LOCOMOTION AND HAPTIC INTERFACE FOR VR EXPLORATION: FEET FOLLOWERS

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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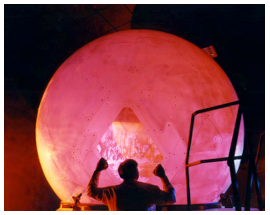
Haptic and Locomotion interfaces

- Types of locomotion interfaces:
  - Pedaling Devices
  - Walking in place systems
  - Treadmils (1D or 2D)
  - Foot Following
  - ...

Tectrix VR bicycle (Georgia Tech)

Iwata's GaitMaster



Cybersphere (university of Warwick)

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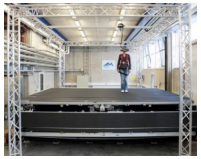
Haptic and Locomotion interfaces

- Haptic interfaces refers to interfaces involving the human hand to manual sensing and manipulation (Duralch et al., 1994)
  - mechanical position tracker
  - actuated joints

PHANTOM Omni (Sensable technologies)

- Locomotion interfaces refers to interfaces involving the human body/legs/feet and to natural or induced locomotion

CircularFloor



CyberWalk platform

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Haptic and Locomotion interfaces: Feet Followers

- Two interesting works:
  - **A foot following locomotion device with force feedback capabilities**, M.Schwaiger, H. Ulbrich and T. Thümmel, *Institute of Applied Mechanics, Technical University Munich.*
  - **Walking Control of a Dual-Planar Parallel Robot for Omni-directional Locomotion Interface**, J. Yoon, *Intelligent Robot Research Division Electronics and Telecommunications Research Institute Gajeong-dong, Yuseong-gu, Daejeon,* J. Park and J. Ryu, *Departement of Mechatronics Gwangju Institute of Science & Technology Oryong-dong, Buk-gu, Gwangju, Korea.*

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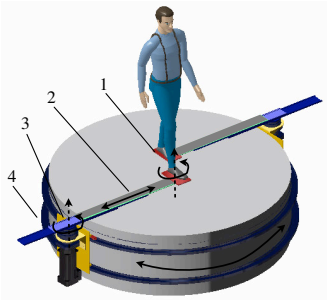
Foot Following Platform

- 2 arms wich carry a footpad that always remains underneath the walker's foot
- 3+1 DOF (each arm)
- The carriage (4) can rotate infinitely around the platform.

1. Footpad connected to arm with a rotational degree of freedom
2. Arm with linear motion
3. The arm can rotate at the carriage
4. The carriage can rotate around the platform



Foot-Following platform

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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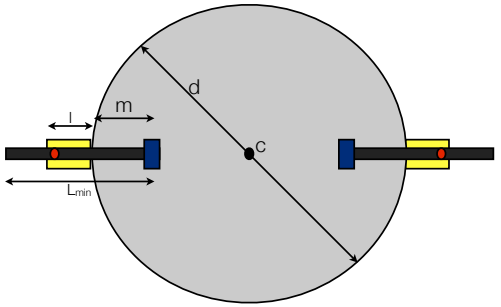
Foot Following Platform

$d = 2500$ mm
$l = 750$ mm
$L_{min} = 1216$ mm
$L_{max} = 2500$ mm
$m = 1216 - 750 = 466$ mm

Cost: 80.000 €



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Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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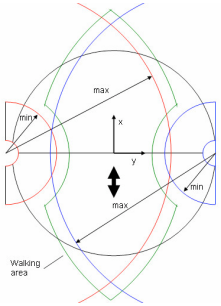
Foot Following Platform

- Arms has circular two circular range operation (min, max).
- Vertical force applied by the walker on the footpads is absorbed by telescopic guide and support bearings wich slide on the platform.
- The angle of footpad is adjusted with a small motor.
- Mounting position of telescopic arm is foundamental.



Walking Area

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Dipartimento di Informatica e Sistemistica Antonio Ruberti
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Foot Following Platform

- Linear Telescopic Guide:
  - The most expensive part.
  - Full lenght not avaiable: rotation of joint 3 generates high lateral acceleration forces wich require both stifness and small masses.
  - Actuated by a combination of gear racks wich provide a synchronous deployment of both segments:
    - PRO: very solid and simple technology, small mass, resonable cost, motor mounted on the carriage
    - CON: dinamics and clearance degradate speed and accuracy

Gear Racks

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Dipartimento di Informatica e Sistemistica Antonio Ruberti
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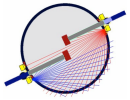
Foot Following Platform

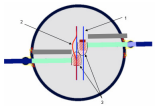
- Tracking & Security:

VICON Tracking System

  - Position of feet tracked by using ART (60 Hz)or VICON (1-10 KHz) + 6DOF Force sensors. Hip provides the orientation of the body and the walker's eccentricity. Heel and toe provide the orientation and position of the foot.
  - 2 States are tracked: Foot landing on the platform but not fully placed and full contact (same procedure for the foot loosing contact with the platform).
  - If the security system recognizes large deviation between actual and reference position or the user misses the footpad the platform is shuted down.
    - Lasers Scanners provide for a complete coverage of the platform
    - Area of protection



Laser Scanners on Platform



1. Normal footpad trajectory, 2.Trajectory respecting the security area (3)

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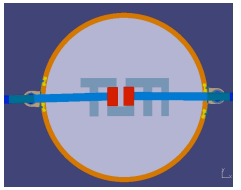
Foot Following Platform

- Controlling the Platform:
  - **The walker steps on the footpads**. Initialization routine to calibrate sensor and tracking information. Weight is stored to determine during the walk if the foot has full contact to the footplate.
  - **The walker starts to walk.** The center of mass will leave the center of the platform while the footpads follows the foot movement. After a certain "dead zone" the control starts to add a recentering component to the movement of the footpad wich has full contact to the foot.
    - **The walker starts to walk a curve.** The carriage will start to turn. The control will try to keep the carriages in a most opposite position for best coverage the whole area. The arms are moved to compensate the movement of the carriages.



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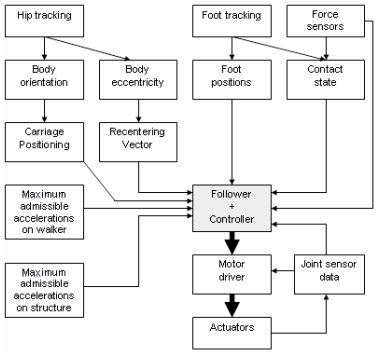
Foot Following Platform

- Controlling the Platform:



Control Scheme of the Platform

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Dipartimento di Informatica e Sistemistica Antonio Ruberti
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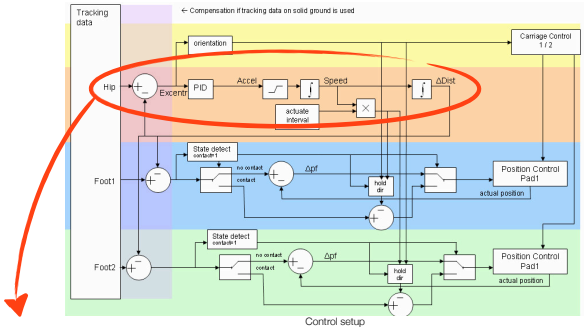
Foot Following Platform

- Controlling the Platform:



Control setup

Analyze the hip coordinates and determines the recentering acceleration and a speed value (virtual walking speed).

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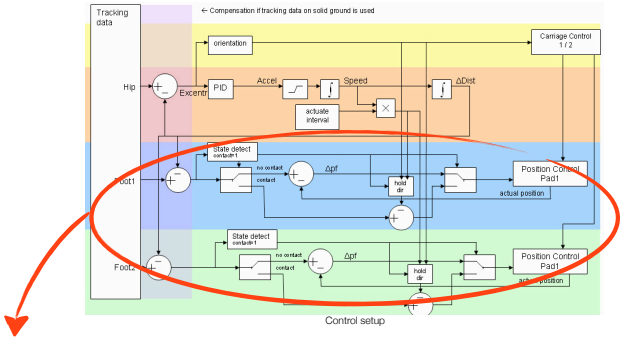
Foot Following Platform

- Controlling the Platform:



Control setup

Position of the footpads: **If no contact** the pad follows the foot

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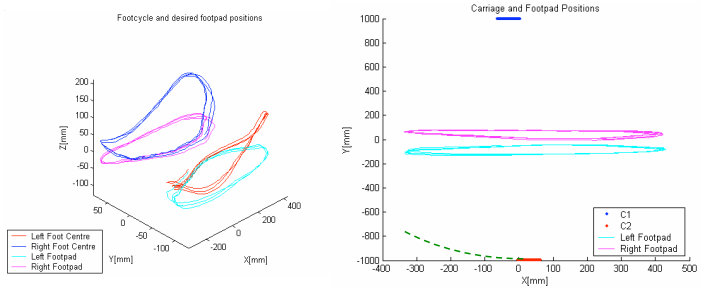
Foot Following Platform

- Experiment's Results:



Gait trajectories and desired footpad motions

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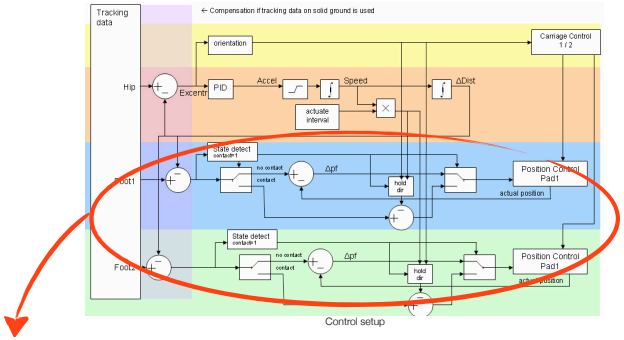
Foot Following Platform

