Projected Profile Humanoid Crawl Gait And Lidar Based Navigation Using GODZILA

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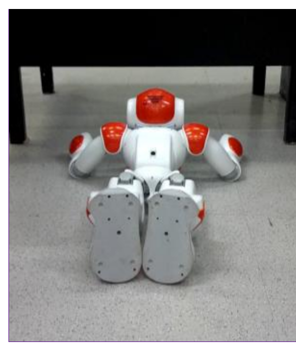
Presentation Outline

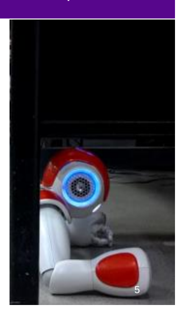


Introduction

Humanoid Platform
- Terrain adaptability
- Mobile manipulation

Navigation
- Safe traversal
- Obstacle avoidance

Crawling
- Stable gait
- Expands navigable area

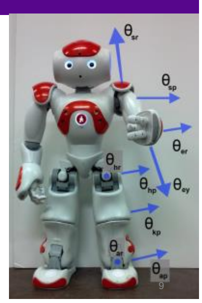


GODZILA Navigation
- Local planner
- Computationally efficient
- Foundation for global planners

Projected Profile
- Crawling gait
- Widely applicable
- Low profile

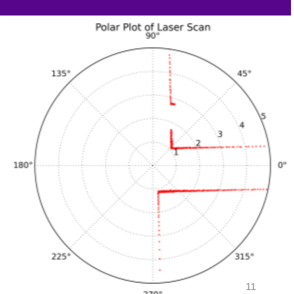
Platform Overview

Nao H25 Humanoid Platform
- Aldebaran Robotics
- 25 DoF humanoid, 58 cm, 4.3 kg
- Atom processor, cameras, sonars, IMU
- Laterally symmetric, no back joint



Hokuyo URG-04LXUG01
- Scanning laser rangefinder
- 5 meter range, 0.3˚ angular resolution
- USB
- Obstacle avoidance

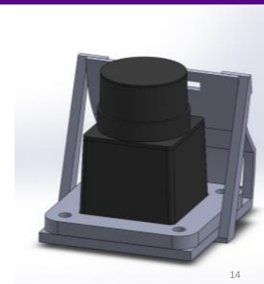
Planar Environmental View
- 720 range measurements
- Room with hallway and door

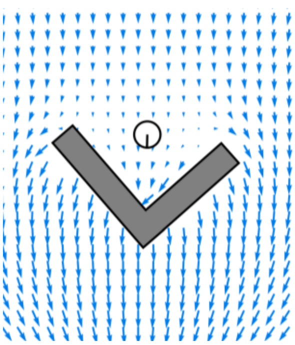


Lidar Mount
- Assembly to attach Lidar to Nao
- 3D printed plastic
- Foam padding
- Strapped to robot

Mount Design
- Waist height, low center-of-gravity
- Minimize wobble
- Conform to body
- Front subassembly, back plate

Front Subassembly
- Interchangeable plates
- Reinforcement gussets





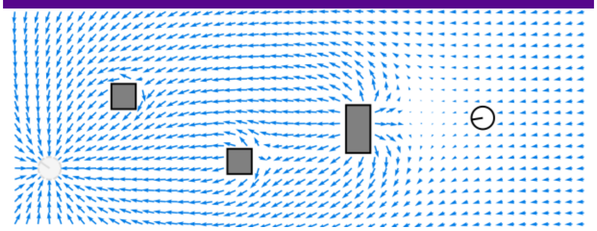
GODZILA Navigation

Game-Theoretic Optimal Deformable Zone with Inertia and Local Approach (GODZILA)
- Local navigation
- Potential Field

P. Krishnamurthy and F. Khorrami. Godzila: A low-resource algorithm for path planning in unknown environments. Journal of Intelligent and Robotic Systems, 48(3):357–373, 2007.

