



ROBOTIC SYSTEMS



Michigan Chapter
NDIA
National Defense Industrial Association

OPTIMAL TIME AND ENERGY EFFICIENCY IN LEGGED ROBOTICS

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Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the 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 a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 19 AUG 2009		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Optimal Time and Energy Efficiency in Legged Robotics				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Ka C Cheok; Paul Muench; Gregory P. Czerniak				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000				8. PERFORMING ORGANIZATION REPORT NUMBER 20184RC	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S) TACOM/TARDEC	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) 20184RC	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES Presented at NDIAs Ground Vehicle Systems Engineering and Technology Symposium (GVSETS), 17 22 August 2009, Troy, Michigan, USA, The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 13	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

OPTIMIZATION

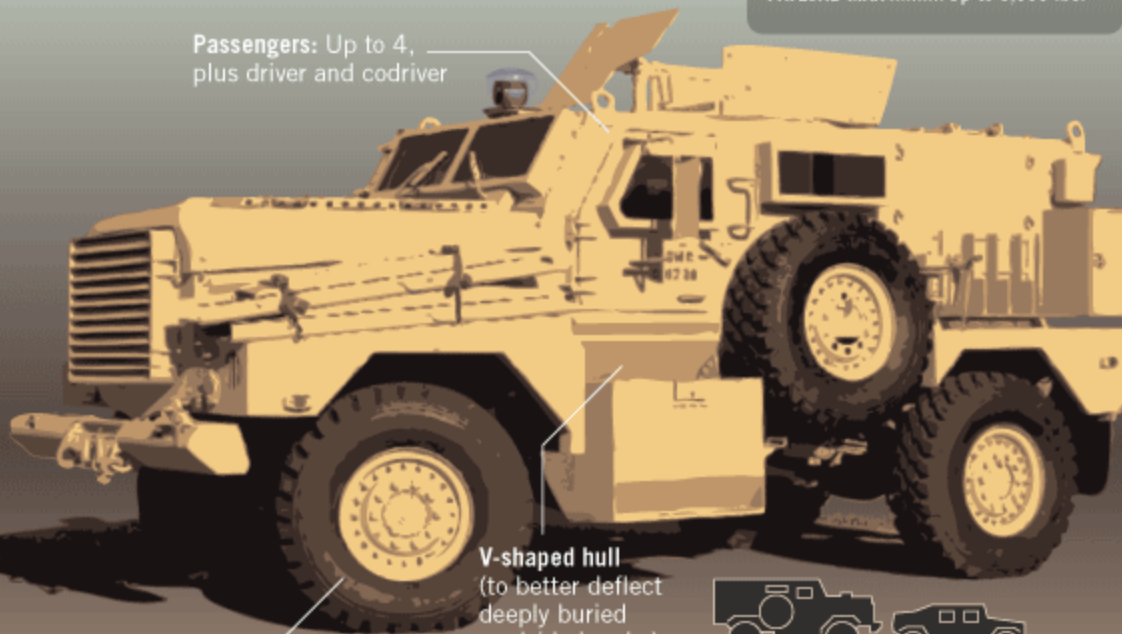
ROBOTIC SYSTEMS

Mine-Resistant, Ambush-Protected Vehicle (MRAP)

MRAPs can weigh two to five times as much as humvees, prompting concerns that they could cause some bridges to collapse. But sitting up high allows soldiers to see more.

HORSEPOWER 330 at 2,400 rpm
RANGE 420 miles
HEIGHT Approx. 104 inches
WIDTH 108 inches
LENGTH OVERALL 233 inches
WEIGHT 32,000 lbs.
PAYLOAD MAX Up to 6,000 lbs.

Passengers: Up to 4,
plus driver and codriver

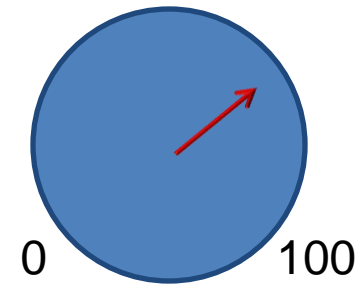


Run-flat tires

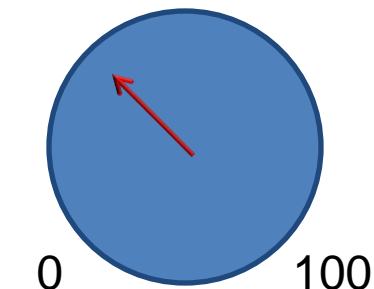
V-shaped hull
(to better deflect
deeply buried
roadside bombs)



