

REPORT DOCUMENTATION PAGE				Form Approved OMB NO. 0704-0188	
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA, 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY)		2. REPORT TYPE		3. DATES COVERED (From - To)	
		Technical Report		-	
4. TITLE AND SUBTITLE Triple compliant limbs with adaptive body structure quarterly report May 2011			5a. CONTRACT NUMBER		
			W911NF-11-1-0113		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
			0620BK		
6. AUTHORS Bill Ross, Hartmut Geyer, Howie Choset			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES				8. PERFORMING ORGANIZATION REPORT NUMBER	
Carnegie Mellon University Office of Sponsored Programs Carnegie Mellon University Pittsburgh, PA 15213 -					
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211				10. SPONSOR/MONITOR'S ACRONYM(S) ARO	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) 59659-MS-DRP.2	
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
14. ABSTRACT Progress report for DARPA M3 Triple compliant limbs with adaptive body structure project.					
15. SUBJECT TERMS Robotics, walking robot, manipulation					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Bill Ross
UU	UU	UU	UU		19b. TELEPHONE NUMBER
					518-891-5889

Report Title

Triple compliant limbs with adaptive body structure quarterly report May 2011

ABSTRACT

Progress report for DARPA M3 Triple compliant limbs with adaptive body structure project.



M3

DARPA-BAA-10-65

Tracks 3 and 4

Technical Area: Mobility and Manipulation

National Robotics Engineering Center

Robotics Institute

Carnegie Mellon University





Project Goals

Develop a concept for a high speed running platform with integrated manipulation capability

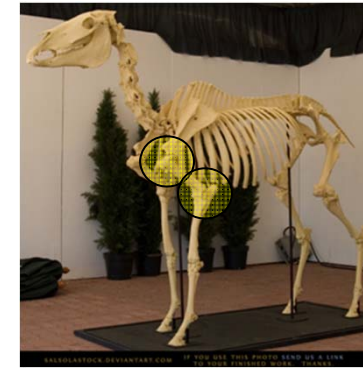
- Biologically inspired focus – Velociraptor as initial model
- Half size of human translates well to a robotic platform scale

Develop mechanisms that will assist in making an efficient running gait

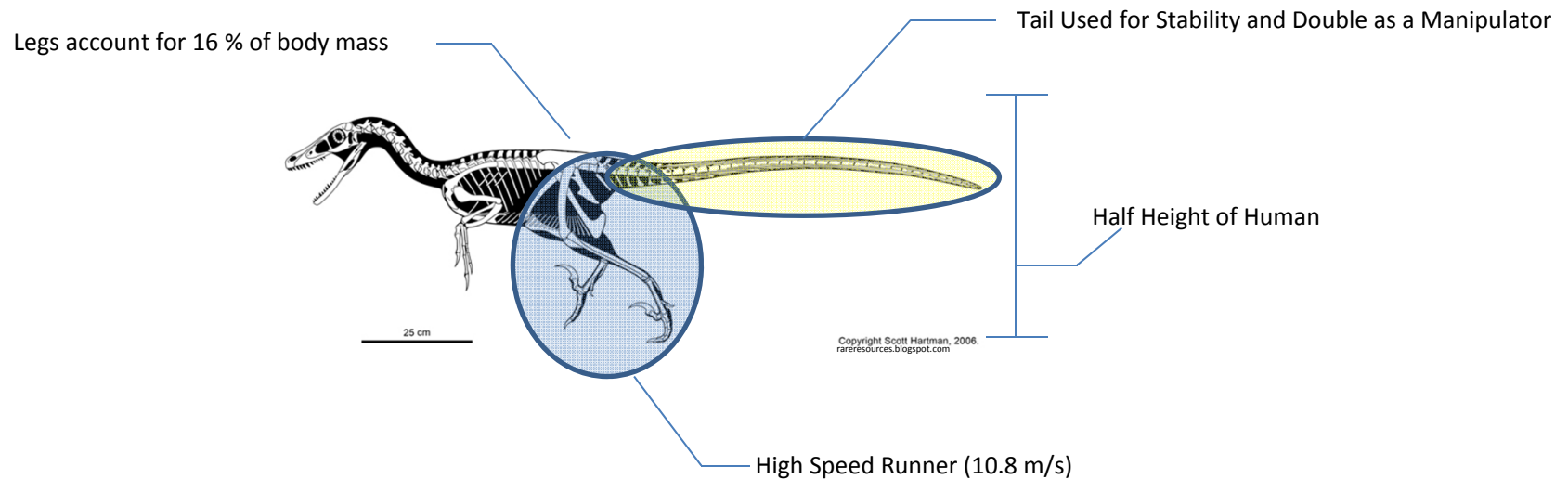
- Mechanisms will mimic the neuromuscular motions of the leg (highlighted)
- Provide a scalable solution that could be used for fast running legged platforms

