Strāta: a Ground Robot for Rough Terrain

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Background and Motivation

- Ground robots commonly used in autonomous exploration of extraterrestrial or unknown environments
  - Typical rover designs have trouble climbing vertical steps
  - Robots designed specifically to climb are complex, expensive, and impractical for most applications

(a) NASA's Curiosity

(b) Stair Climbing Robot

- Sensitive instruments often need to be transported while traversing difficult terrain
  - Few robots have active stabilization systems implemented to counteract the effect of the environment
- We propose a low-cost system that implements a passive suspension system for driving over rough terrain and an active stabilized platform for protecting its payload
  - Optimized rocker-bogie wheelbase with six driven wheels for climbing over large obstacles
  - Actively stabilized platform for reducing forces on the payload
  - Autonomous control of robot using position and orientation data from indoor motion capture system
  - Autonomous navigation using path planning algorithms and depth measurements of the surrounding environment

Platform

- A 6DoF Fixed Rotary Stewart Platform was designed
- The kinematics and dynamics of the system were tested using MATLAB and the Simscape Multibody plugin
- High torque metal gear hobby servos were used to provide adequate force and a fast response time for quickly overcoming disturbances
- All mounts, brackets, and arms were 3D printed using PLA plastic; steel ball joints were used for smooth actuation of joints

(a) Platform Render

(b) Constructed Platform

- A 9-axis inertial measurement unit (IMU) mounted on the actuated platform provides orientation and acceleration data for control

Platfrom Control

- Nonlinear control law accounts for platform orientation, translation, and acceleration:

$$x_n(t) = A_n \sin(\alpha(t)) + B_n \sin(\beta(t)) + C_n \sin(\gamma(t)) + D_n x(t) + E_n y(t) + F_n z(t)$$

$$d\theta_n(t) = x_n(t) + G_0 \int_0^\infty \zeta(t)\, x_n(t)\, dt + H\ddot{x}_n(t)$$

$$\theta_n(t) = \theta_n(t - t_o) + d\theta_n(t)\Delta t$$

- Simscape Multibody simulation with implemented controller
  - Platform base was subjected to rolling and pitching in a Lissajous motion with maximum inclinations of 20°
  - The controller was instructed to maintain a platform roll and pitch of 0° while minimizing yaw and translational motions

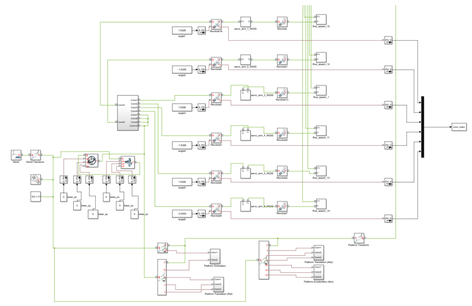
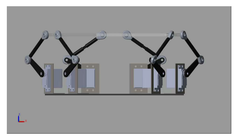
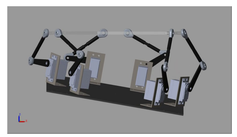