HUMVEE



SURVIVABILITY

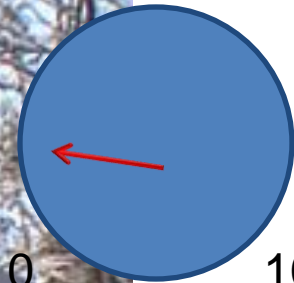


MOBILITY



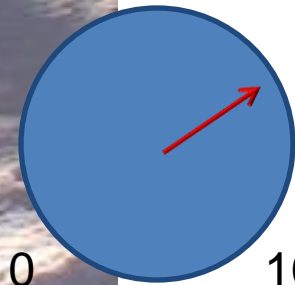
OPTIMIZATION

ROBOTIC SYSTEMS



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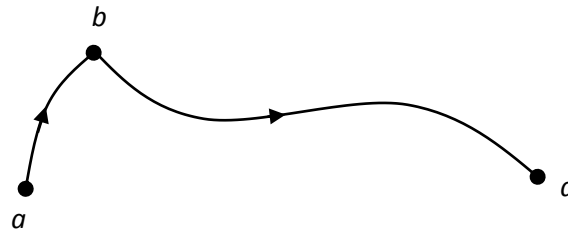
EFFICIENCY



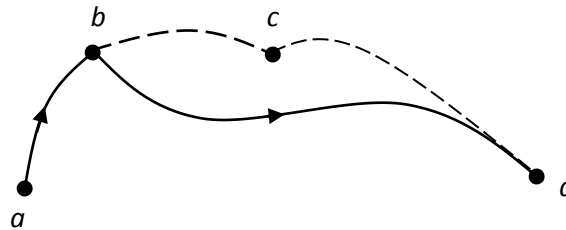
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MOBILITY

- PRINCIPLE OF OPTIMALITY
- OPTIMAL CONTROL
 - POYNTRYAGIN'S MAXIMUM PRINCIPLE
 - DYNAMIC PROGRAMMING
- EXAMPLE: SWITCHING CURVE IN POWERED PENDULUM
- HARDWARE IMPLEMENTATION
- CONCLUSIONS & FUTURE WORK

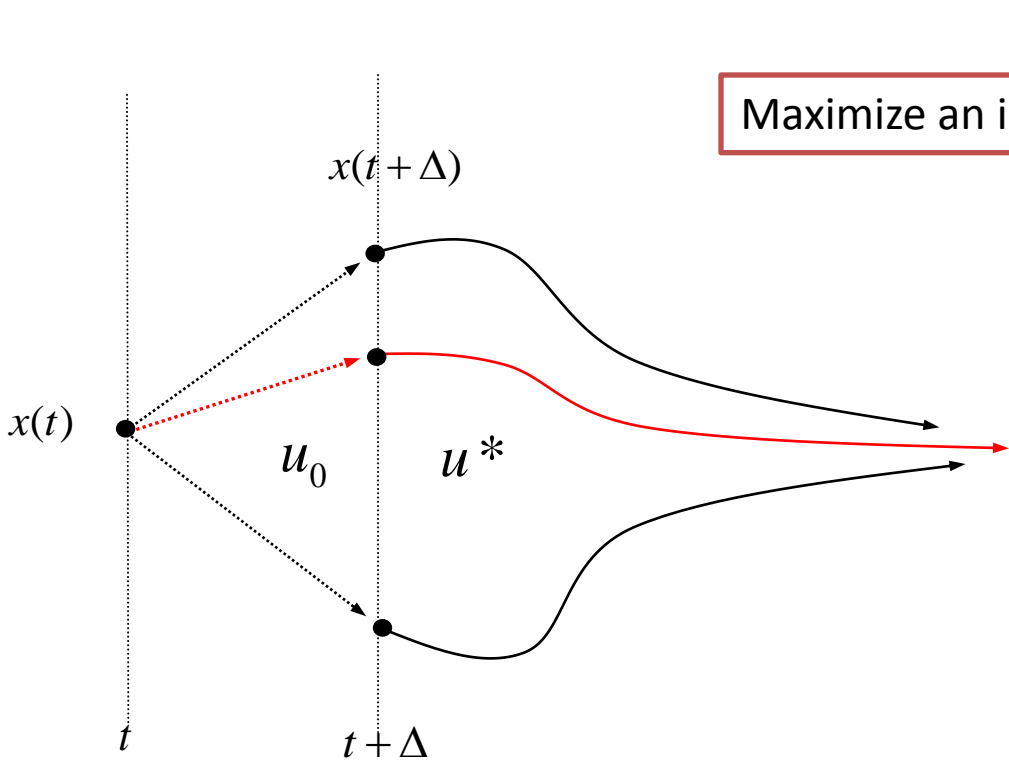


If $a-b-d$ is the optimal path from a to d , then $b-d$ is the optimal path from b to d .



