
COURSE
Perceptually Inspired Methods for Naturally Navigating Virtual Worlds
SIGGRAPHASIA2011 HONG KONG

Welcome to this course on « Natural Interactive Walking on Virtual Grounds » !

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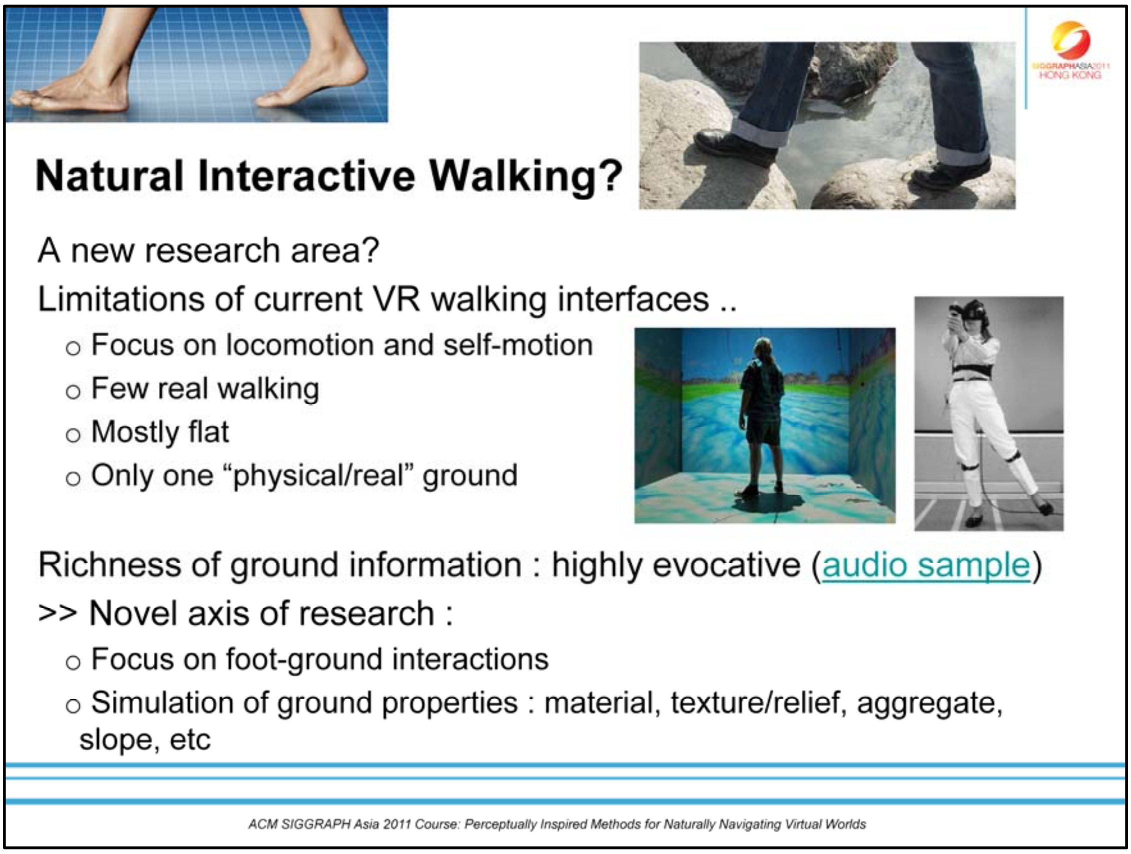
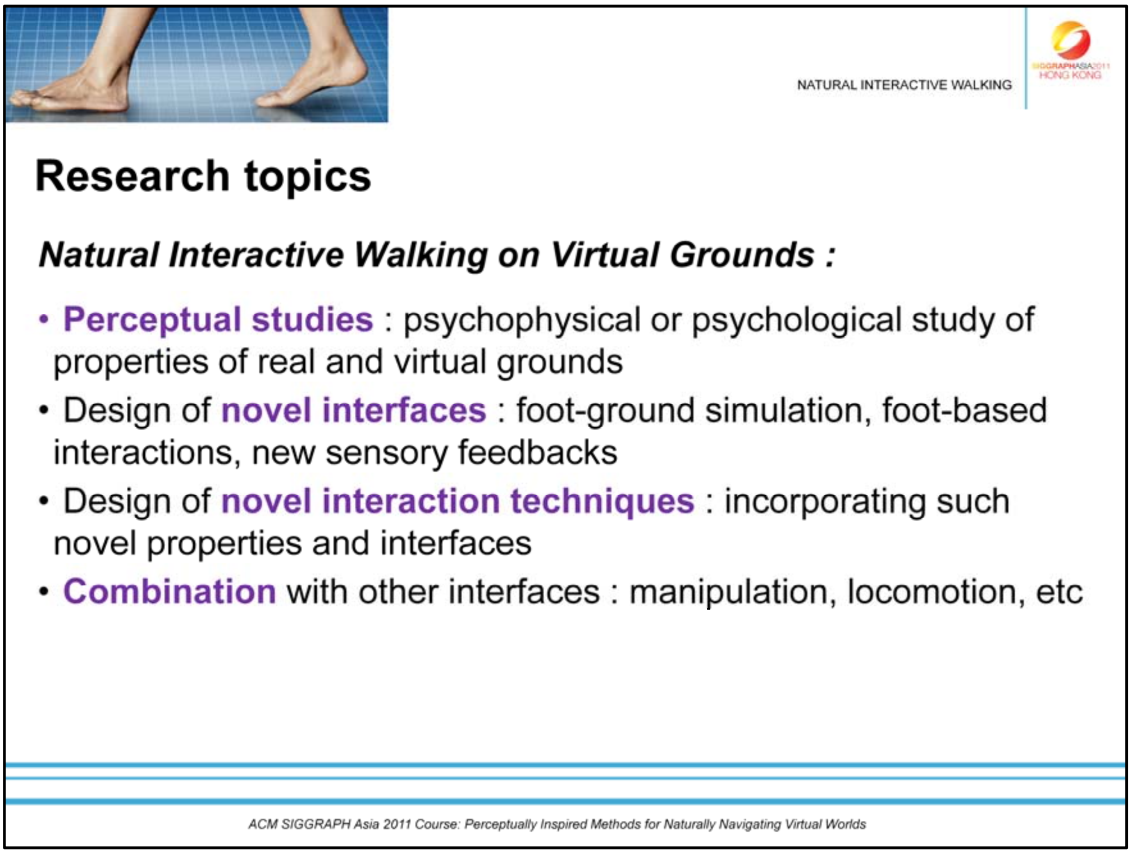


The field of « Natural Interactive Walking » refers to a rather new topic in virtual reality. It focuses on the study of simulation and interaction with virtual grounds. This encloses the rendering of ground properties such as material, texture, relief, or viscosity, by means of multiple and immersive sensory feedback using auditory, haptic, and visual channels. This new research area changes the focus to target « foot-ground interactions ». Traditional views on « walking in virtual environments » were indeed rather meant to enable global walking capabilities by means of locomotion interfaces or 3D navigation techniques until now.



The « Natural Interactive Walking » field encloses four different topics of research : (1) the perceptual studies related to foot-ground interactions, feet-based perception of ground properties, multi-sensory integration of ground cues, etc; (2) the design of novel hardware/software techniques for the rendering of interactions with virtual grounds; (3) the design of 3D interaction techniques taking into account feet-based interactions and natural walking in virtual worlds; and (4) the integration of such novel techniques together with more classical and standard virtual reality interfaces (locomotion interfaces, visual displays, etc).