Simulate the proposed solution

- CAD concept models
- Kinematic analysis
- Neuromuscular model simulation

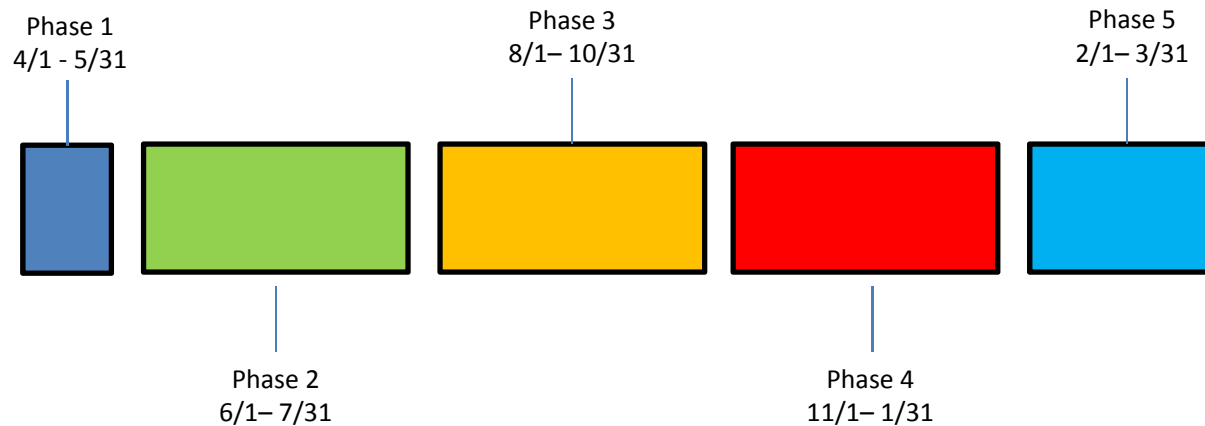


Many animal legs have oversized moment arms as well as joints with shifting centers of rotation





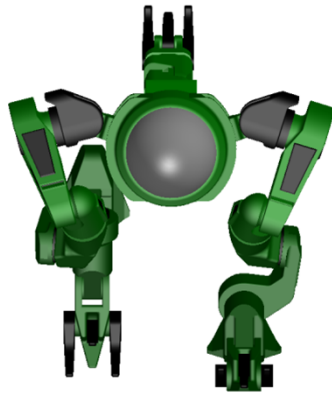
Project Scope Overview



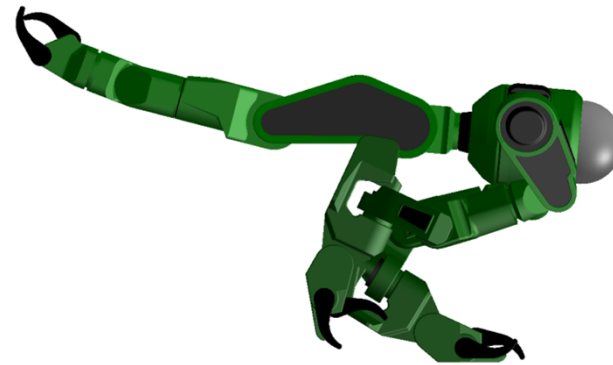
- Phase 1:** Preliminary analysis, develop simple torque model
Decision Point: Select appropriate scale of platform and actuation methods
- Phase 2:** Develop simulation of simple model, concept leg actuation mechanisms
Decision Point: Select leg actuation mechanisms for mobility and efficiency
- Phase 3:** Add tail / manipulator and foot impact pad to analysis and concepts
Decision Point: Select workspace of manipulator, determine total degrees of freedom
- Phase 4:** Move to 3D Leg model, add hip abduction and ankle rotations
Decision Point: Select mechanisms to actuate hip and ankles to achieve desired workspace of manipulator and running gait
- Phase 5:** Compile data and form conclusions
Decision Point: Determine all effective locomotion modes for final concept



