URAI2012

Controlling and Maximizing Humanoid Robot Pushing Force Through Posture

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Nov. 27th 2012

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Drexel Autonomous Systems Lab

Motivation

Ultimate Goal of Humanoid is,

To work, To assist, and To interact with Human

It requires that,

1) Humanoid has to have an ability to manipulate an object, and
2) to interact with environment including human

Fundamental Continuous Dynamic Motion of Human in Manipulation

Pushing

Pulling

Lifting

Rotating and Twisting

Motion in Horizontal Direction (Pushing, Pulling)

Motion in Vertical Direction (Lifting)

Angular Motion (Rotating and Twisting)

DASL
Drexel Autonomous Systems Lab

• ultimate goal & requirements
•3D motion in manipulation (basic motion)

Motivation – Pushing

Application of Pushing Motion

In moving a heavy object

To support and hold

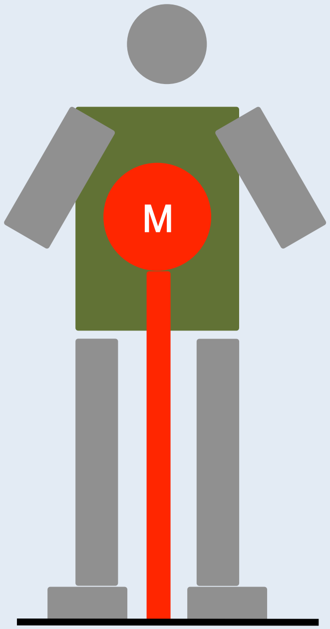
In working and manipulating

- How to make a humanoid push?
- How to control the humanoid not to fall down during pushing?
- How to control the magnitude of pushing force?

Previous Works (1)

Harada's Works

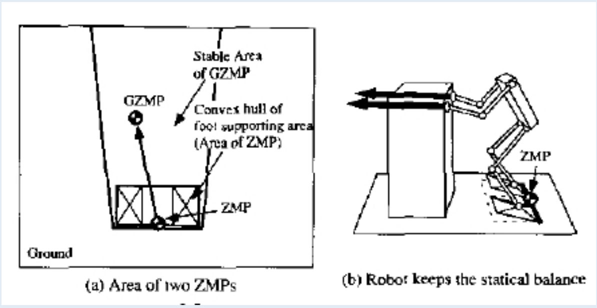
- Modeled a humanoid as Table-Cart (SIP)
- Derived mathematic relation of ZMP change by pushing force
- Controlled pushing force by change of CoM
- Applied impedance controller on arms not to tip over



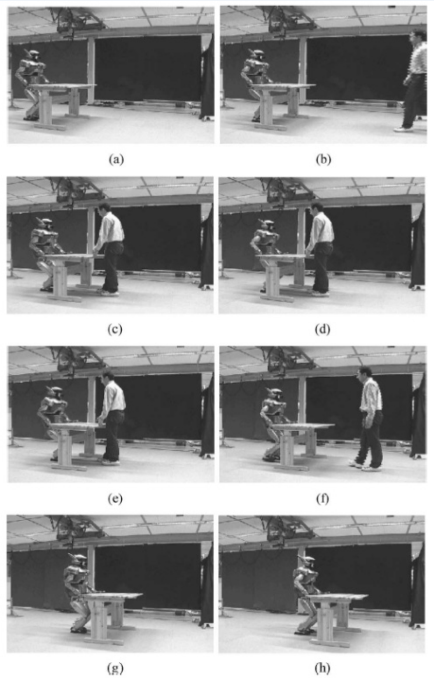
$$\Rightarrow Xzmp = x - \frac{l}{g}\ddot{x} + \boxed{\Delta x}$$

$$\Rightarrow Yzmp = y - \frac{l}{g}\ddot{y} + \boxed{\Delta y}$$

Additional ZMP compensation

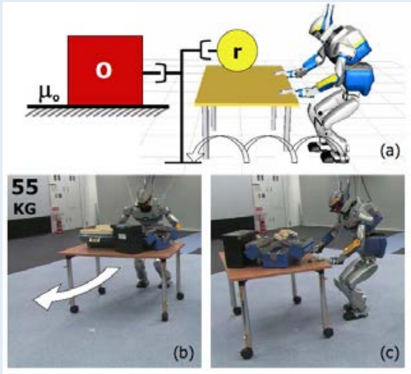


Two ZMPs "Harada2003"