GODZILA Components
- Rewards directions towards goal
- Rewards directions towards far obstacles
- Penalizes directions towards near obstacles
- Penalizes changes in heading

Potential Field
- Force fields
- Obstacle repulsion
- Attractive goal



Goal x_g Obstacles m_i Robot x_r

Obstacle Force Vector f_i

Tuning parameter c_i

Power α

$$\|f_i\| = \frac{-c_i}{\|m_i - x_r\|^{\alpha}}$$

$$\angle f_i = \angle(m_i - x_r)$$

Goal Force Vector f_g

Tuning parameter c_g

Power γ

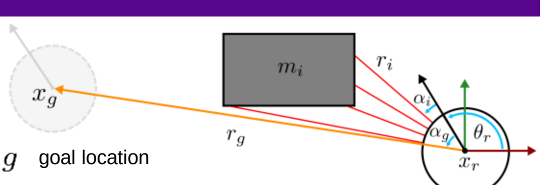
$$\|f_g\| = \frac{c_g}{\|x_g - x_r\|^{\gamma}}$$

$$\angle f_g = \angle(x_g - x_r)$$

Robot Force Vector f_r

Obstacle Set M

$$f_r = f_g + \sum_{i=1}^{\|M\|} f_i$$



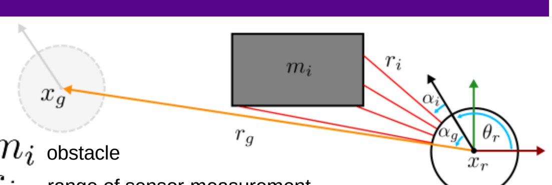
x_g goal location

r_g range to goal

α_g bearing to goal

x_r robot location

α'_r new bearing command



m_i obstacle

r_i range of sensor measurement

α_i bearing of sensor measurement

GODZILA Navigation: Equations

Bearing Command Vector

$$\alpha'_r = \frac{\alpha}{\|\alpha\|}$$

Sum of Component Vectors

$$\alpha = \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4$$

GODZILA Navigation: Reward Vectors

Goal Reward Vector

$$\alpha_1 = \overline{f}_{11} g_{11}(r_g)\alpha_g$$

Far Obstacle Reward Vector

$$\alpha_3 = \overline{g}_{26} \sum_{i \in \mathcal{I}_2} f_{21}(r_i) g_{25}(\alpha_g - \alpha_i)\alpha_i$$

GODZILA Navigation: Penalty Vectors

Near Obstacle Penalty Vector

$$\alpha_2 = -\overline{g}_{24} \sum_{i \in \mathcal{I}_1} g_{21}(r_i)\Big[g_{22}(\alpha_g - \alpha_i) + g_{23}(\alpha_i)\Big]\alpha_i$$

Inertia Vector

$$\alpha_4 = \overline{f}_{31}\alpha_r$$

GODZILA Navigation: Forward Velocity

Angular Rate Command

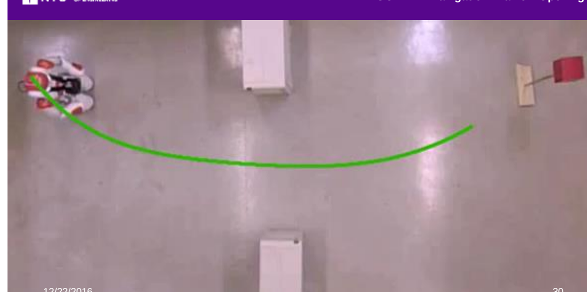
$$\dot{\alpha}'_r$$

Forward Velocity Command

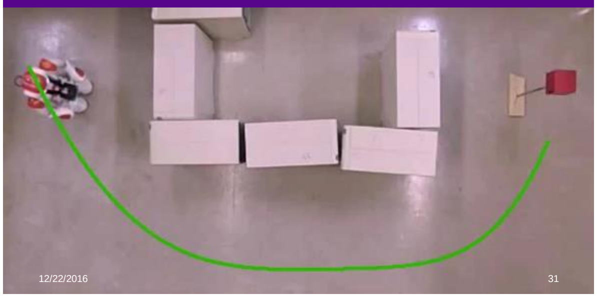
$$v_r = f_v(\min(R))g_v(\dot{\alpha}'_r)$$

GODZILA Navigation: Open Area

GODZILA Navigation: Narrow Opening



GODZILA Navigation: Square Area



Projected Profile

Projected Profile

Projected Profile
- Crawling gait
- Sagittal plane projection
- 25 DoF to 6 DoF

G. Brooks, P. Krishnamurthy, and F. Khorrami. Low-profile crawling for humanoid motion in tight spaces. In 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pages 5930–5935, Sept 2015.