The « Natural Interactive Walking » (NIW) field has been notably addressed by a pioneer project funded by Québec region (Canada) and European Commission through the NIW project. The NIW project involved 6 partners in 2009-2012 : INRIA (Rennes, France), McGill University (Montréal, Canada), University of Udinese (Udine, Italy), Aalborg University (Copenhagen, Denmark) and University Pierre and Marie Curie (Paris, France). The novel results obtained can be consulted on the project website : www.niwproject.eu

Outline

1. Perception of virtual grounds
2. Sensory feedback of virtual grounds
3. Multimodal grounds
4. Natural interactive walking techniques
5. Conclusion

[Outline of the course]

NATURAL INTERACTIVE WALKING

Outline

1. **Perception of virtual grounds**
2. Sensory feedback of virtual grounds
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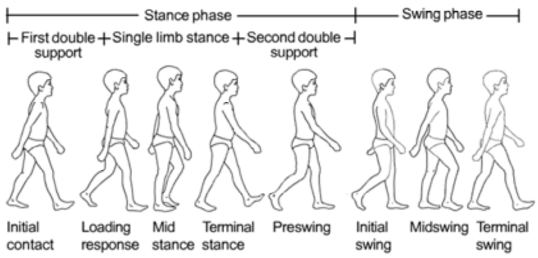
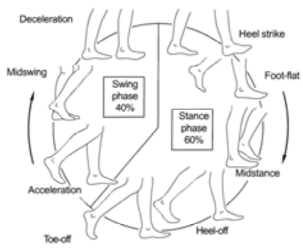
We will now address the topic of perceptual studies of virtual grounds.

Walking perception studies

Walking : extended bibliography (biomechanics, dynamics, posture, gait, sensory-motor behavior, neuroscience and control, spatial cognition, etc)

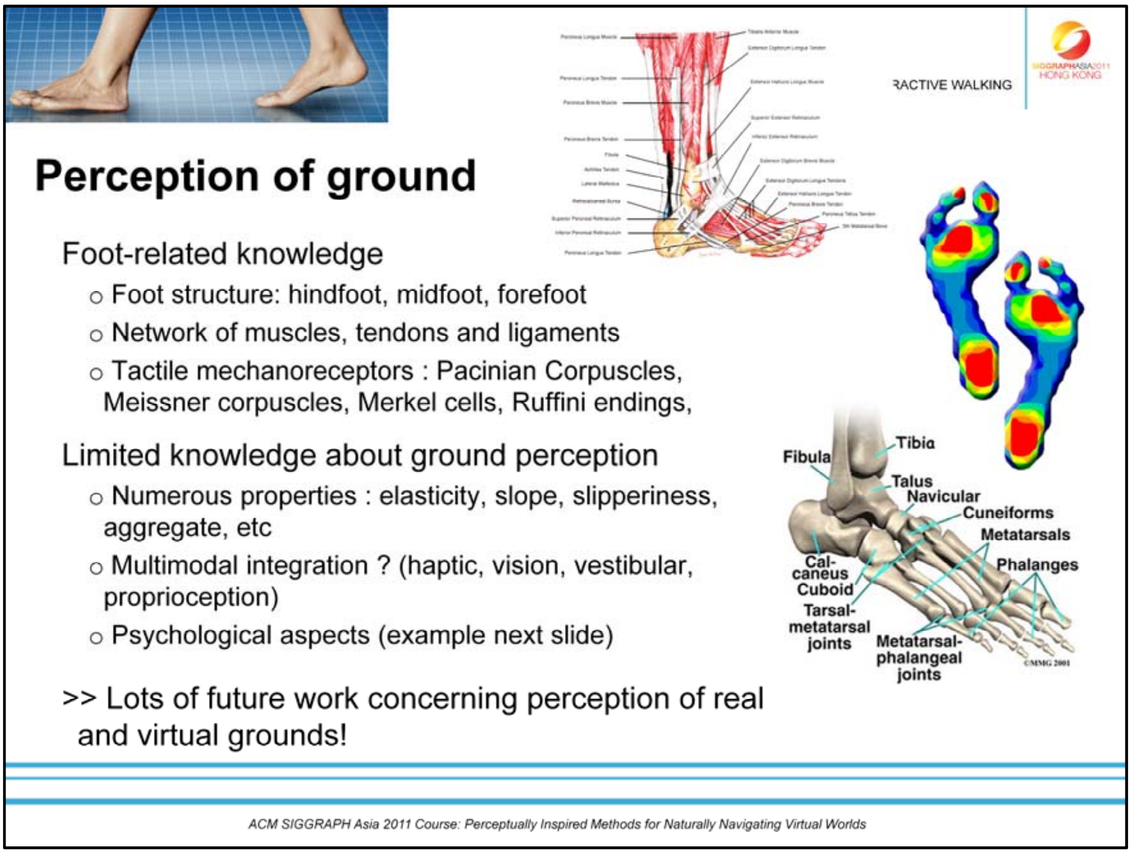




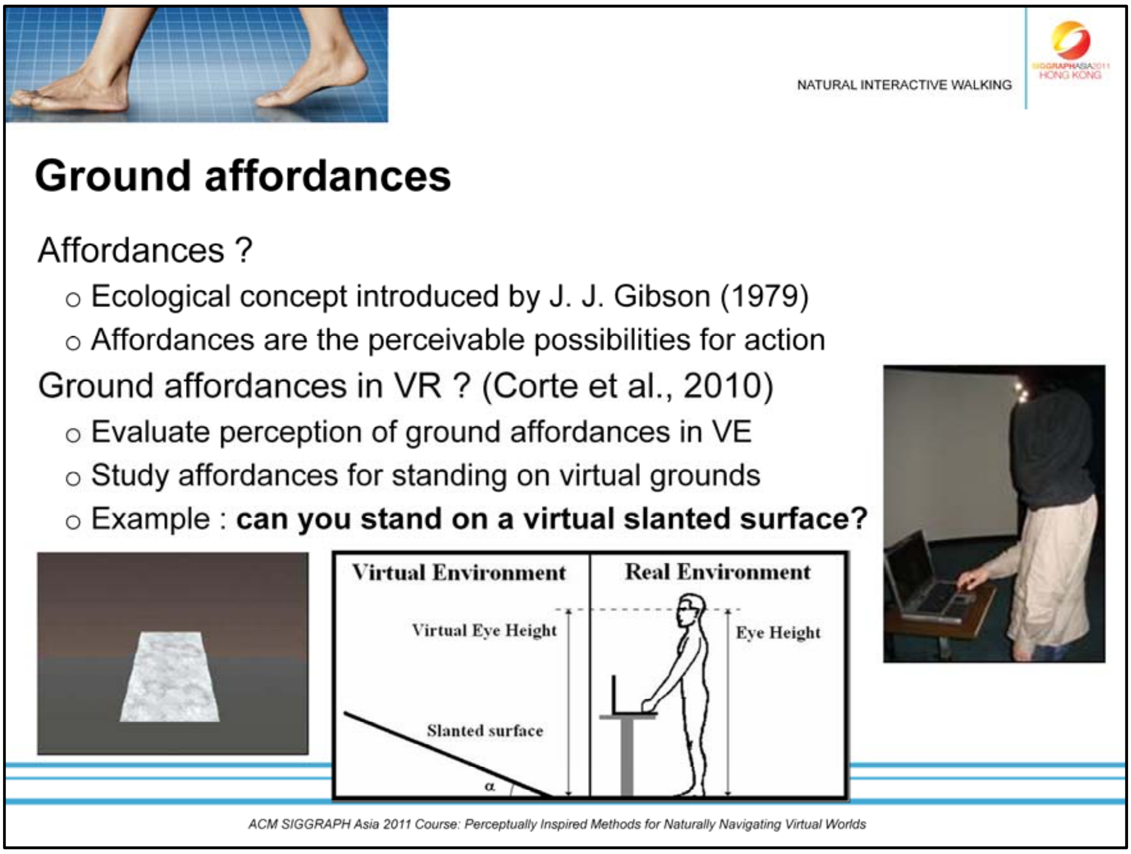
Ground perception :

- Smaller bibliography
- Related to feet sensing and properties
- Physiology and psychology

When considering the numerous existing studies in the field of perception which are related to the topic of « human walking », it is interesting to notice that very few papers are related to the perception of ground attributes during the walk. Most papers concern : biomechanics of walk, posture, gait, sensory-motor behavior, spatial cognition, etc; but we miss a lot of information concerning feet-based perception of ground properties (slope, material, etc) on both physiological and psychological aspects…



State-of-the-Art in the field of human perception of ground is very limited. One can find papers dealing with the physiological properties of human feet : foot structure, network of muscles, tendons and ligaments, or even resolution and repartition of tactile sensors. But this actually leaves a lot of space for more (and future) perceptual studies...