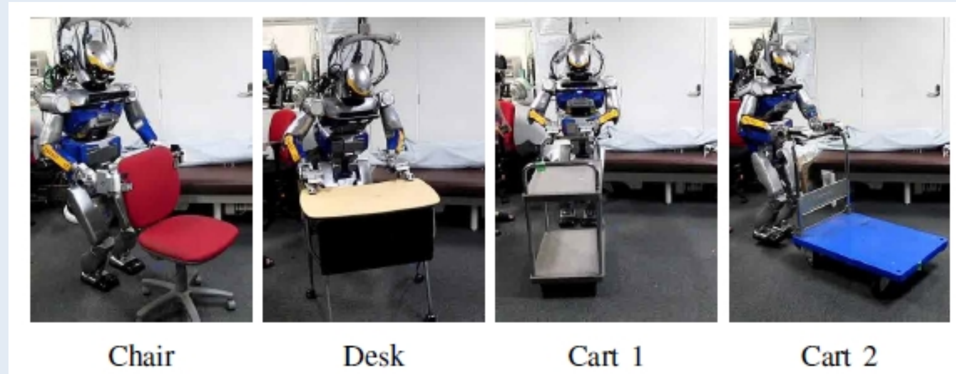


Exp "Harada2007"

Previous Works (2)



Model-based Approach
"Stilman2007"



Dual-Arm reference "Inaba2012"

Stilman's Works

- **Extended Harada's idea to manipulate an object in 3D**
- **Modeled the target object to generate force trajectory**
- **By trajectory optimization based on the humanoid, designed CoM trajectory**

Inaba's Works

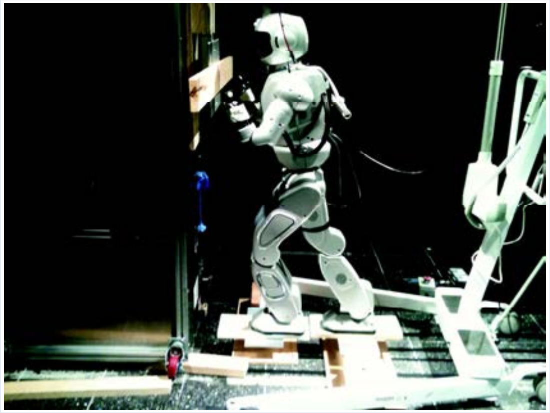
- **Extended Harada's idea to manipulate an object in 3D**
- **Control CoM position based on friction estimation**
- **More focused on impedance controller on arms for real-time motion planning**
- **Angular pushing force was achieved based on the force difference between arms**

Summary

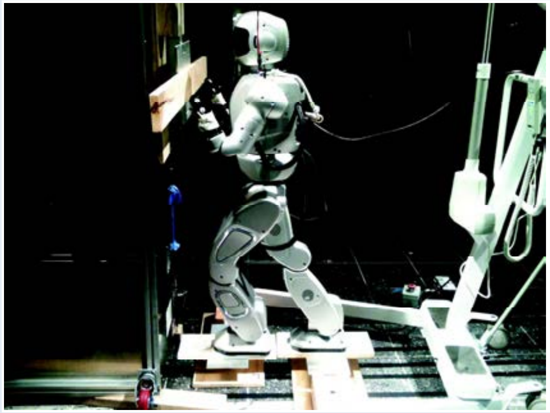
- **They focused on pushing during walking**
- **They considered environmental model to control the pushing force**

