CRITICAL NATIONAL NEED IDEA

Coordinated Agile High-velocity Vehicle (CAHV)

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Current Approach and Limitations
Currently deployed ground robots move relatively slowly, particularly on challenging terrain. They have very limited articulation capabilities in the mobility platform, and use standard wheeled or tracked

locomotion modes. Essentially, they are limited to statically stable operating modes. They either need to maintain a low center of mass, a large (and usually fixed) footprint, or both. Also, those with skid steering have a variable center of rotation depending on ground conditions and center of mass location.

Desired Capabilities

A more agile mobility platform would greatly extend the operating range of ground robots. Such a platform would feature locomotion capabilities approaching, and even surpassing, those of humans. The platform would be fast, highly agile, and capable of performing highly dynamic maneuvers. Whole-body control modes would be used to enable traversal of challenging terrain automatically, using a large variety of locomotion modes. The platform should be able to operate in human environments (indoors, as well as outdoors), and therefore, should be roughly humanoid in size and shape. A key consequence is that it would have a high center of mass relative to its base of support.

Challenges

The desired capabilities present a number of challenges, both in the mechanical design, and the control system. First, the mechanism must be light enough and strong enough to execute locomotion movements quickly. Second, the mechanism must have significant articulation, and should have hybrid walking/wheeled capabilities so that it has a large variety of locomotion modes at its disposal. Third, the limited ground contact (base of support) and the high center of mass position restricts the horizontal forces that can be exerted on the center of mass, and therefore, limits balancing capability. Therefore, highly dynamic maneuvers require careful maneuvers that take these limits into account. Fourth, execution of highly dynamic maneuvers in a manner that is robust to disturbances requires careful maneuver planning, and comprehensive control policies. Fifth, automatic selection of locomotion mode depending on task requirements and terrain requires detailed understanding of terrain types, good elevation and traversability maps of the terrain immediately in front of the robot, and a comprehensive mapping from terrain situation, robot state, and task goals to control actions.

Novelty of Approach

The CAHV system addresses these challenges using a novel mechanism combined with a novel control approach. The mechanism is bipedal featuring articulated legs with wheels allowing for novel combinations of rolling and walking locomotion, as shown in Fig. 1. This supports efficient locomotion across a wide variety of terrain types. CAHV will be lightweight and initial small-scale prototypes will leverage current inexpensive technologies that are very cost and weight efficient. A key component of the CAHV is the articulated wheeled foot at the end of each leg, which allows for various types of humanoid locomotion including rolling, roller skating, and walking. Additionally, the joint for this foot incorporates passive and active adjustable compliance, allowing for hopping and running motions. Movement of the leg joints is used to maintain the correct ground reaction force vector to maintain balance, even when carving turns, as shown in Fig. 1. The upper body will house a sensor suite and on-board processing to allow for semi-autonomous operation.