On the psychological side, some studies reveal important factors influencing ground perception. In the Ecological approach to Perception and Action (Gibson 1979), the perception is viewed as the active pickup of information specifying affordances, that is, the action possibilities offered by the environment. The affordance can be defined as the "functional utility of an object, a surface or an event for an animal with given physical characteristics (height, weight) and some action capabilities (effectivities) defined according to the species and ontogenetic development". (Corte et al., 2010) evaluated the perception of ground affordances in virtual environments. They considered the affordances for 'standing on a virtual slanted surface'. They notably found that participants were able to extract and to use virtual information about friction (given by the texture of the surface : woody or icy), in order to judge whether a slanted surface supported an upright stance. Such kind of information can thus be taken into account by VE designers.

NATURAL INTERACTIVE WALKING

Outline

1. Perception of virtual grounds
2. **Sensory feedback of virtual grounds**
   - **Visual feedback**
   - **Haptic feedback**
   - **Auditory feedback**
3. Multimodal grounds
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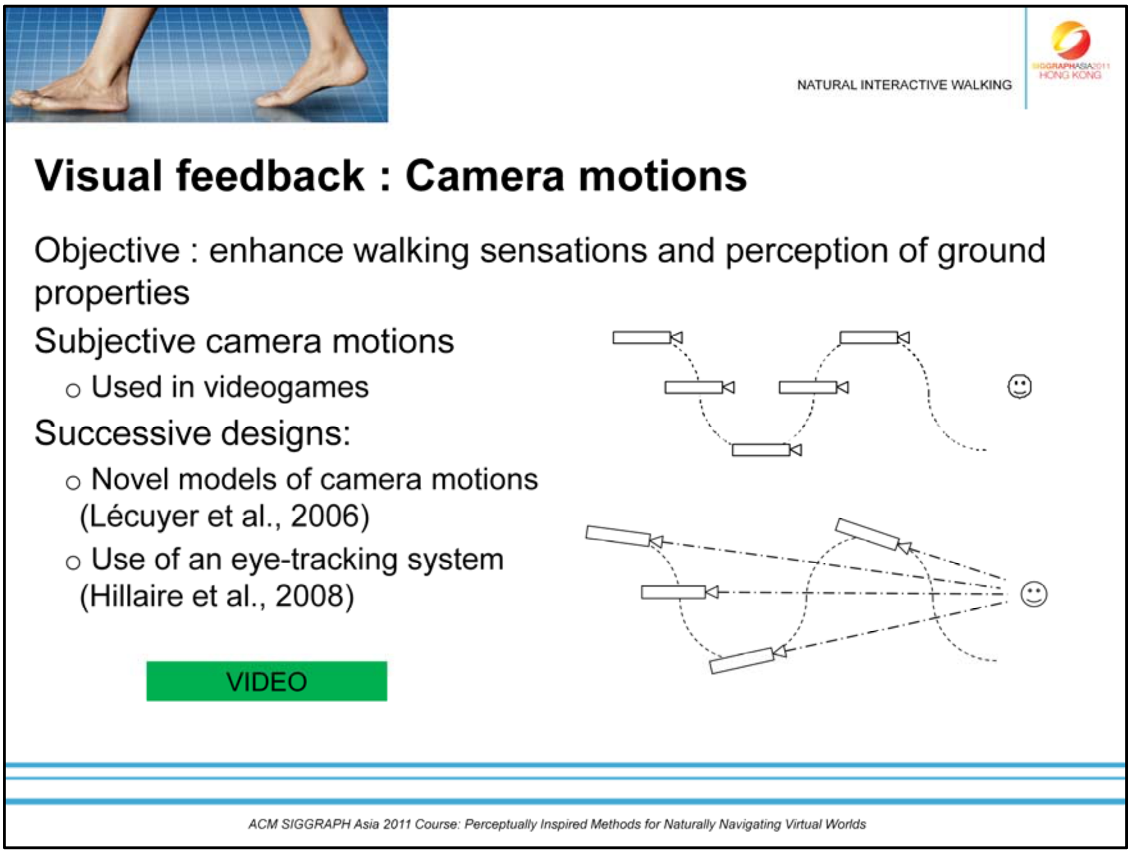
We now review the existing techniques for simulating sensory feedback of virtual grounds.



A first set of techniques is devoted to enhance the ‘visual feedback’ of walking. Several papers are proposing advanced « camera motions » for improving walking sensations. The subjective camera used to display the virtual environments if artificially oscillated, in order to reproduce the visual flow generated by human walk (Figure – top). Such kinds of oscillating motion of the camera are mimicking vestibulo-occular reflexes. A compensation motion on the orientation of the camera can then be added to enable a constant focalization on a target object (Figure – bottom).

Influence on walking perception?

Experiment on *perception of traveled distance*

- Task : « estimate a traveled distance »
- Two conditions= CM vs. no CM
- 4 distances : 5, 7, 10, 13 meters

Apparatus

- Passive visual navigation
- Immersive room, Monoscopic viewing

Results

>> Camera motions increased accuracy of reproduced distances (short distances)

>> Camera motions have a positive influence on subjective perception of distances and sensation of walking (questionnaire)

(Terziman et al., 2010)

Camera motions were shown to improve the sensation of walking in virtual worlds when standing or sitting and using controllers. But they were also found to improve, to some extent, the perception of the traveled distance.

NATURAL INTERACTIVE WALKING

Camera motions for rendering ground slope

Objective : Visual simulation of virtual ground slope

Principle : Modify the motion of the virtual subjective camera according to ground height variations

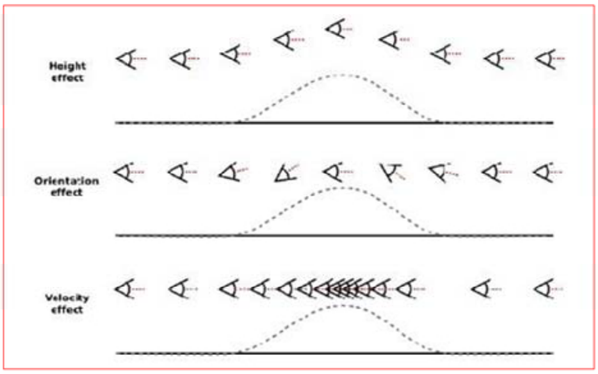
Various Effects :

1. Change height (classical in videogames)
2. Change orientation
3. Change velocity (pseudo-haptics)

Results :

- Strong effect
- Dominance of orientation effect

(Marchal et al., 2010)