Phase 1 Concept



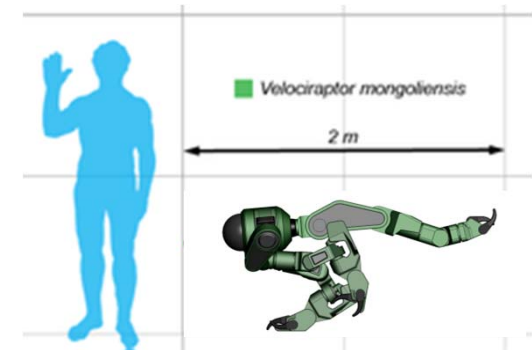
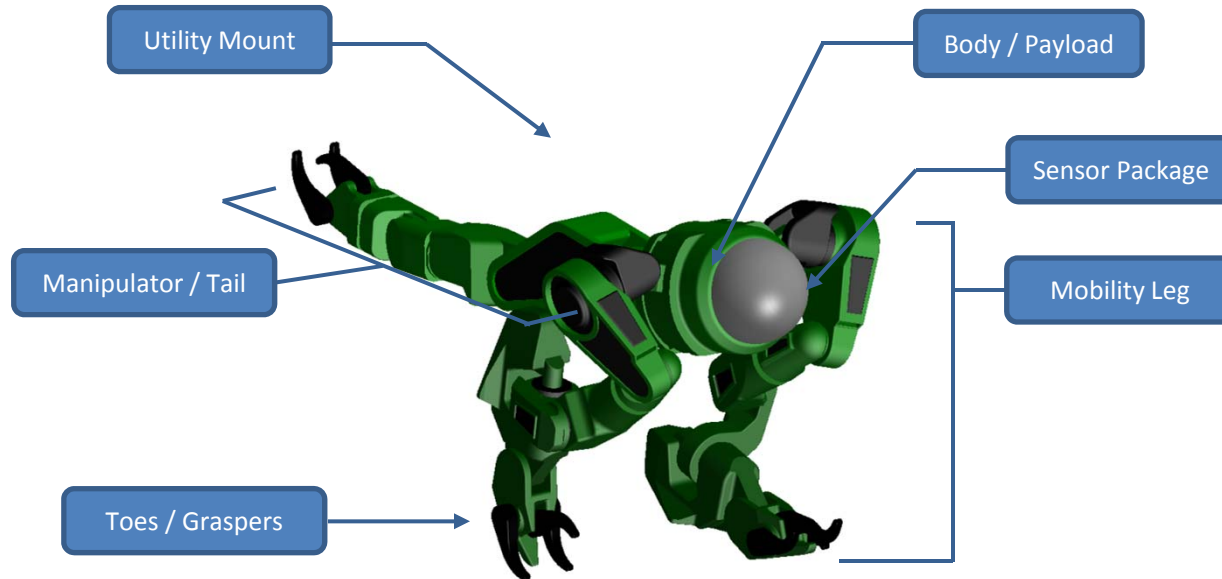
FRONT VIEW