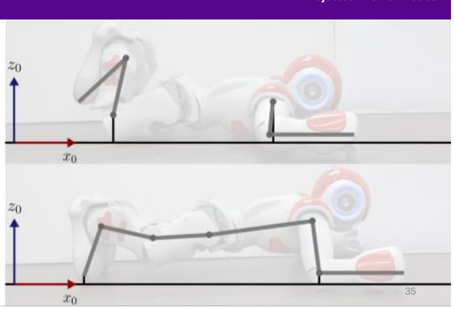
Projected Profile: Modes

Modes
- Open chain, move end effectors
- Closed chain, move center-of-mass

Projected Profile: Modes

Open Chain

Closed Chain

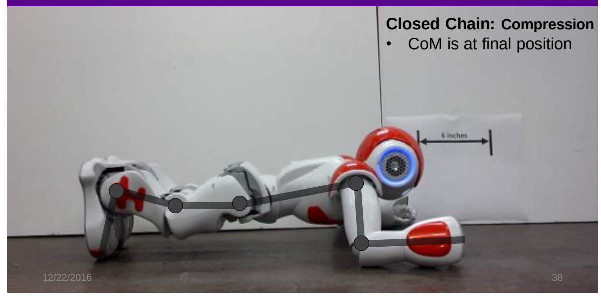


Projected Profile: Open Chain

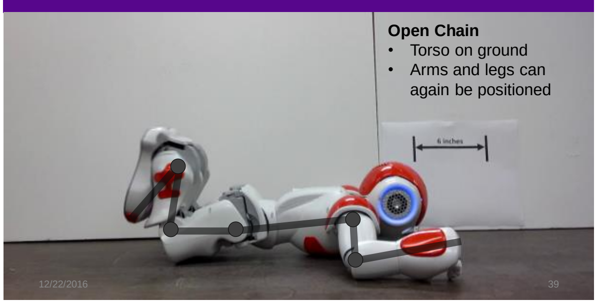
Open Chain
- Torso on ground
- Arms and legs are positioned

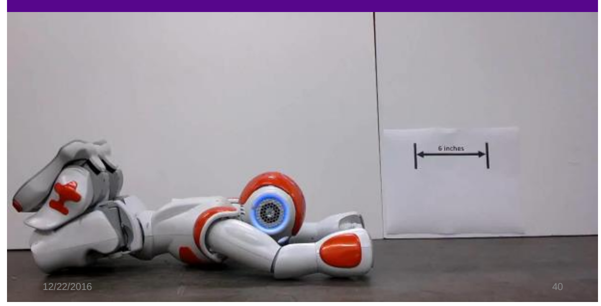
Closed Chain: Extension
- Arms and legs on ground
- Torso can be positioned
- CoM is at initial position

Closed Chain: Compression
- CoM is at final position

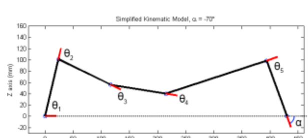


Open Chain
- Torso on ground
- Arms and legs can again be positioned





$$
\begin{aligned}
d_e &= \sum_{i=1}^{5} l_i \cos\left(\sum_{j=1}^{i} \theta_j\right) \\
0 &= \sum_{i=1}^{5} l_i \sin\left(\sum_{j=1}^{i} \theta_j\right) \\
\alpha &= \sum_{i=1}^{5} \theta_i
\end{aligned}
$$



Foot "joint" is not actuated

Knee and hip as free variables

Remaining joints function of Projected Profile elbow

Ankle Joint Equation
- Squared sum formulation

$$
2l_1K_1\cos(\theta_2) + 2l_1K_2\sin(\theta_2) = [d_e - l_5\cos(\alpha)]^2 + [l_5\sin(\alpha)]^2 - l_1^2 - K_1^2 - K_2^2
$$

Ankle Joint Solution

$$K_1 \triangleq l_2 + l_3\cos(\theta_3) + l_4\cos(\theta_3+\theta_4)$$
$$K_2 \triangleq -l_3\sin(\theta_3) - l_4\sin(\theta_3+\theta_4)$$

Yields two solutions for Ankle

- One is kinematically infeasible

Foot Joint Solution

- Follows from ankle solution

$$\theta_1 = tan^{-1}\left(\frac{sin(\theta_1)}{cos(\theta_1)}\right)$$

$$cos(\theta_1) = \frac{K_3(d_e - l_5\cos(\alpha)) + l_5K_4\sin(\alpha)}{K_3^2+K_4^2}$$
$$sin(\theta_1) = \frac{K_4(d_e - l_5\cos(\alpha)) - l_5K_3\sin(\alpha)}{K_3^2+K_4^2}$$

Foot Joint Solution

$$K_3 = l_1 + K_1cos(\theta_2) + K_2sin(\theta_2)$$
$$K_4 = K_2cos(\theta_2) - K_1sin(\theta_2)$$