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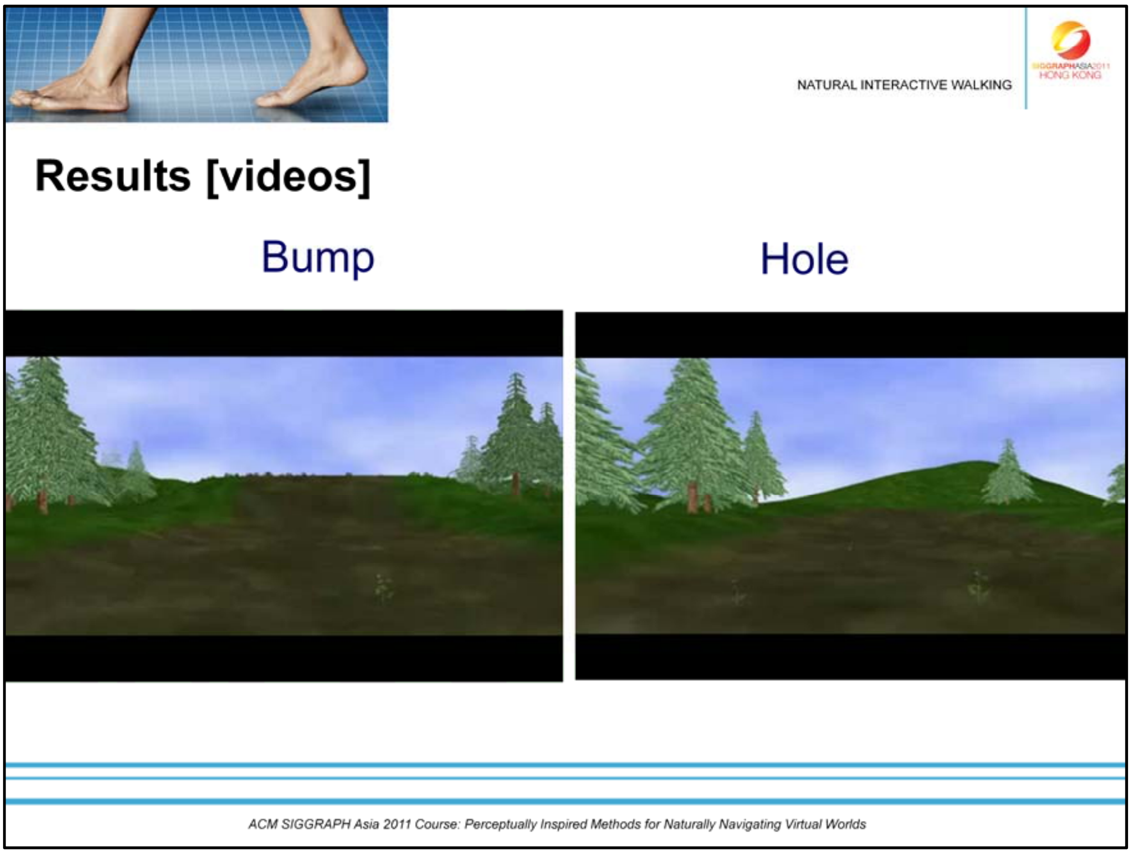
Another set of camera motions is devoted to the simulation of virtual ground slope. The objective is here to give the impression of climbing or descending over the virtual terrain by simply modifying the motion of the subjective camera. Three effects were shown to achieve this goal : (1) a change in camera's altitude (which naturally follows the height of the terrain and which is classically used in videogames), (2) a change in the orientation of the camera, and (3) a change in the velocity of the camera, which is generating slope effect similar to the well-known pseudo-haptic illusion (Lécuyer et al., 2000). The orientation effect was surprisingly found to dominate the other ones, and notably the change in height.


NATURAL INTERACTIVE WALKING
Results [videos]
Bump
Hole
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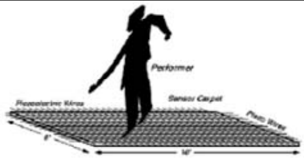
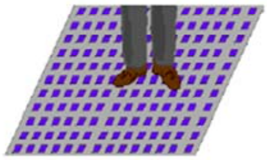
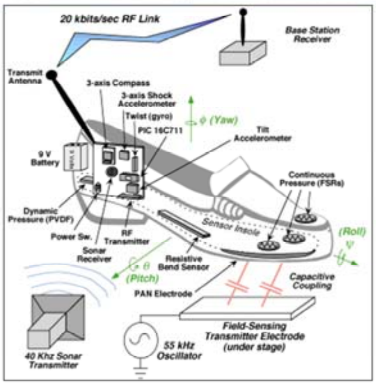
[videos]



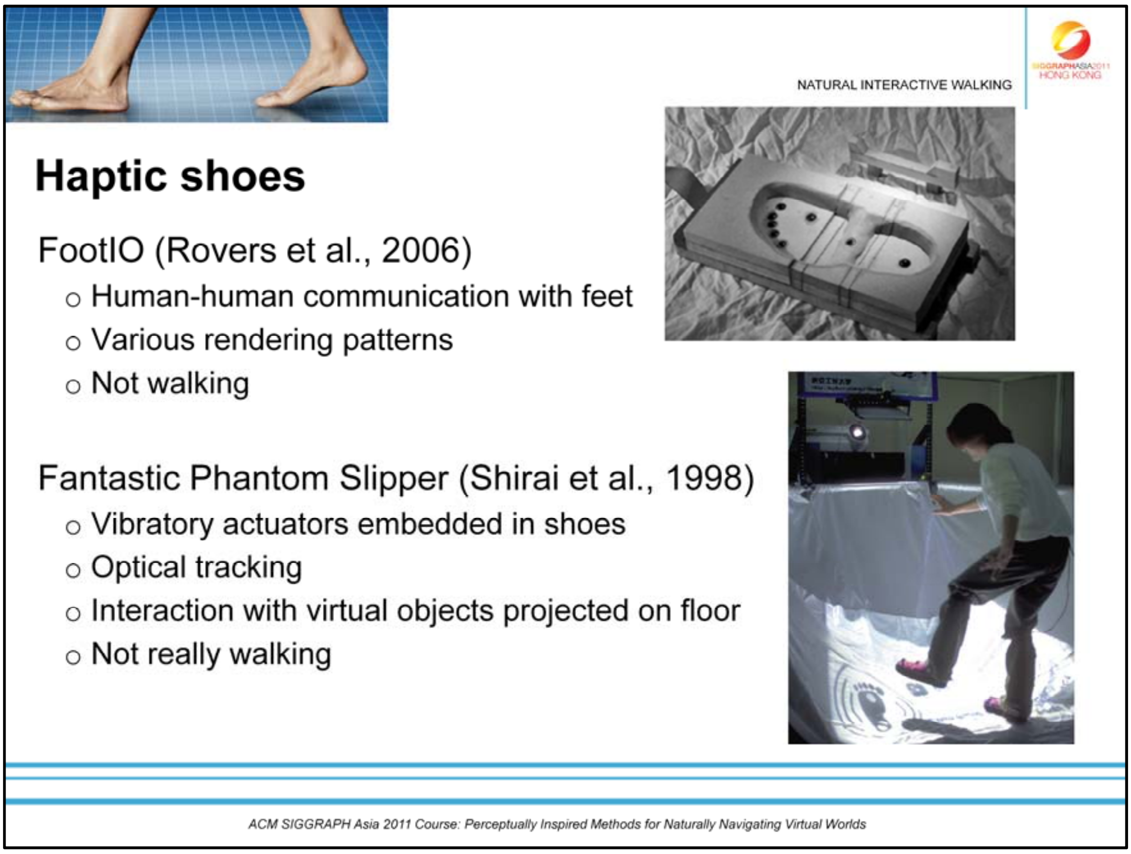


Sensing the feet

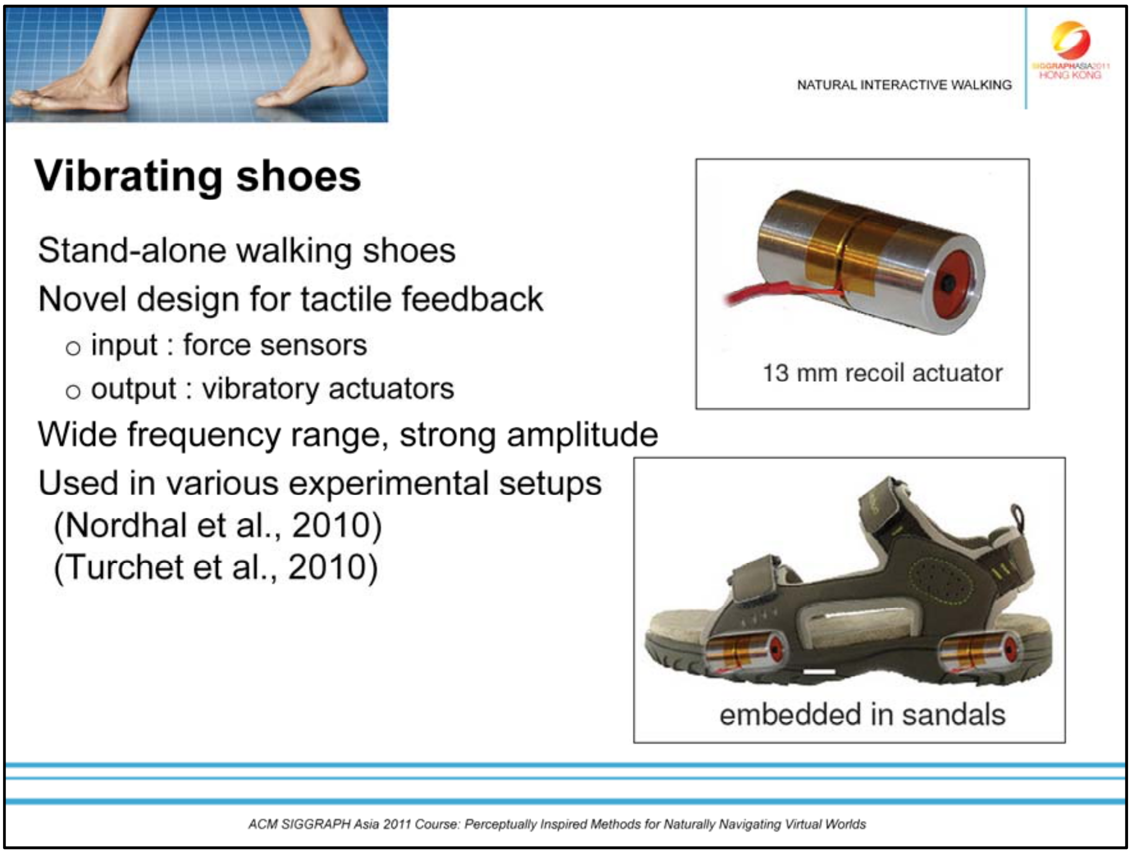
- Sensing Floors
  Z-Tiles (Richardson et al., 2004),
  LiteFoot (Grith and Fernstrom, 1998),
  Magic Carpet (Paradiso et al., 1997), etc
- Game input devices
  Dance Dance Revolution Stage (KONAMI)
  WiiFit Balance Board (NINTENDO)
- CyberShoe (Paradiso et al., 2006)
  32 parameters (16/shoe), 60Hz
  Sensors : gyroscopes, pressure, height, etc
  Walking parameters (stride length, orientation, force distribution, height, etc)