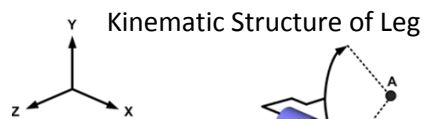
SIDE VIEW



Phase 1 Concept

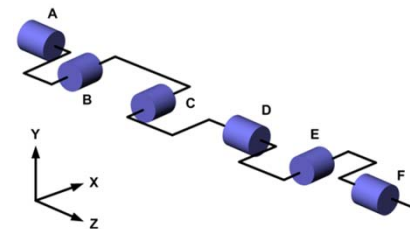


Size Comparison



$(R_X R_X R_Z R_Z R_Y R_X R_Z R_Z)$

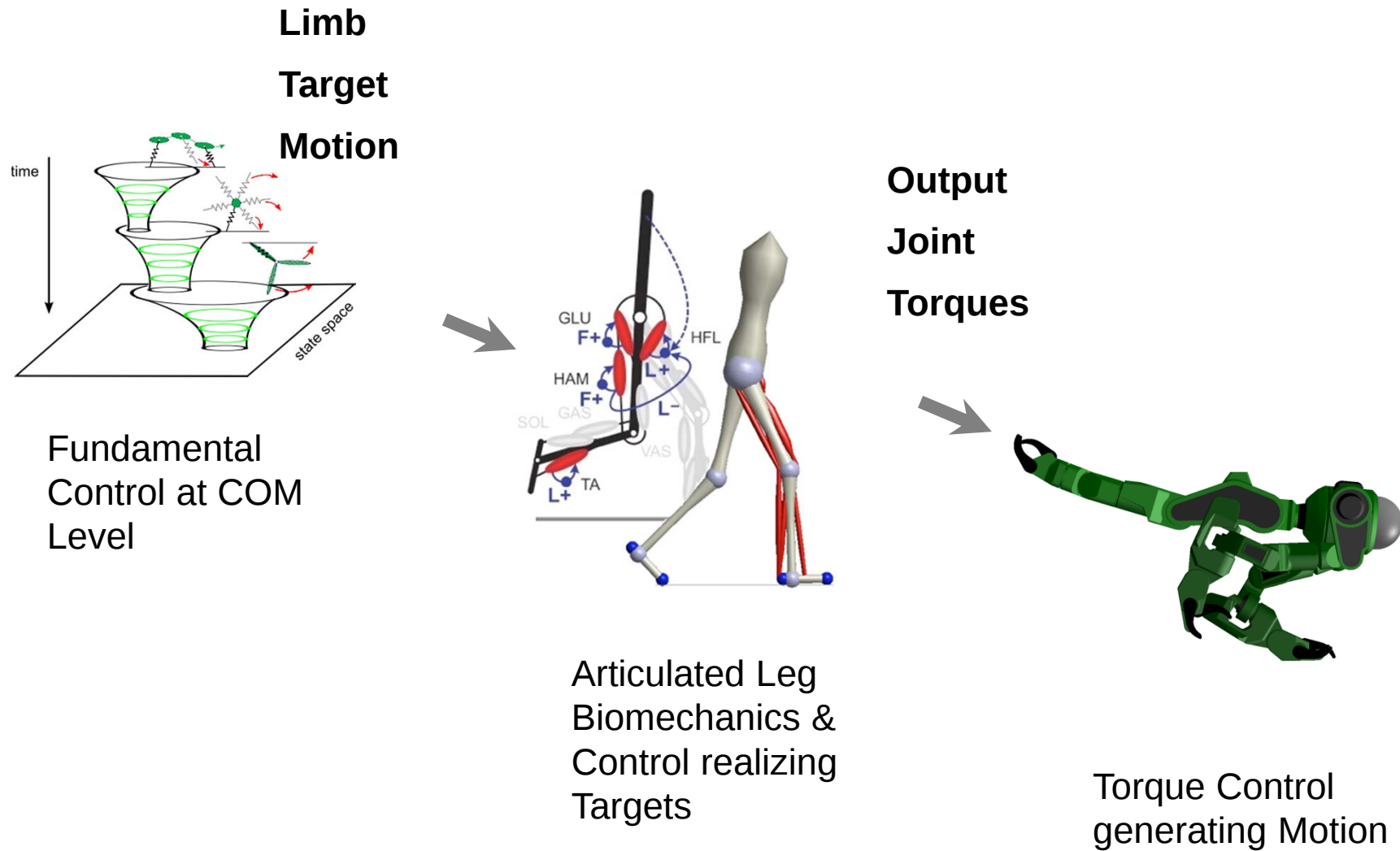
Kinematic Structure of Tail / Manipulator