POYNTRYGIN MAXIMUM PRINCIPLE

ROBOTIC SYSTEMS

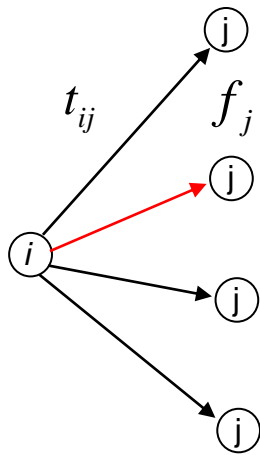


Maximize an integral-type cost

$$J[x_0, \vec{u}] = \int_0^T \phi(x, u) dt$$

vs.

$$J^*(x_0) = \max_u J[x_0, \vec{u}]$$



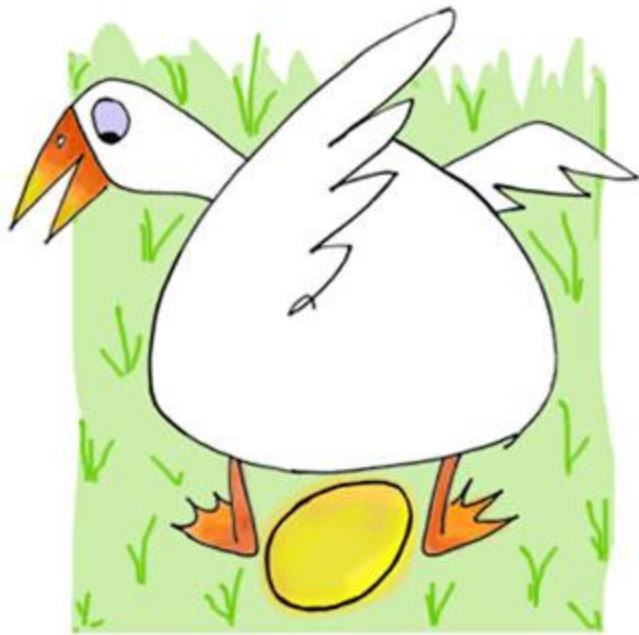
Minimize (-max) over all possible arcs (i, j)

$$f_i = \min_j \{t_{ij} + f_j\}$$

t_{ij} = cost of the directed arc (i, j)

f_i = min travel time from node i to end

GOOSE VS. GOLDEN EGGS



Revenue produced

$$\phi(x, u)$$

vs.

Value added

$$\frac{d}{dt} [z(t)x(t)] = z\dot{x} + \dot{z}x$$

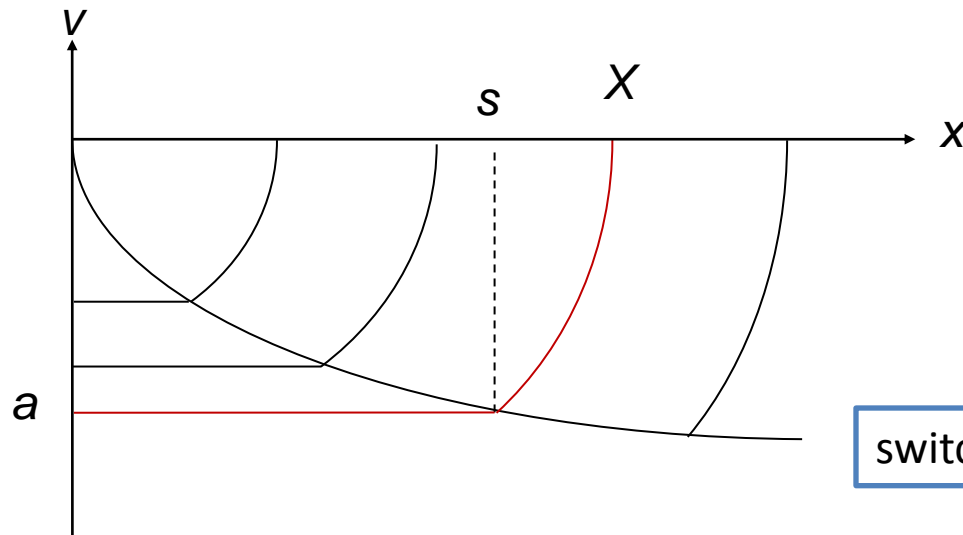
where $z \equiv \frac{dJ^*(x_0)}{dx_0}$ marginal value of state