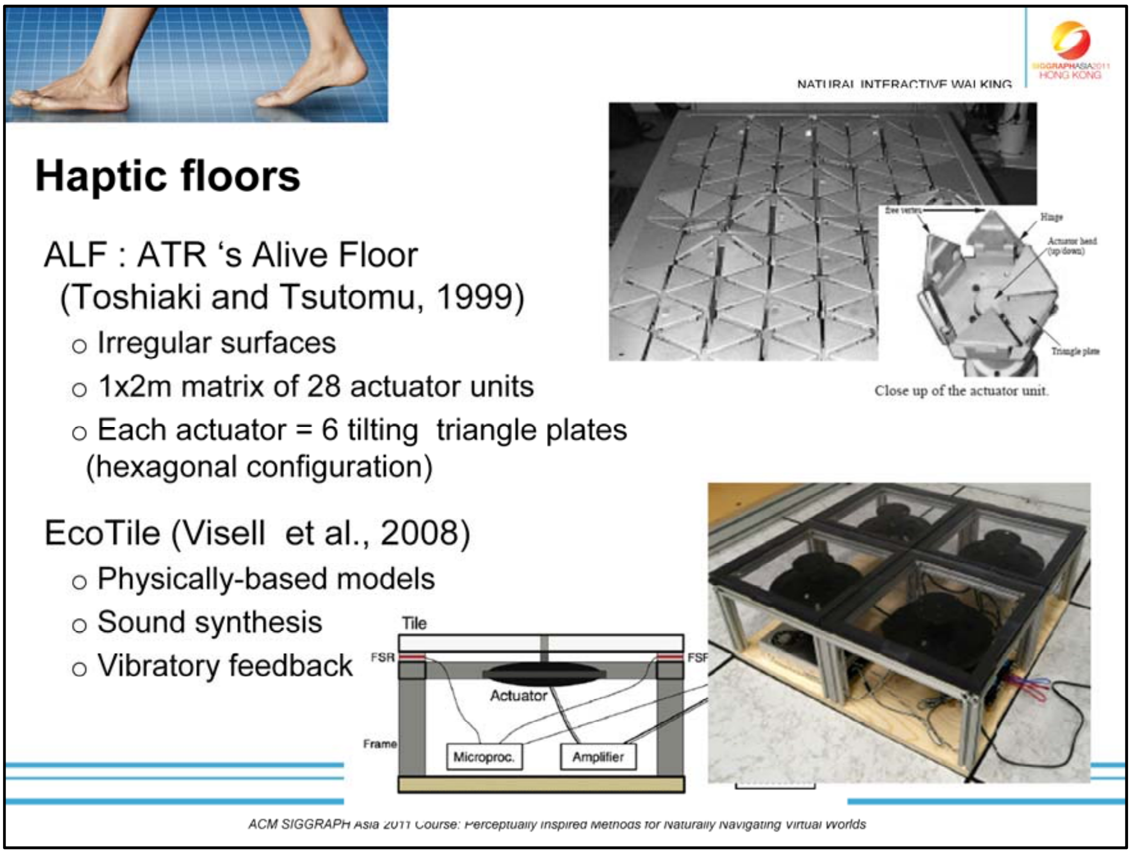
Various kinds of technology have been developed so far to sense the foot-floor contacts and track user's walk for the purpose of interacting with virtual environments. We can stress two categories : (1) sensing floors (with well-known game input controllers and "carpets"), and (2) sensing shoes.



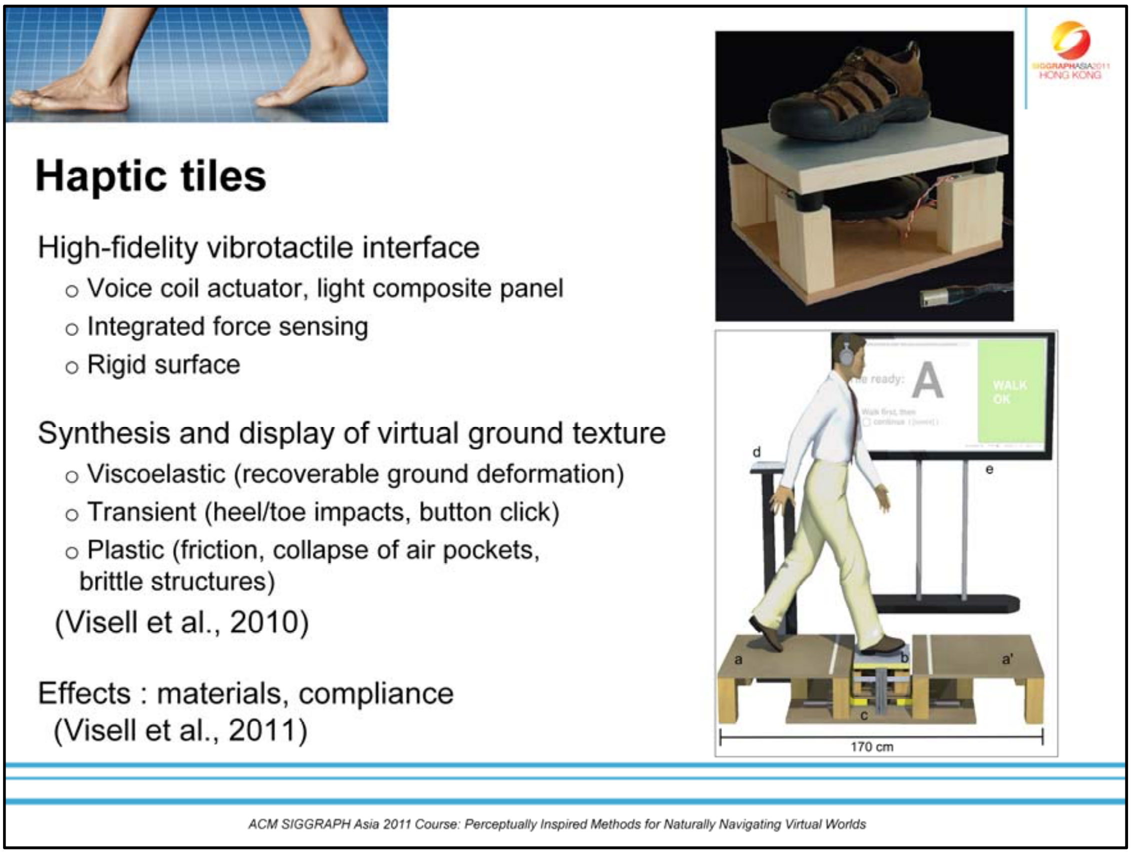
Few haptic shoes sending vibrotactile stimulations have been demonstrated in an interactive context. The early Fantastic Phantom Slipper system enables to step on vibrating objects. FootIO can be used for remote communication enhanced with tactile feedback at the level of the feet. FootIO device is static and not meant for walking (sitting position).