$(R_Z R_X R_X R_Z R_X R_Z)$



Simulation & Control Overview

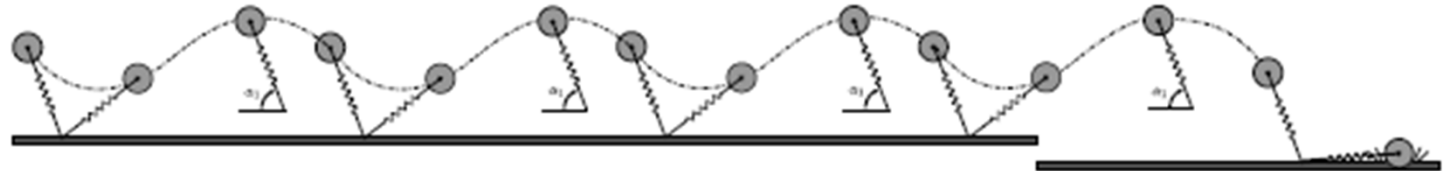




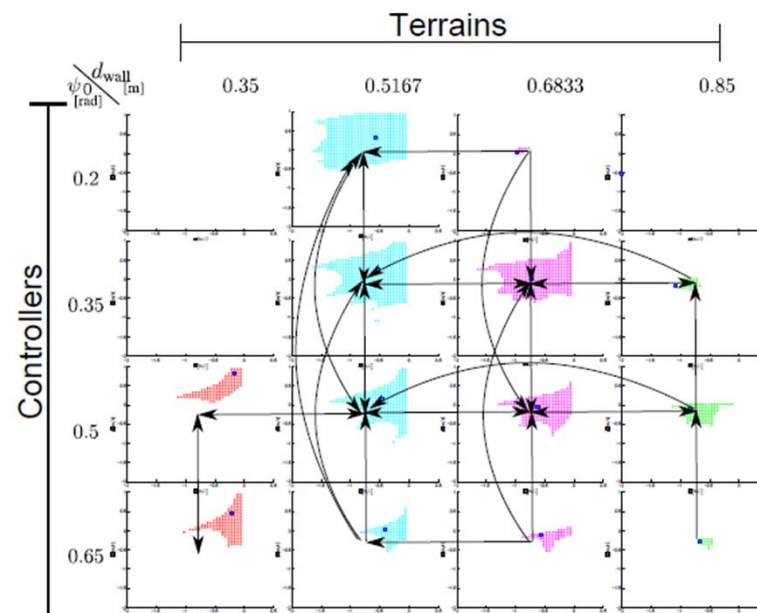
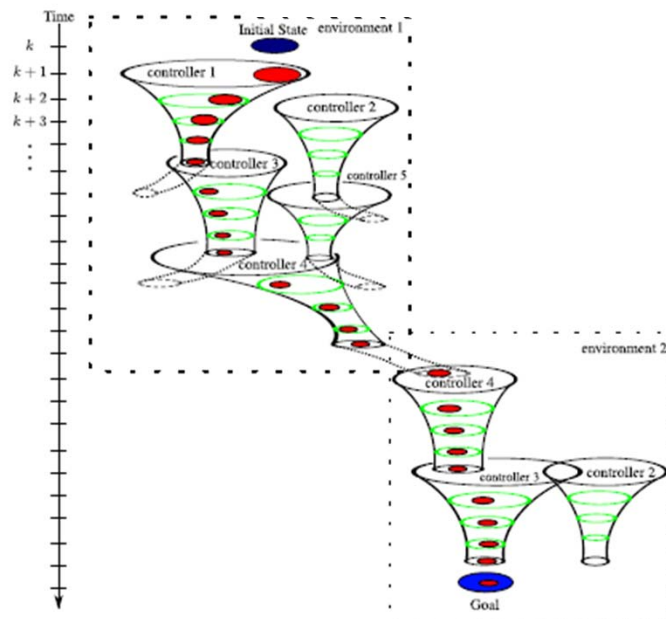
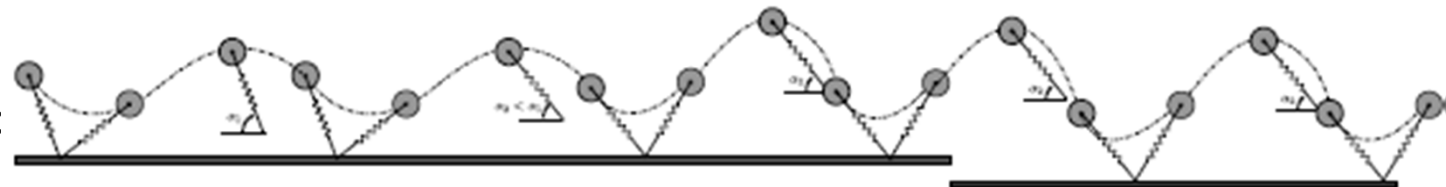
First Step – Gait Transitions: Terrain Switching

Toy Example – SLIP changing controller before terrain switch

Failed transition
(fixed leg angle):



Successful transition
(changing leg angle):





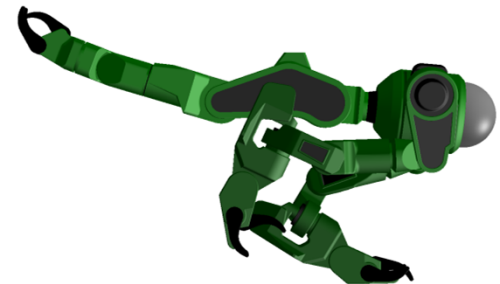
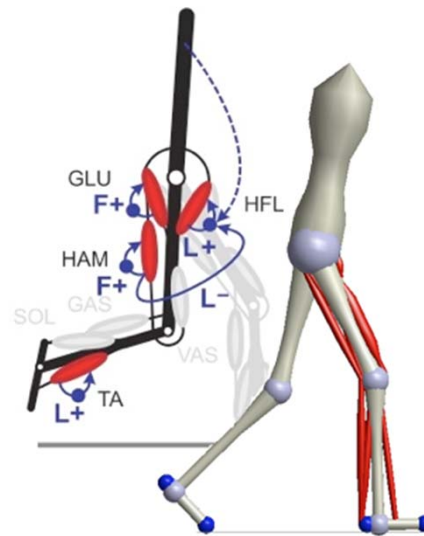
Simulation & Control Focus