SWITCHING CURVE



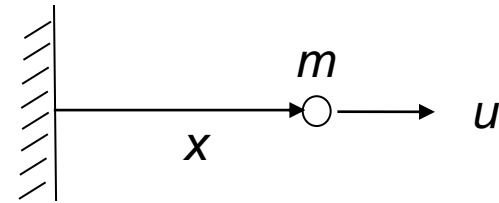
coasting line, a

$$s = -\frac{m}{k} a^3$$



switching curve, s

Positioning Problem



$$J = \int_0^T (k + uv) dt$$

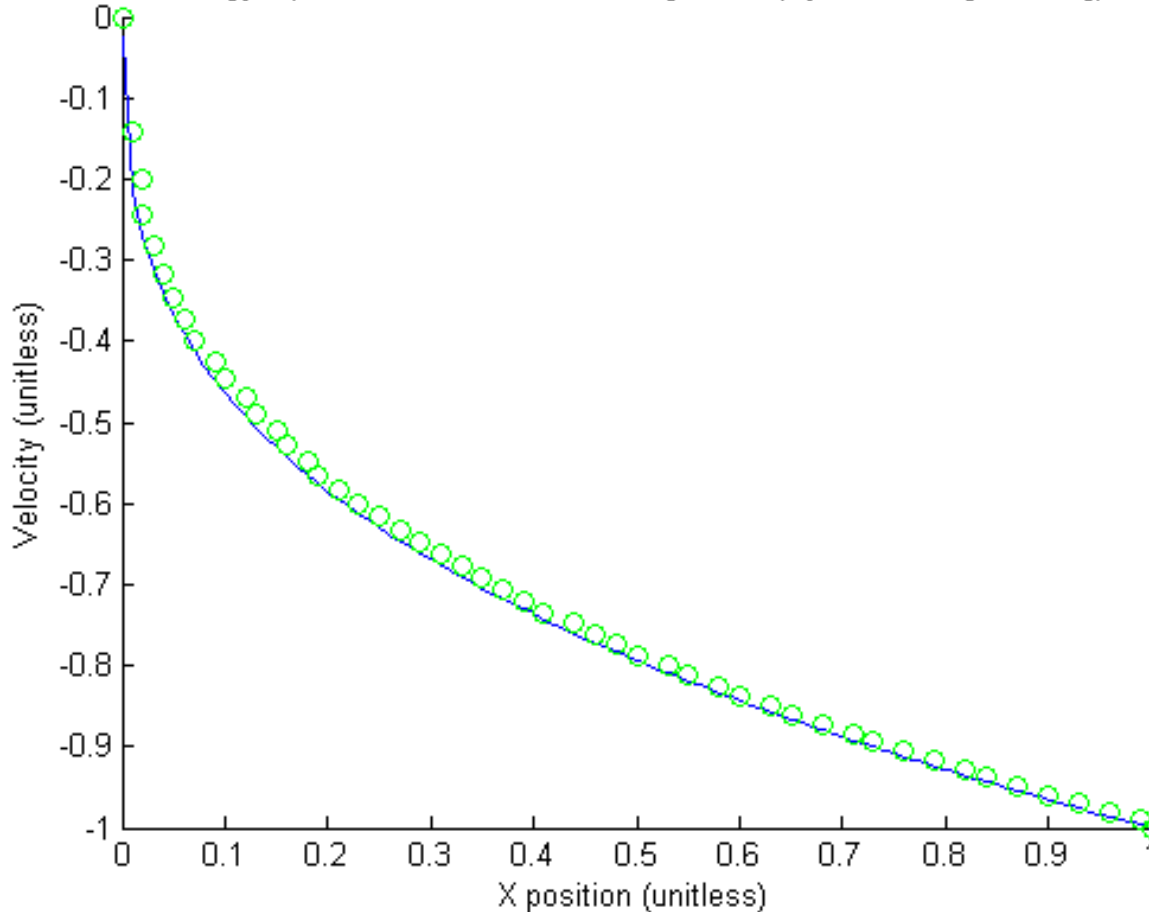
Time + energy cost

SWITCHING CURVE

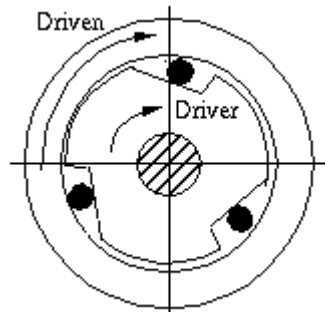
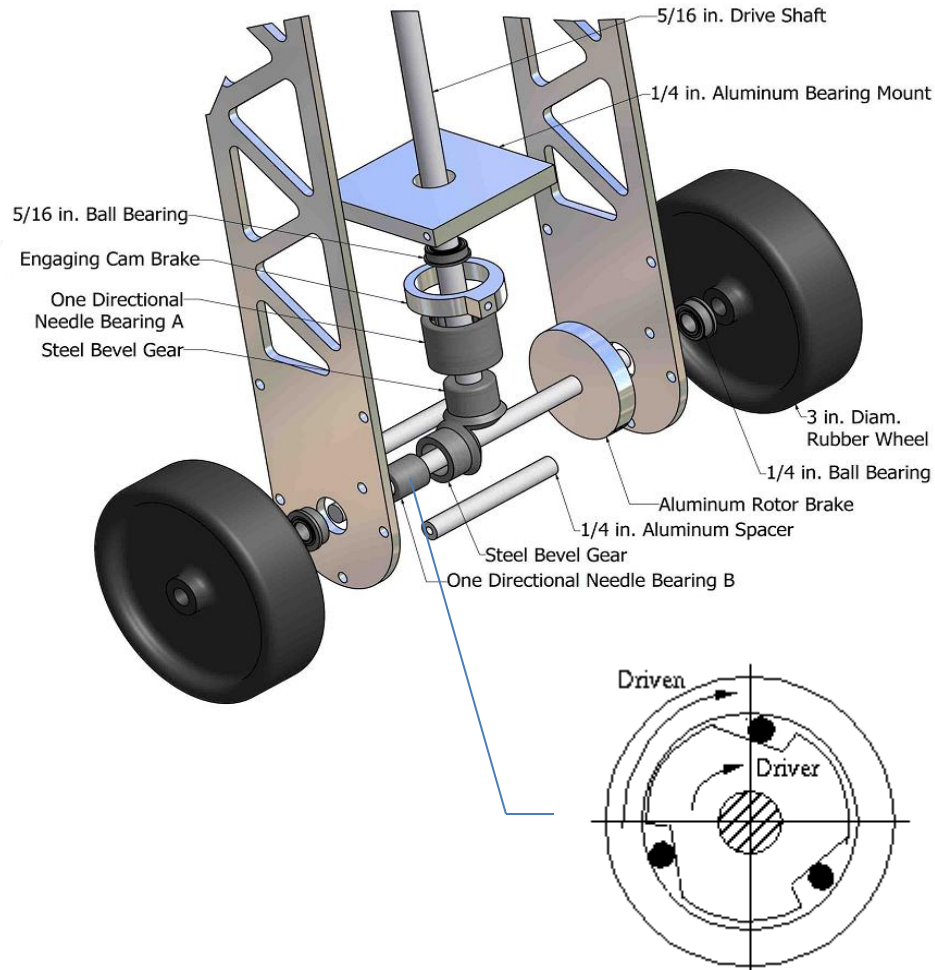
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Energy-Optimal Rocket Car Switching Curve (Dynamic Programming)



- Calculated Data Point
- Theoretical Curve



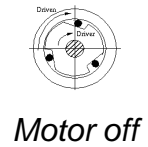
Overrunning clutch

Powered Phase



- Clockwise motion engages wheels

Free Spinning Phase



- Unpowered motor enables this phase

Brake



- Counterclockwise motion engages cam brake

- Game theory approach to disturbances
- Sensor and Acuator uncertainty
- Dissipation



CONCLUSIONS

ROBOTIC SYSTEMS



- Unmanned Systems allow for different optimization schemes (e.g. Mobility over Survivability)
- Legged Mobility still requires greater efficiency for real-world applications.
- **GREAT PROMISE AND POTENTIAL** usually requires **GREAT EFFORT AND SACRIFICE** to finish the job
- Thanks!