A new generation of vibrotactile actuators with wide range of frequencies and low weight can now be embedded in haptic shoes. This is the case for a pair of tactile shoes developed by Aalborg University and University Pierre and Marie Curie which incorporates two powerful (and very small) actuators per foot and enables various vibration patterns during the walk over simulated virtual grounds.

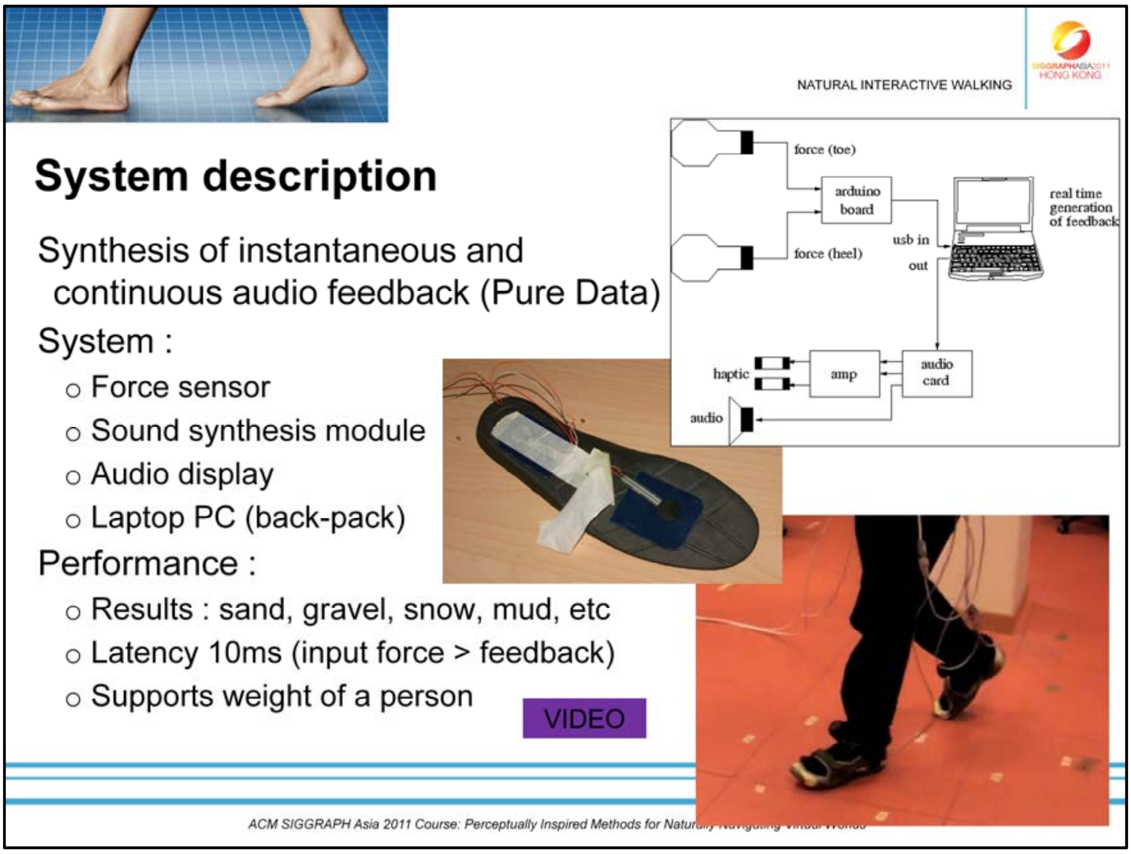


Haptic floors mostly correspond to actuated grounds made of tiles individually activated. The tiles of the ATR Alive floor are triangle plates which are locally displaced and oriented to approximate the local shape of the virtual terrain simulated. The EcoTiles are equipped with large loudspeakers generating a high-amplitude vibratory feedback under the feet.

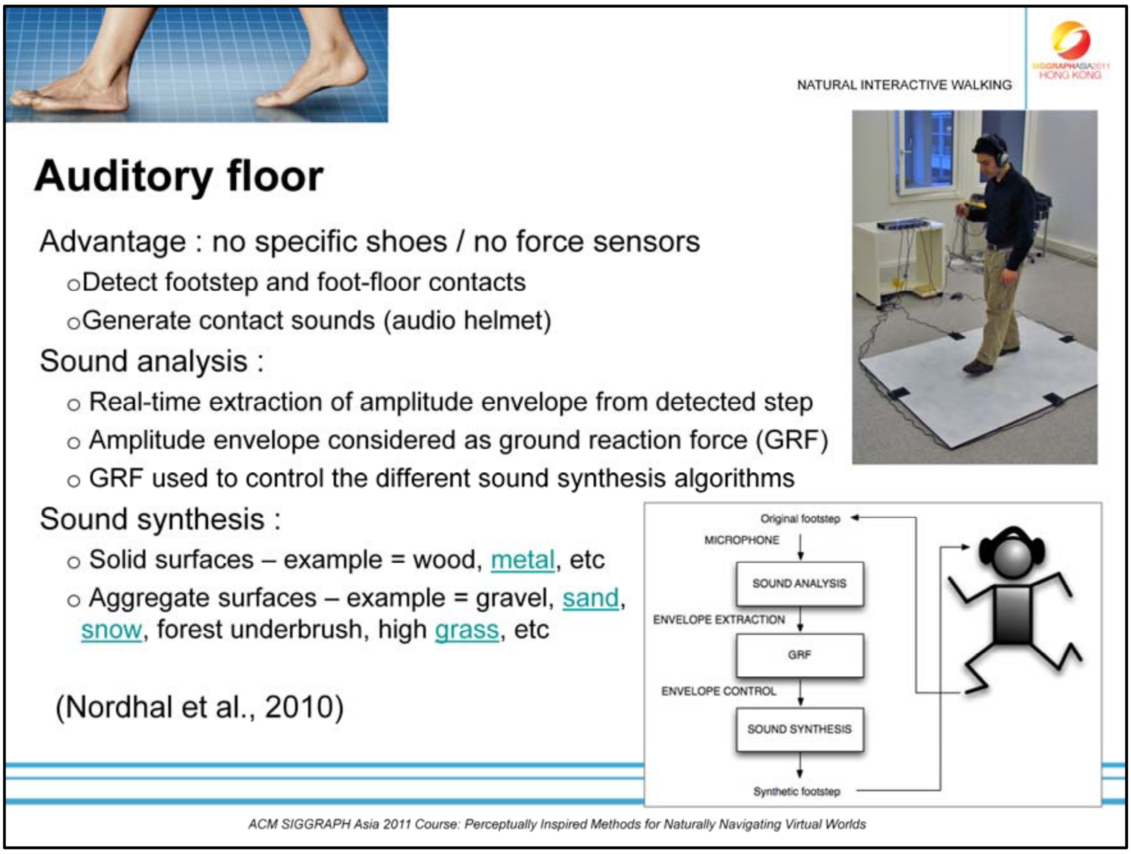


Different tile-based vibratory floors were developed at McGill University and integrated with virtual reality displays (stereo screens). Recent studies have shown how this vibratory feedback can successfully evoke virtual ground properties such as material type (texture) and, more surprisingly, vertical compliance of ground.

Auditory feedback can also be embedded and emitted by shoes using loudspeakers. Sonic shoes have been proposed by University of Verona/Udine with different and progressive prototypes (see photos).



Each sonic shoe encloses a set of force sensor(s) and loudspeaker(s). Force sensors can detect heel and toe contacts with the ground. An audio synthesis module running on a wearable computer enables to compute and generate a physically-based contact sound at each step corresponding to the intensity of the contact and the types of material involved. Examples [audio files] of such feedback are sounds of walking over : gravel, snow, mud, sand, etc.