Develop simulation of robot locomotion in 2D

Adapt current model to robot dimensions and leg morphology

Replace muscle-reflexes with actuator and sensor models

Develop forward dynamic robot simulation of locomotion control



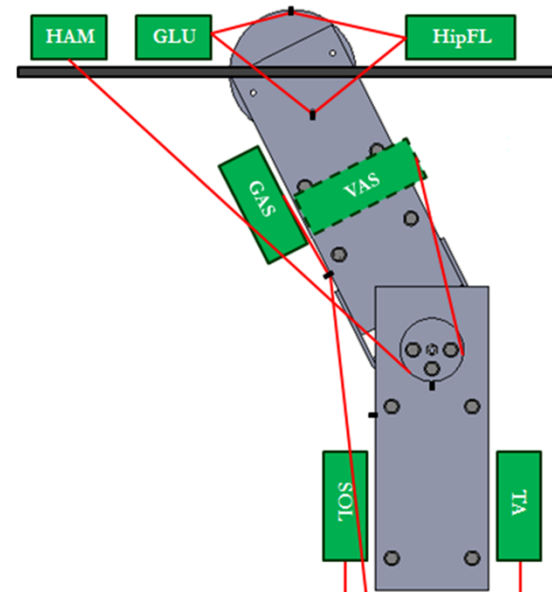


Simulation & Control Leg Actuation

Leg actuator placement and target specs

Identify key mono and biarticular actuator placements

Suggest target specs from human model scaled to velociraptor with 0.5m leg length and 26 kg mass



	SOL	TA	GAS		VAS	HAM		GLU	HFL
Fmax (N)	1300	260	500		2000	1000		500	700
ro (cm)	2.5	2.0	2.5	2.5	3.0	2.5	4.0	5.0	5.0
Tmax (Nm)	35	5	12	12	60	25	40	25	35
Joint	Ankle	Ankle	Ankle	Knee	Knee	Knee	Hip	Hip	Hip

$$m_{raptor}=0.3211m_{human}$$

$$I_{raptor}=0.489I_{human}$$

$$F_{raptor}=0.3211F_{human}$$

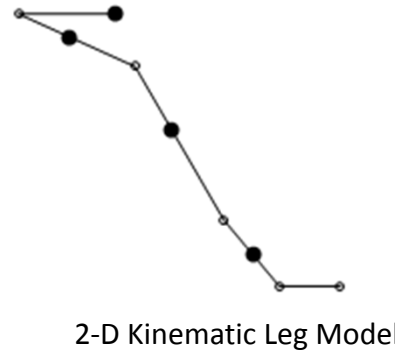


Mechanical Analysis of Leg

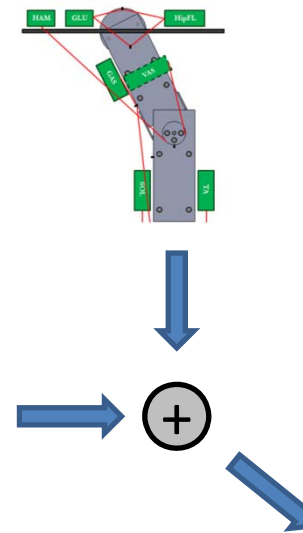
Velociraptor Geometric Data

<i>Velociraptor</i>	
Length (m):	
thigh	0.16
shank	0.221
metatarsus	0.108
foot	0.076
trunk	2.9
Mass (kg):	
thigh	1.4
shank	0.94
metatarsus	0.21
foot	0.14
trunk	17.3
m _{body}	20
CM position (m):	
thigh	0.090
shank	0.13
metatarsus	0.051
trunk:	
extant	0.12

Data from Hutchinson (2004)



