioning when docking two vehicles on rough terrain.

Currently, driving commands are implemented as standard 2D Ackerman driving primitives for all-wheel steered vehicles. This means the vehicle can drive along arbitrary circular arcs - about any pivot point. Ankle roll actuators are used for steering, and wheel speeds are scaled according to the turn radius at each wheel (wheels on the outside of a turn must spin faster than those on the inside of a turn). Straight-line driving and turn-in-place are special cases of the arbitrary circular arc primitive.

5.SUMMARY AND CONCLUSION

This paper describes the rover vehicle prototype concept and the details of fully-operational Software Development Models. This vehicle concept is capable of efficient rolling mobility on moderate terrain. This rover vehicle is designed with smaller wheels and wheel drive actuators than would be used in a conventional vehicle.

REFERENCE

[1] Brian H. Wilcox, "ATHLETE: A Mobility and Manipulation System for the Moon", Aerospace Conference 2007 IEEE, pp. 1-10, 2007, ISSN 1095-323X.

[2] Brian H. Wilcox, "ATHLETE: A cargo-handling vehicle for solar system exploration", Aerospace Conference 2011 IEEE, pp. 1-8, 2011, ISSN 1095-323X.

[3] Brian H. Wilcox, "ATHLETE: A limbed vehicle for solar system exploration", Aerospace Conference 2012 IEEE, pp. 1-9, 2012, ISSN 1095-323X.

[4] A. Scott Howe, Brian Wilcox, "Outpost assembly using the ATHLETE mobility system", Aerospace Conference 2016 IEEE, pp. 1-9, 2016.

[5] Torres, R.J.; Allan, M.; Hirsh, R.; Wallick, M.N.; "RAPID: Collaboration results from three NASA centers in commanding/monitoring lunar assets", Aerospace conference, 10.1109/AERO.2009.4839635, 2009

[6] B. Wilcox, "ATHLETE: An Option for Mobile Lunar Landers", proc. IEEE Aerospace Conference, March 7, 2008.

[7] T. B. Simth, D. Chavez-Clemente, "A Practical Comparison of Motion Planning Technique for Robotic Legs in Environments with Obstacles", Proceedings of the Third IEEE International Conference on Space Mission Challenges for Information Technology-Volume 00, pp. 155-162, 2009