Main advantage of auditory floors consists in proposing the auditory feedback without using specific (electronic) shoes. The system can detect pressure or sound related to user's footsteps. It can then generate artificial sounds of virtual footsteps using different kinds of sound synthesis algorithms. User is wearing audio helmet in order to mask the sound of his/her real footsteps.

User feedback

Task : identification of ground materials

Ground conditions : wood, creaking wood, snow, etc

Walking conditions :

- footsteps in real-time
- recorded synthesized
- recorded real

Efficient identification

(Nordhal et al., 2010)

	Correct answers	Wrong answers	I don't know	Degree of certainty
Beach Sand	53.34	46.67	0.	4.5
Gravel	86.67	13.33	0.	5.07
Dirt pebbles	43.33	56.67	0.	4.8
Snow	63.33	36.67	0.	5.93
Frozen Snow	70.	16.67	13.33	5.66
High Grass	10.	83.33	6.67	3.5
Forest Underbrush	36.67	60.	3.33	4.14
Dry Leaves	56.67	43.33	0.	4.77
Concrete	70.	23.33	6.67	4.43
Wood	80.	16.67	3.33	5.17
Creaking Wood	90.	6.67	3.33	6.14
Metal	96.67	3.33	0.	6.33
Carpet	66.67	23.33	10.	4.78
Puddles	33.33	66.67	0.	5.8
Water	86.67	13.33	0.	6.57

A pilot study conducted with an auditory floor gives preliminary user feedback. Results suggest that participants could efficiently identify different kinds of ground material, under different conditions : walking or not, real (recorded) or synthesized sounds.

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We will now talk about the integration of different kinds of sensory feedback, i.e., multimodal virtual grounds.

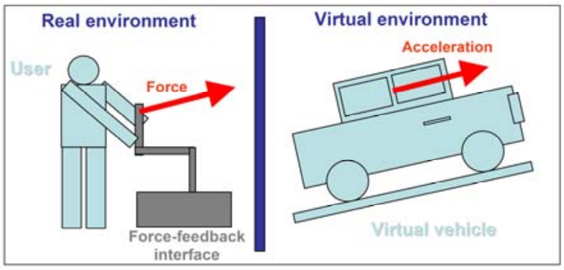
Visuo-haptic enhancement of self-motion

Objective: enhance self-motion sensation when navigating in VR with multisensory cues

Novel bimodal (visuo-haptic) effect (Ouarti et al., 2010)

Principle

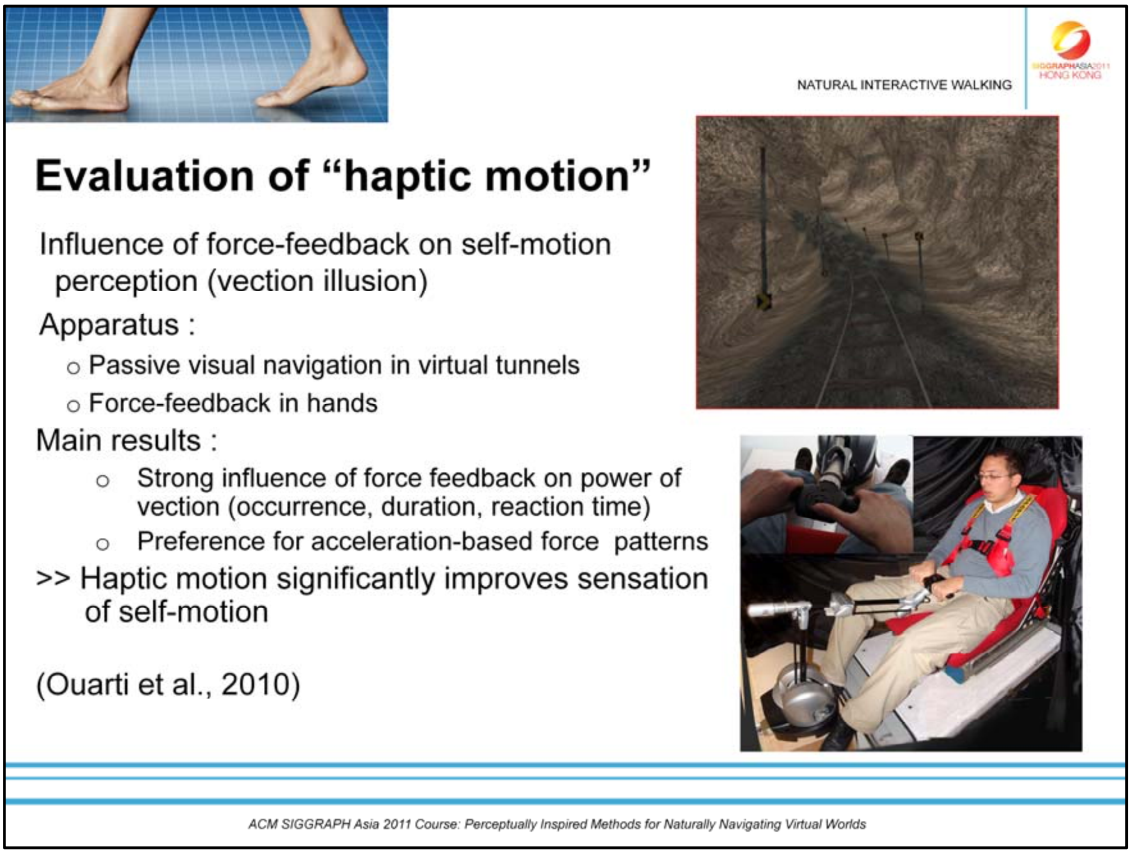
- Visual exposition and navigation
- Force-feedback in the hands
- Force-feedback proportional to virtual accelerations
- Force-feedback consistent/ synchronous with visual feedback



Hypothesis

- Generates higher sensation of self-motion than vision alone

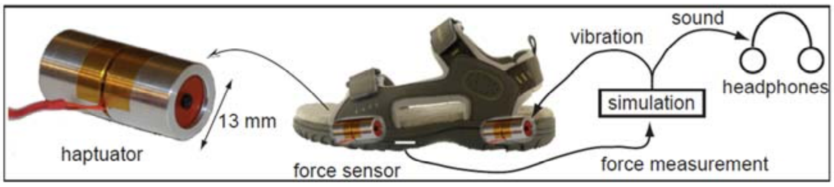
A multimodal technique integrating visual and haptic cues was proposed by (Ouarti et al., 2010) to enhance the feeling of self-motion in virtual worlds. The idea is to use a force-feedback applied in the hand(s) of the user and proportional to the acceleration of the visual navigation. This additional and synchronous haptic feedback is expected to improve the self-motion illusion at (relatively) low-cost.



The technique described in the previous slide was evaluated using passive virtual navigations in 3D tunnels. The presence of force-feedback was found to increase significantly the power of the vection illusion (illusion of self-motion) generated by the visual feedback of the navigation. Force patterns proportional to acceleration were found more powerful than ones related to velocity.