- Controlling the Platform:



Control setup

Position of the footpads: **If contact** the controller applies the virtual walking speed to the foot

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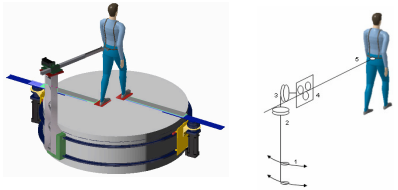
Foot Following Platform

- Force Feedback Extension:



Force Feedback assembly and reduced mechanical model

By this setup is possible to apply forces in two dimensions to have a highly immersive experience for the user. In this case is possible to reduce the dimension of the platform and maintain the walker in the center from the first moment.

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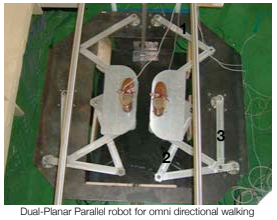
Dual-planar Parallel Robot

Allowed walk:

step = 0.8m
foot angle = 20 deg



Dual-Planar Parallel robot for omni directional walking

- The device is composed of two indipendent planar parallel robots.
- Each planar parallel robot is composed by three limbs with three serial revolute joints with the actuated first joint. The revolute joints has not mechanical limits to maximize the workspace.
- Links are made of light alluminium, rotary servomotors (3 KW, m.t. 86 Nm) are directly connected to lower bars without reduction gears.

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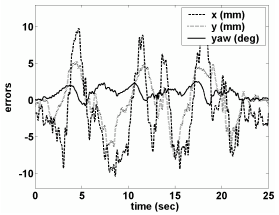
Dual-planar Parallel Robot

- Position Sensing of Human Walking

With both "true and magnetical position" the position/orientation error can be calculated. This error can be subtracted from the tracked values.



Calibration results of a magnetic tracker

After calibration the maximum error for x, y and yaw are respectively about 10 mm, 6 mm and 3 deg.

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Dual-planar Parallel Robot

- Position Sensing of Human Walking

- Position and orientation of the foot are measured using Polhemus 3D magnetic trackers FASTRACK (25 Hz), one of this tightly attached to the shoe.
- Magnetic Tracker does not suffer of line of sight problem but suffers of magnetic noises caused by metal in the platforms. Good accuracy is garanteed for distance of 30 cm.

FASTRACK

- Calibration is needed to improve the accuracy of the magnetic tracker by compensation of the position and orientation error, the reciver is attached on the shoe on the platform and is moved by the motion of the platform:
  - True position/orientation acquired by numerically calculating forward kinematics of the platform
  - Magnetically measured tracked position/orientation of the reciver are stored

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Dipartimento di Informatica e Sistemistica Antonio Ruberti
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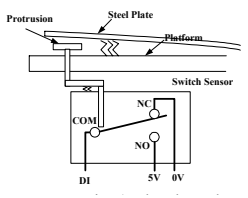
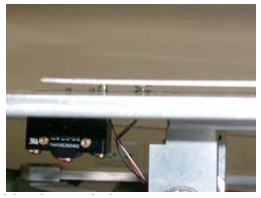
Dual-planar Parallel Robot

- Phase Transition Detection by Switch Sensors




Micro switch sensor

Simple and robust method to detect phase transiction regardless user's weight

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Dipartimento di Informatica e Sistemistica Antonio Ruberti
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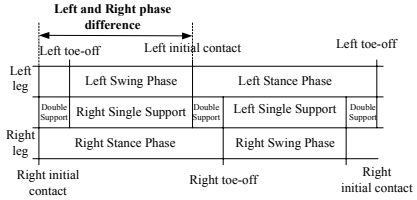
Dual-planar Parallel Robot

- A New cancellation method



Normal Gait Cycle with double support

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Dipartimento di Informatica e Sistemistica Antonio Ruberti
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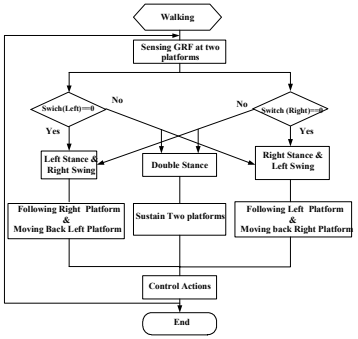
Dual-planar Parallel Robot

- A New cancellation method



New Cancellation Method

New cancellation method considering double stance phase.