Shoulder Joint Solution

$$\theta_5 = \alpha - \sum_{i=1}^{4}\theta_i$$

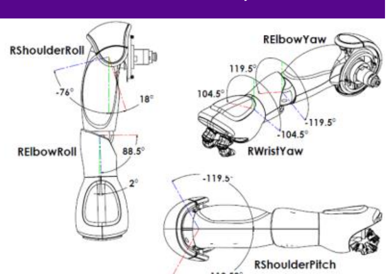
Nao Arm

- Not planar

Shoulder Roll θ_{sr}

Elbow Yaw θ_{ey}

Elbow Roll θ_{er}

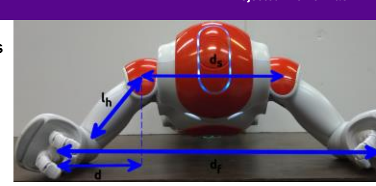


Arm Brace Parameters

Humerus Length l_h

Shoulder Width d_s

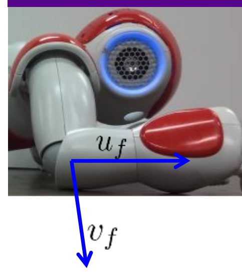
Forearm Width d_f



Elbow Extension $d = \frac{d_f - d_s}{2}$

Shoulder Roll Solution

$$\theta_{sr} = sin^{-1}\left(\frac{d}{l_h}\right)$$



Forearm Vector

$$v_f$$

Desired Forearm Vector

$$u_f = R_{v_{er},\theta_{er}} R_{v_{ey},\theta_{ey}} v_f$$

Desired Forearm Vector $u_f = [1, 0, 0]^T$

Projected Humerus Length $\tilde{l}_h = \sqrt{l_h^2 - d^2}$

Forearm Vector

$$v_f = v_{ey}$$

Elbow Yaw Axis $v_{ey} = [\tilde{l}_h \cos(\alpha), d, \tilde{l}_h \sin(\alpha)]^T / l_h$

Elbow Roll Axis $v_{er} = [-\sin(\alpha), 0, \cos(\alpha)]^T$

Required Elbow Roll Axis

$$u_{er} = v_f \times u_f$$

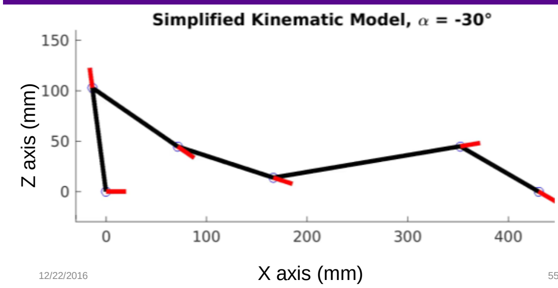
Elbow Yaw Solution

$$\theta_{ey} = \cos^{-1}(v_{er} \cdot u_{er})$$

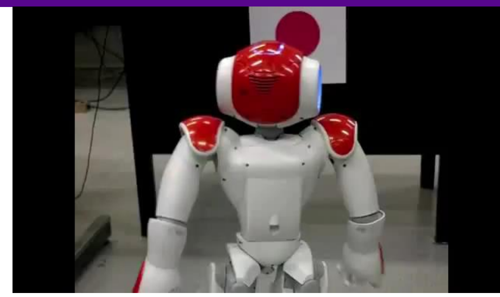
Elbow Roll Solution

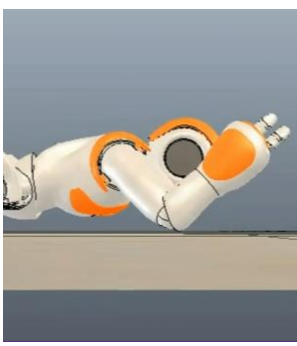
$$\theta_{er} = \cos^{-1}(v_f \cdot u_f)$$