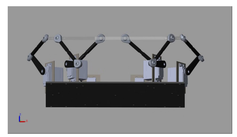
Figure: Simulink Model for Platform



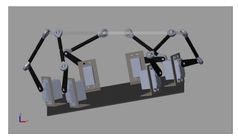
(a) 0 sec



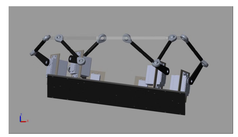
(b) 5 sec



(c) 10 sec



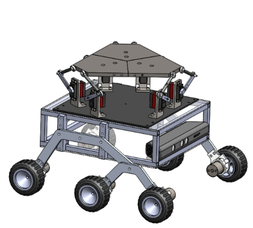
(d) 15 sec



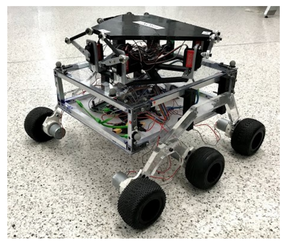
(e) 20 sec

Robot

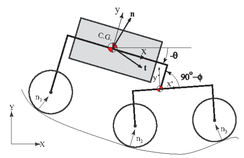
- NVIDIA Jetson TX2 embedded GPU runs all control and path planning algorithms
- Servo and motor commands sent over hardware serial ports to Arduino Megas
- Modular design allows for simple system alterations
- Lightweight yet durable aluminum structure
- 3D printed components reduce manufacturing time and allow for rapid testing of prototypes
- Six-wheeled Rocker-Bogie system allows for climbing a greater step size



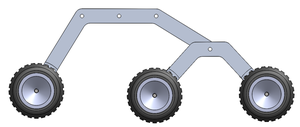
(a) Robot Render



(b) Constructed Robot



(a) Rocker-Bogie Geometry



(b) Wheelbase Render

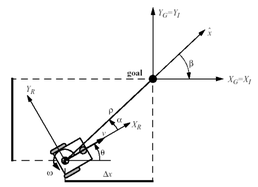
Robot Control

- Differential drive robot model assumed for simplicity
- Using geometric relationships between the robot's position and orientation and the goal, a control law can be developed:

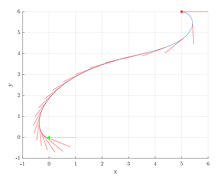
$$\rho = \sqrt{\Delta x^2 + \Delta y^2}\ ,\ \alpha = -\theta + \operatorname{atan2}(\Delta y, \Delta x)\ ,\ \beta = -\theta - \alpha + \theta_g$$

$$v = k_\rho \rho\ ,\ \omega = k_\alpha \alpha + k_\beta \beta$$

- Able to control robot to drive to desired position and orientation in global coordinates or to a series of way-points to follow a more complex trajectory



(a) Differential Drive Robot



(b) Controller Simulation

- Tuning the controller gains (k_ρ, k_α, and k_β) varies the shape of the robot's trajectory

Autonomous Navigation

- Path planning system uses depth and localization data to navigate around obstacles towards its goal

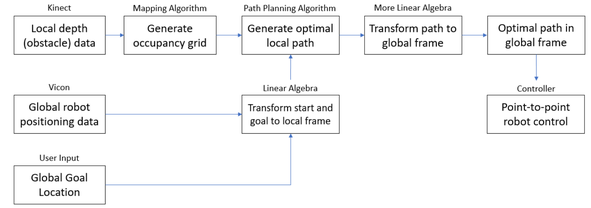


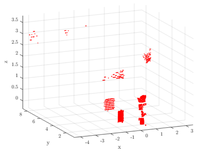
Figure: Navigation System Block Diagram

- Vicon motion capture system provides data on robot's global position
- Microsoft Kinect provides local data on obstacle locations using a 3D point cloud of the surrounding environment
- Point cloud data converted to 2D occupancy grid based on obstacle characteristics (height, gradient, etc.)
- Dijkstra's algorithm calculates minimum cost path to goal in the local frame and is transformed into global frame for point-to-point navigation

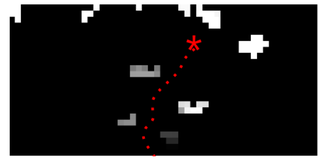
Experimental Results and Conclusion

- Incline test

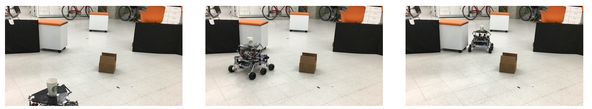
- Obstacle avoidance test



(a) Point Cloud Data



(b) Occupancy Grid & Trajectory



- Was able to successfully traverse through and over obstacles while protecting a payload on the platform
- Designed autonomous navigation, control, and obstacle avoidance system that significantly exceeds project requirement scope
- Project exceeded all customer design requirements and was overall a great success