Our Work

Pushing Posture: Lean



Pushing Posture: Maximum Force



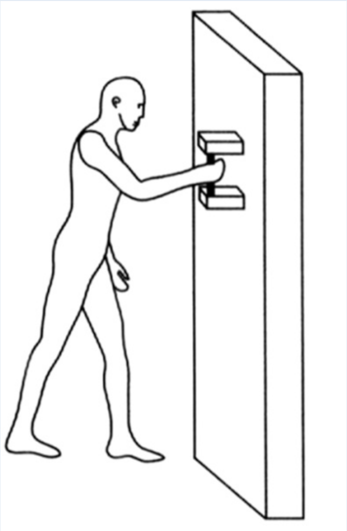
Pushing Posture: Straight Up

Our Focus

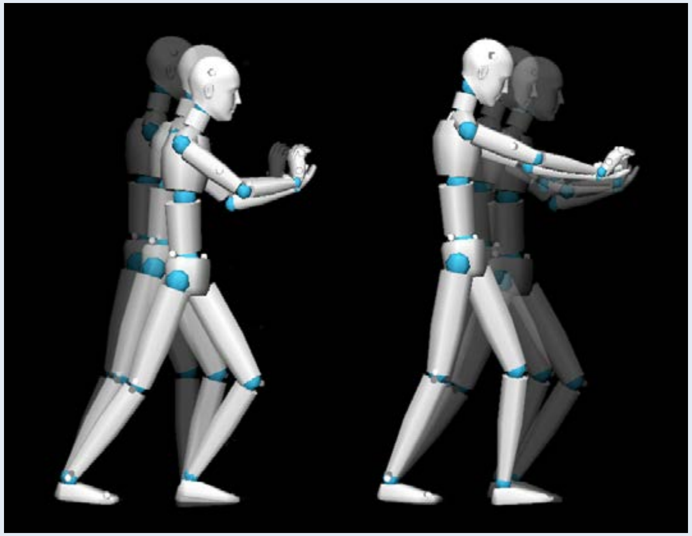
- Extending the previous works to push in place
- Relationship between body posture and pushing force
- Controlling the pushing force by body posture
- Deriving Maximum pushing force

Important!
Since the robot is mechanically limited, and There is no fixed point to the ground

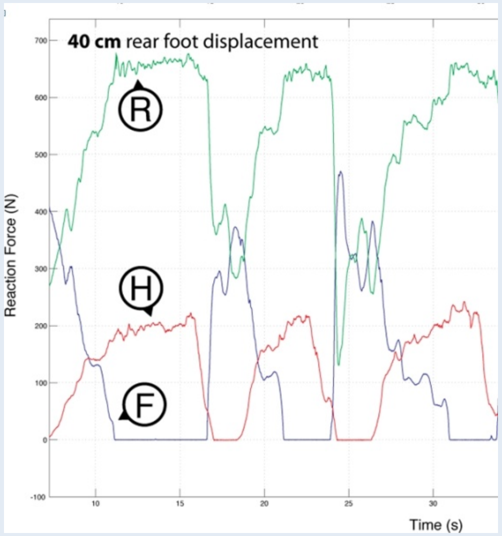
Human Pushing Motion Analysis



Feet-apart strategy
"Rancourt2001"



Human pushing captured by MoCap



Feet & Reaction force measurement

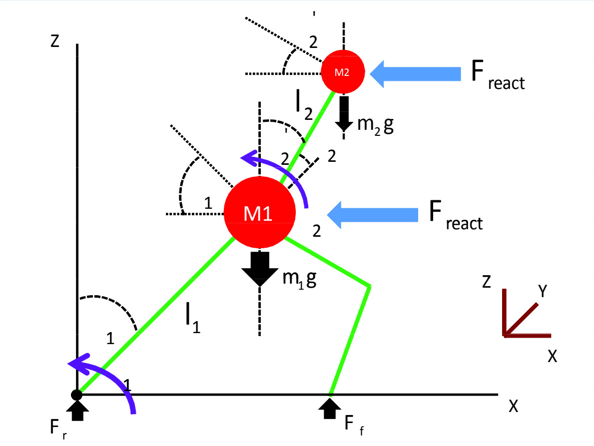
Condition

- **Pushing height is constrained**
- **Foot displacement is specified**

Conclusion

- **Pushing force magnitude is limited by its posture**
- **Maximum force is not achieved by CoM position but by pushing angle & upperbody posture**