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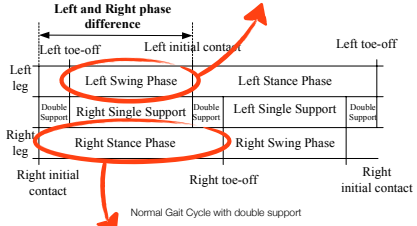
Dual-planar Parallel Robot

- A New cancellation method

accounts 40%



Normal Gait Cycle with double support

accounts 60%

During swing phase the swing phase the platform follow the foot, during the stance phase the platform should move back the same distance that it has moved forward. Without considering double support phase a user had difficulties in starting or stopping walking.

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
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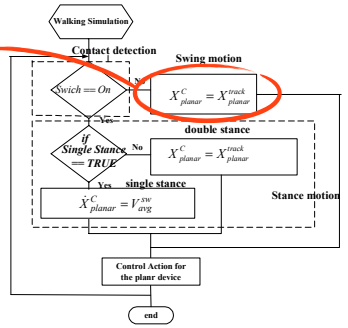
Dual-planar Parallel Robot

- A New cancellation method

The planar motion X^{tr}_{pl} is used to comand the motion of the footpads to follow the foot in the swing phase



Control action for each platform

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Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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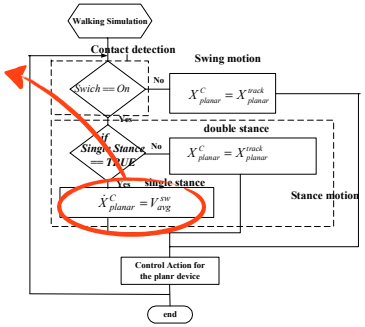
Dual-planar Parallel Robot

The V^{sv}_{avg} is the average velocity of a foot during the swing phaseuse to move back the footpads.

$$V^{sw}_{avg} = \frac{1}{T_{sw}} \int_{t}^{t+T_{sw}} \dot{X}^{sw}_{planar} dt$$



Control action for each platform

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
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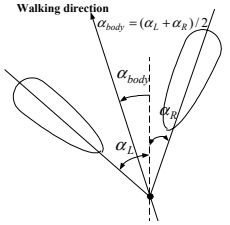
Dual-planar Parallel Robot

- Estimation of body angle for Turning Walking



Instant body angle estimation

- Istant orientation of human body estimated by averaging direction of two feet at starting stance phase point.
- Maximum allowable angle is set to 20° to prevent collisions.

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Dipartimento di Informatica e Sistemistica Antonio Ruberti
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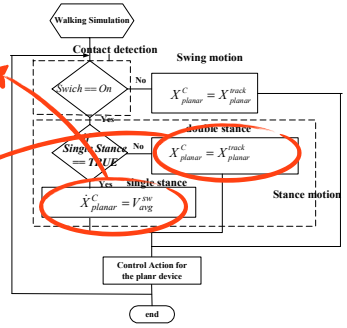
Dual-planar Parallel Robot

- A New cancellation method

The V^{sv}_{avg} is the average velocity of a foot during the swing phaseuse to move back the footpads.

The current tracker positions are inserted so each platform will sustain current position



Control action for each platform

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
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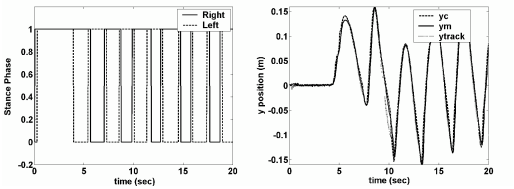
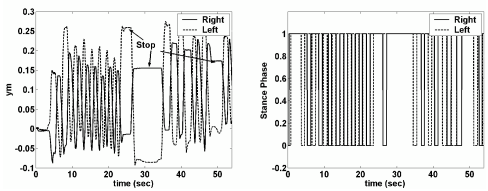
Dual-planar Parallel Robot

- Experiment's Results:



Walking test



Starting and stopping during walk

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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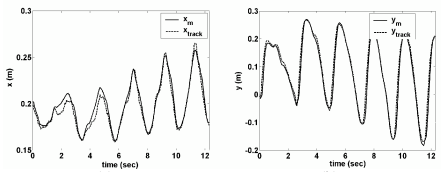
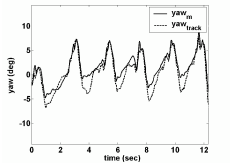
Dual-planar Parallel Robot

- Experiment's Results:



(a) x

(b) y



(c) yaw

Planar Omni directional walking (right platform)

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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Conclusions

- Two different approach using feet followers:
  - Foot-following platform permit high velocities and high turn angle
    - High cost, hardest control scheme (respect the other platform)
  - Dual-planar Parallel robot takes in count also double-stance phase:
    - Not so fast walk, low angles

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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QUESTIONS???

Mingo Enrico
Dipartimento di Informatica e Sistemistica Antonio Ruberti
Università di Roma "La Sapienza"

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