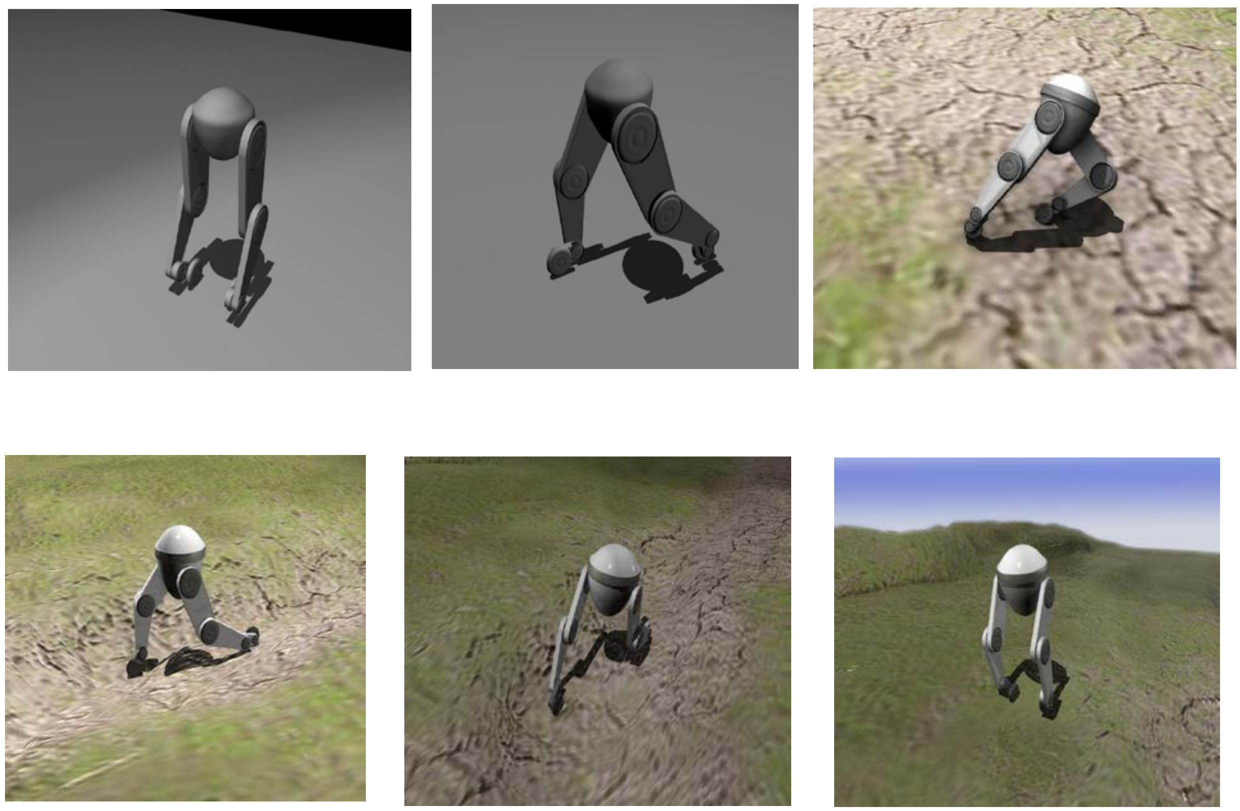

Fig. 1 – The CAHV mechanism

The hip and knee joints will be powered by high-torque moderate speed actuators, to support agile motions. The wheels on the feet use moderate-torque, high speed actuators to support fast rolling and balancing. The ankle joint will use a high-torque low speed actuator that will incorporate passive and active adjustable compliance, allowing for hopping and running motions. The compliance provides shock mitigation, and acts as a low-pass shock filter for the knees and hips.

An important characteristic of a typical CAHV application is that there is often significant spatial and temporal flexibility in the task specifications. For example, the task of moving the robot to a position may have significant flexibility in timing, as well as the final pose of the robot. Note that this is different from typical factory manipulator "pick and place" applications, where exact timing and position repeatability are crucial. At the same time, when executing dynamic maneuvers, the system is often operating near its actuation limits.

Successful execution of dynamic maneuvers requires understanding of the actuation limits, and also taking advantage of task flexibility in order to react appropriately to disturbances. Most currently existing robots do not do this and therefore, are not suitable for operation in unstructured environments. The proper exploitation of plan flexibility represents a significant gap in current capabilities. Conversely, it represents a significant opportunity for advancing the state of the art.

The approach we describe here addresses this gap. We view this problem as one of dynamic plan execution, where the plan representation must capture the flexibility inherent in the goal specification. Our approach is based on techniques for dynamic execution of temporally flexible plans, but extends this using recently developed algorithms for state reachability analysis and optimal controller synthesis. The resulting plan execution system is able to take advantage of spatial and temporal flexibility in the plan specification to improve handling of disturbances while the plan is executing. This approach is superior to traditional robotic planning and control approaches that focus on generating and following individual state trajectories, and therefore, are unaware of the more complete set of execution options when a disturbance occurs. This makes the system aware of all possible options in responding to a disturbance, even when executing challenging maneuvers of the type shown in Fig. 2.

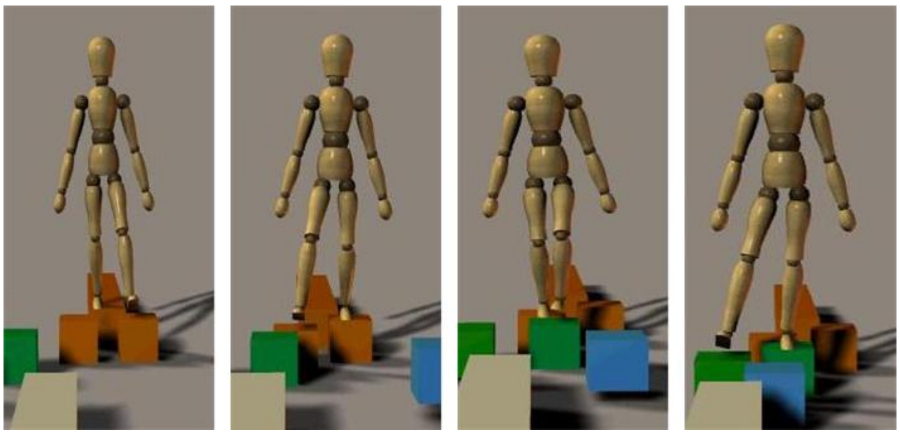

Fig. 2 – Maneuvering on an obstacle course with limits on foot placement.

Applications and Impact
CAHV represents a leapfrog improvement in robot dynamic motion capability, and traversal over difficult terrain. Its small footprint allows it to operate in tight spaces designed for humans. Thus, it will be able to negotiate stair landings, doors, and other tight indoor spaces. Also, its determinate center of rotation allow it to maneuver more easily in tight spaces. These capabilities, combined with its speed, makes the CAHV system ideal for a number of military applications including patrol, perimeter control, and reconnaissance. Commercial applications include transportation, delivery, logistics, and security.

Proposed Schedule When considering the development plan for CAHV, a schedule and cost estimate for the project could be:

Phase I: $180k, 6 months: Simulation, analysis, and ¼ scale prototype
Phase II: $750k, 12 months: Prototype
Phase III: $1.1M 18 months: Field testing

Phase I will provide the analysis, simulations, and prototyping needed at a very low risk to give the necessary feasibility information. Phase II poses a higher risk, but with the payoff of producing the base vehicle platform. Phase III poses only a moderate risk since after completing Phase II, the vehicle platform will be stable and reliable. The results of field testing will demonstrate and validate the full capabilities of CAHV. Some of the milestones to indicate the progress of development for will be:

- Pose transitions while balancing
- Fast driving on smooth terrain
- Sideways acceleration
- Rapid start/stop
- Carved turns
- Driving on smoothly changing terrain (skateboard park)
- Driving on rough terrain, active suspension
- Traversing obstacles greater than the radius of the drive wheels
- Walking on rough terrain (stairs for example)
- Skipping rope, jumping, running

Possible future extensions include the addition of arms, and a quadruped, rather than biped morphology.