Dynamic Model & Force Graph

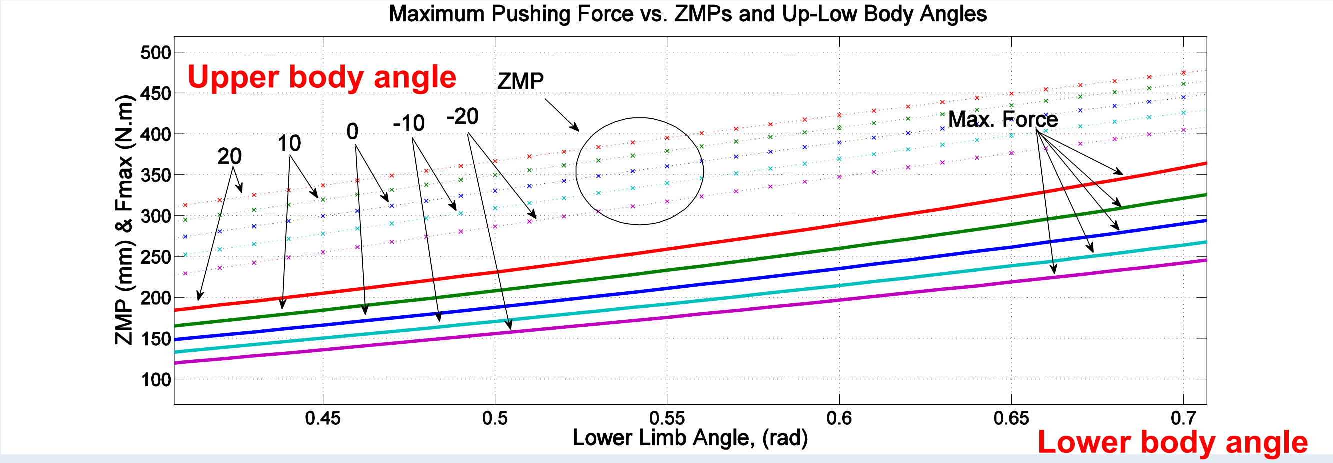


Double Inverted Pendulum Model

Dynamic Equation & Maximum Force

$$\begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} = M(\theta)\ddot{\theta} + V(\theta,\dot{\theta}) + G(\theta)$$

$$F_{\max} = \frac{(m_1+m_2)l_1 g\sin(\theta_1) + m_2 l_2 g\sin(\theta_1+\theta_2)}{l_1\cos(\theta_1) + l_2\cos(\theta_1+\theta_2)}$$



Maximum Pushing Force vs. ZMP and Postures

$$m_1 = 30kg$$
$$m_2 = 17kg$$
$$l_1 = 560mm$$
$$l_2 = 367mm$$

Pushing Force Controller

Horizontal Drilling

Horizontal Jack-Hammering
Breaking a Wall

Condition

- **Pushing height is fixed**
- **Varies the reaction force a lot**
- **Foot location is fixed**