Neuromuscular Model

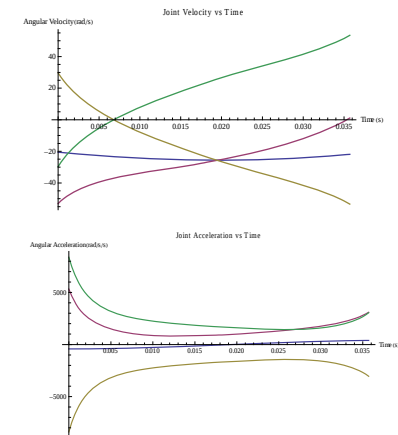


Scale Data & Iterate

Estimate mass of
each limb segment

Actuator Selection

Joint Movement Data





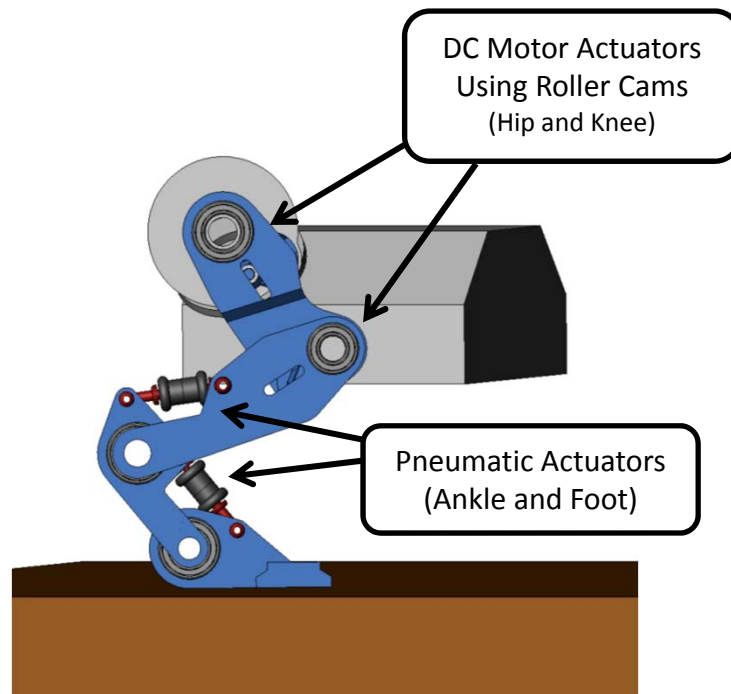
Mechanism Design Concept

Running gaits require the legs to quickly cycle to prepare for consecutive steps

- Hip and Knee provide the most force/torque towards running
- Tendons in ankles and foot act as springs to absorb and release energy

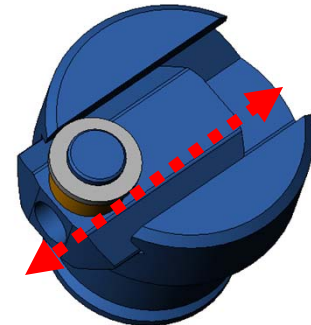
Leg needs to be able to provide full range of motion and controllability of all joints when manipulating objects

- Hip, knee, ankle, and foot all independently actuated
- Fine adjustment could be required

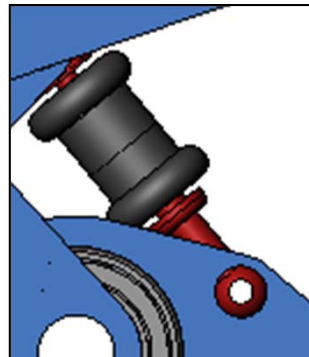


- Provides continuous oscillating motion while minimizing inertial change
- Cam length can be adjusted to change gait or output force
- Cams can be coupled to a rotary spring to allow for a moderate amount of suspension