Projected Profile: Animation



Projected Profile: Crawl Sequence



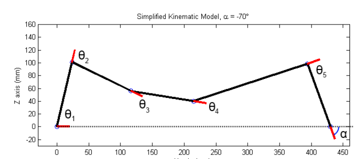


Gait Optimization

Gait Optimization

Knee and hip as free variables

- Optimize joint torque use
- Pseudo-static formulation



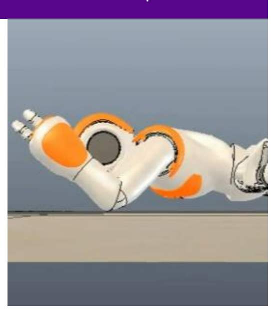
Gait Optimization: Method

V-REP simulation

Table of joint-angles-to-torques

- 2.5° resolution
- ± 30° about initial pose
- Linear interpolation

Genetic algorithm for optimization

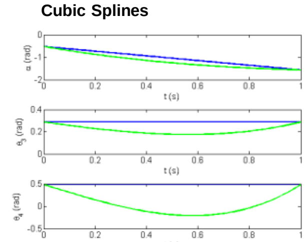


Gait Optimization: Triplet

Angle Triplets

Configuration Parameter	Minimum Angle (degrees)	Maximum Angle (degrees)
θ_3	-5	45
θ_4	15	-30
α	-30	-90

Cubic Splines



Torque Cost Function

- Minimize joint torques
- Shoulder weighted more to minimize use

$$c_\tau(t) = \sum_{i=1}^{4} w_i \tau_i^2(t)$$

Joint Limit Indicator Functions

$$c_{\theta_i}(t) = \begin{cases} 1 & \text{if } \theta_i(t) > \theta_{i_{max}} \text{ or } \theta_i(t) < \theta_{i_{min}} \\ 0 & \text{otherwise} \end{cases}$$

$$c_\alpha(t) = \begin{cases} 1 & \text{if } \alpha(t) > \alpha_{max} \text{ or } \alpha(t) < \alpha_{min} \\ 0 & \text{otherwise} \end{cases}$$

Hip Height Indicator

$$c_{z_{hip}}(t) = \begin{cases} 1 & \text{if } z_{hip}(t) < z_{hip_{thresh}} \\ 0 & \text{otherwise} \end{cases}$$

Backtracking Indicator

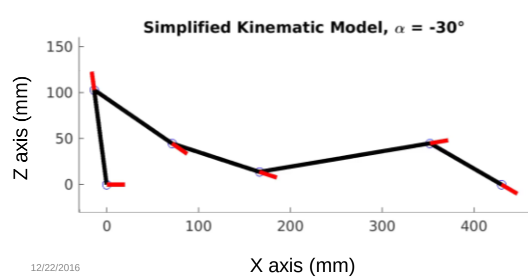
$$c_{\dot\alpha}(t) = \begin{cases} 1 & \text{if } \dot\alpha(t) \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

Indicator Cost Function

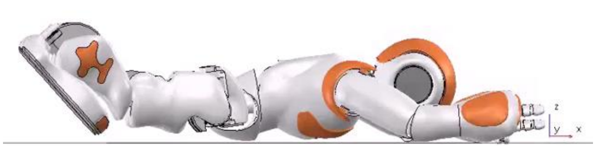
$$c_I(t) = C_v\left(c_{\dot\alpha}(t) + c_\alpha(t) + c_{z_{hip}}(t) + \sum_{3}^{4} c_{\theta_i}(t)\right)$$

Total Cost Function

$$c_s = \int_0^T c_\tau(t) + c_I(t)\, dt$$

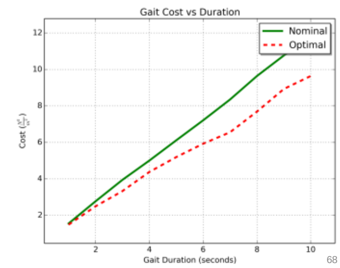


Crawl Gait: Projected Profile



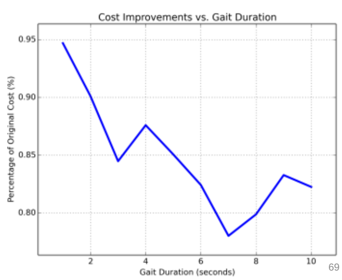
Gait Optimization: Torque Cost Improvement

Joint Torque Cost
- Torque use
- Simulated in V-REP
- Gait duration
- Pseudo-static



Gait Optimization: Torque Cost Improvement

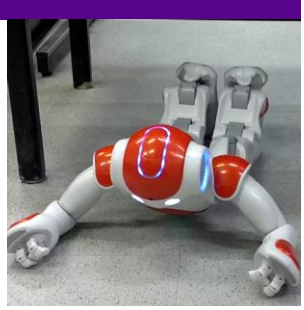
Joint Torque Cost
- Torque use improvement



Conclusion

Conclusion

Platform
GODZILA
Projected Profile
Optimization



Conclusion

Future Work
- Structure from motion
- Trap avoidance
- Crawl gait turning