$$P_h = l_1 \sin(\theta_1) + l_2 \sin(\theta_1 + \theta_2) = const.$$

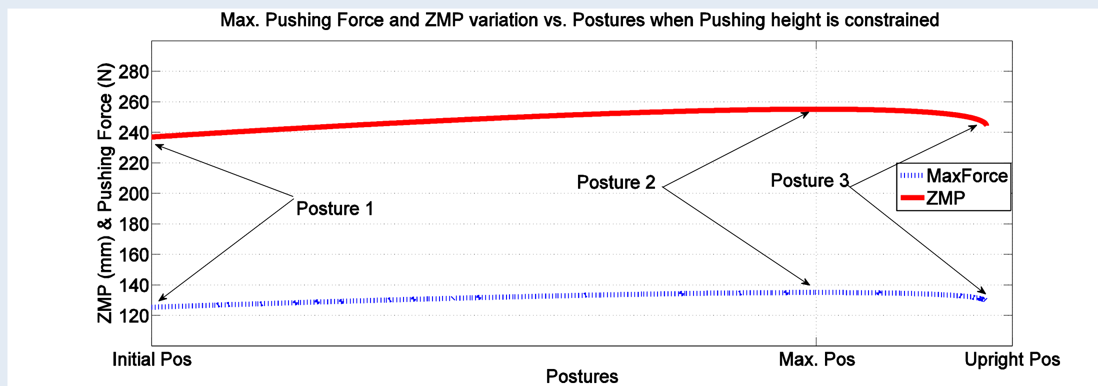
Iterate

Input = force

$$F = \frac{(m_1 + m_2) l_1 g \sin(\theta_1) + m_2 l_2 g \sin(\theta_1 + \theta_2)}{l_1 \cos(\theta_1) + l_2 \cos(\theta_1 + \theta_2)}$$

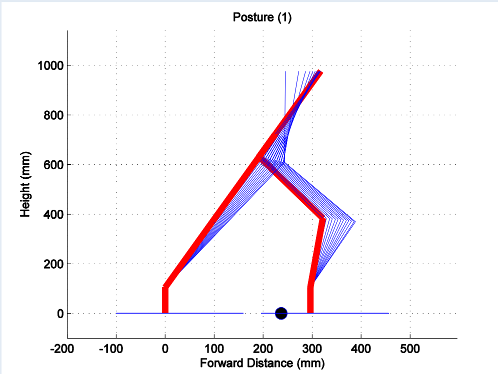
Design Impedance Model

End

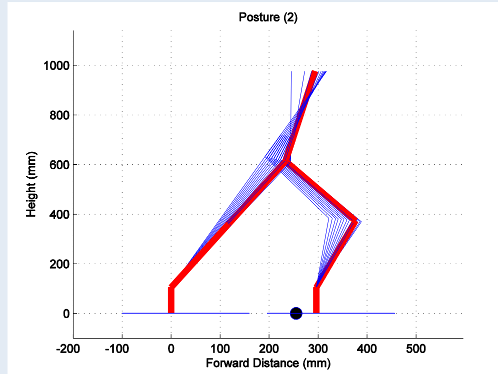


Force & ZMP variation under the conditions

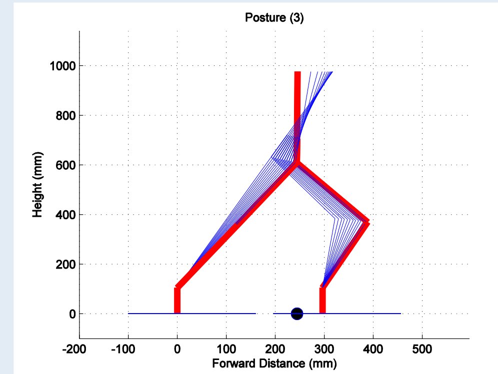
Experimental Validation



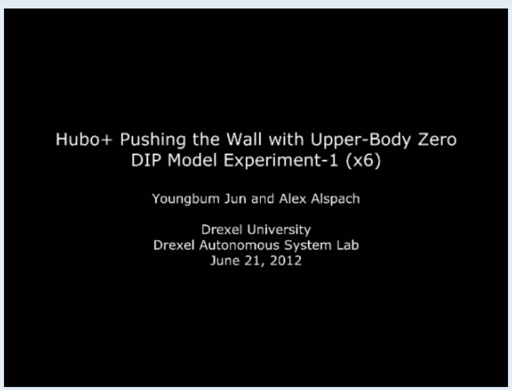
Posture 1
LowBody Angle = 20deg
UpperBody Angle = 0 deg