Roller Cam Detail



Pneumatic Actuator Detail



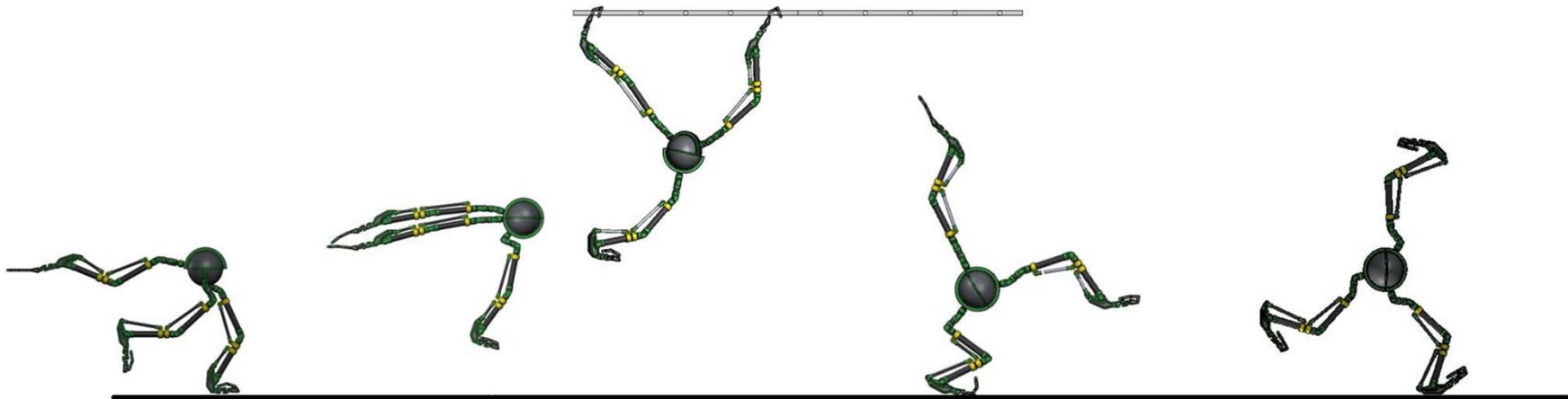
- Act as variable shock absorbers (comparable to tendons) during running
- Can be fully actuated when platform is being used for manipulation and slower gaits



Mobility Analysis

Revisit the varying modes of locomotion that are capable with a 3-legged platform

- Running
 - Hopping
 - Brachiating
 - Rolling
 - Other Novel Modes
- This will be performed during the final phase of the year long effort
 - Based on the range of motion and mobility of the final concept



M3 Concept from Proposal



Project Scope Detail

Item #	Task	Priority	Phase (3 Month Ea)	Previous Task Requirement	Lead	Description
1	Torque Analysis	1	1	None	Goldman	Develop torque analysis to use as a bases for actuator selection.
2	Actuator Research	1	1	None	Smith	Gather data on commercially available actuators (hydraulics, pneumatics)
3	Drive Mechanism Concepting	2	1	1	Rice	Actuation mechanism concepts for leg
4	Neuromuscular Velociraptor Gait Simulation (2d Leg Only)	3	1	1,2	Geyer	Compare Human Neuromuscular model with the geometry of the velociraptor
5	Concept CAD (v2)	3	2	1,3	Goldman	Create a revision of CAD concept including leg actuator concepts
7	Manipulator / Tail Concepting	4	2	None	Goldman	Develop Workspace requirement of tail, determine desired DOFs of tail
8	Usage Studies for final system	5	2	None	Smith	Give several real world example cases where our concept will be used.
9	Manipulator Torque / Workspace Analysis	5	2	8	Goldman	Produce several images showing the concepts
10	Foot Pad Analysis/ Concepts	5	2	1	Rice	Develop appropriate tail dimensions based on tasks outlined in item 8
11	Tail Stability Analysis during Running	6	2	6	Geyer	Develop simple model of a foot pad that can absorb initial impact during run, develop CAD concepts
12	Dynamic Analysis of Tail	6	2	6	Geyer/Choset	Develop simple simulation that incorporates the tail into a running body
13	Concept CAD (v3)	6	2	5,6,8	Rice	Control model of tail
14	Hip Abduction, ankle rotation Analysis / Concepting	8	3	4,9	Rice	Iterate CAD concept
15	Hip Abduction/ ankle rotation load analysis	9	3	12	Goldman	Add hip abduction and ankle pivot concepts to model
16	Gait Simulation with Tail, Hip Abduction, Ankle Rotation	10	3	13	Geyer	Determine appropriate type of actuators for hip abduction and ankle
18	Concept CAD (v4)	11	3	10,11,14	Goldman	Compare actuation of hips and ankles to other biological models
19	Novel gait analysis (is brachiating still an option?)	12	4		Goldman	Iterate the original concept from start of project based on analysis
20	Example test plan (for future work)	12	4	None	Smith	Determine if any novel locomotion modes are still an option
21	Compile Findings	13	5	All	Goldman	How would the system be implemented in a future phase

Important Deliverables		
Item #	Description	Lead
1	Limb Concept Study	Goldman
2	Multisegment Leg Model	Geyer
3	Dynamic Gait and Transition Control	Geyer/Choset



Conclusion

Three-Limb Platform

- High Speed Running
- High Degree of Freedom Manipulation
- Investigate multiple other forms of locomotion

Focus on Mechanism Development

- Analyze gait to determine limb speeds and loads
- Mimic the efficiency of biological running
- Have robustness of a manipulation platform

Understand the dynamics and control of the system

- Kinematic model for gait simulation
- Neuromuscular model for comparison