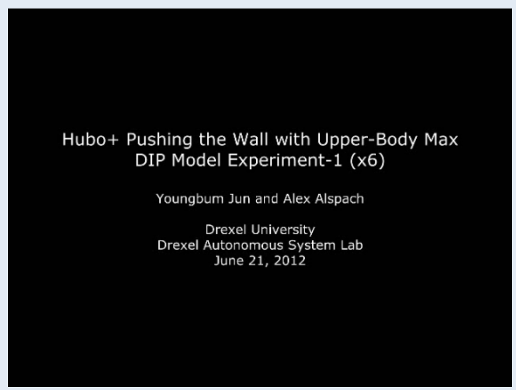


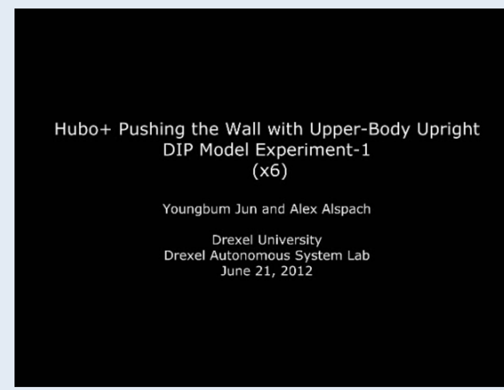
Posture 2
LowBody Angle = 24.63deg
UpperBody Angle = -15.21 deg



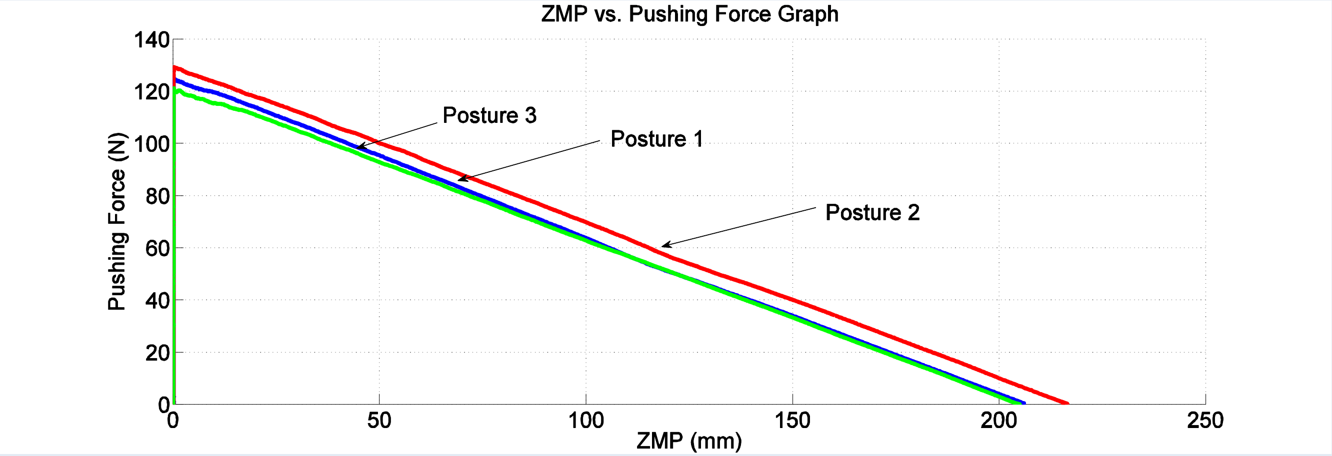
Posture 3
LowBody Angle = 25.81deg
UpperBody Angle = -25.60 deg







Result & Future Work



Pushing force comparison to validate the dynamic model & pushing force changed by robot's posture

Conclusion

- **Double inverted pendulum model is a valid model to describe robot's dynamic pushing model**
- **There is a unique posture that generates the maximum pushing force**
- **Posture is the important criterion to control the pushing force**

Future Work (this study is still on going..)

- **Research on robot's stiffness in terms of postures**
- **Apply impedance controller based on its stiffness to control the pushing force sophisticatedly**

Congratulation !!
DREXEL University has been selected for DARPA Robotic Challenge !!

Question ?
Thank You !

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