Audio-haptic virtual grounds

Combination of haptic and auditory feedback

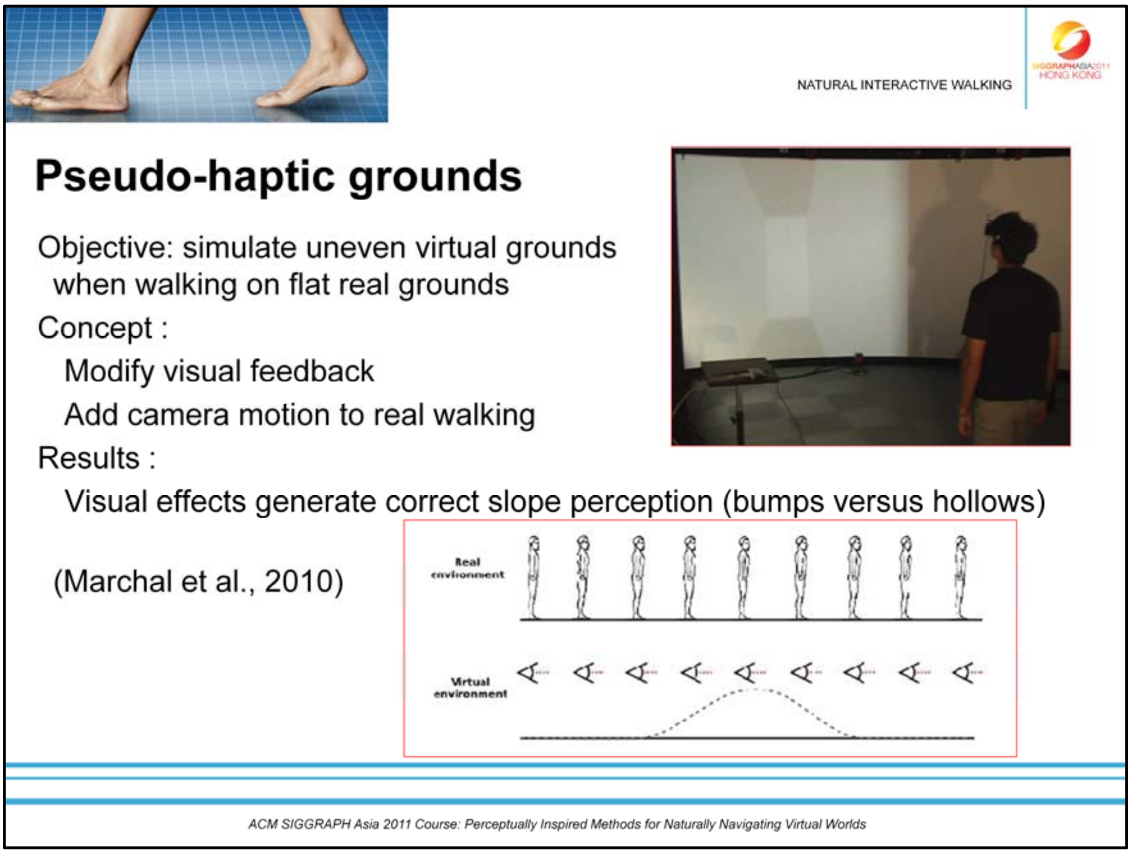


Results

- Haptic vibratory cues give the possibility to recognize surface categories
  - Solid surface not confused with aggregates such as snow, underbrush, grass;
  - Wood simulation easily confused with metal, or concrete
- Auditory simulation led to higher recognition rates
- Conflict combination : auditory is dominant
- Consistent combination : not necessarily better as if conflict was created

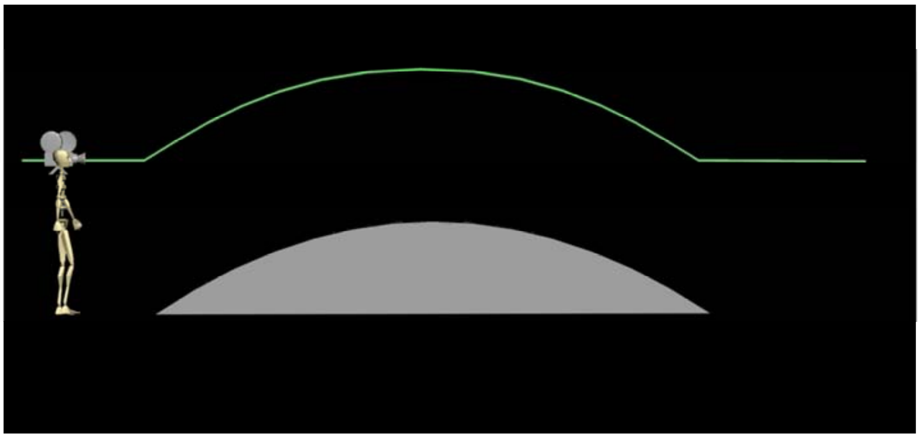
(Serafin et al., 2010) (Turchet et al., 2010)

The combination of auditory and tactile feedback of virtual grounds was tested using actuated shoes. Preliminary experimental results show that both cues enable successful identification of ground materials. Auditory feedback seems more efficient and dominant versus vibrotactile feedback.

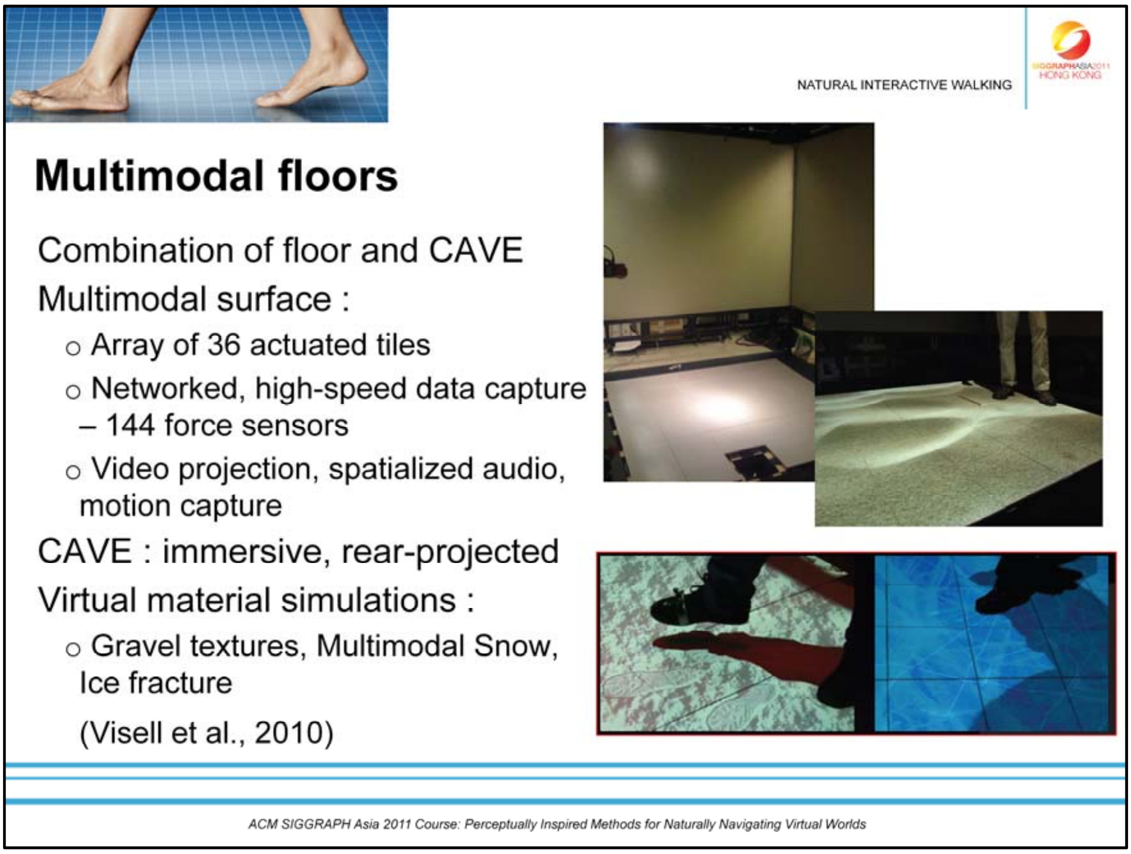


A concept of pseudo-haptic ground was proposed that uses visual feedback to distort perception of ground's slope. In most virtual reality setups the user is walking over a flat physical surface. He/she wears an Head Mounted Display (HMD) for visual feedback with head-tracking for updating visual feedback. Main idea consists here in distorting visual feedback by adding camera motions, in order to generate the sensation of walking over an uneven terrain. Various experiments have shown that such pseudo-haptic effects (changes in height, orientation and/or velocity of the subjective camera) are well associated with changes in virtual ground slope.

Pseudo-haptic slopes [video]



[videos]



An example of multimodal floor mixing visual (CAVE-like display based on multiple rear-projected stereoscopic screens), auditory (spatialized sound), and haptic (actuated floor made of vibrotactile tiles) feedback was developed at McGill University. The system was demonstrated by simulating different multimodal outdoor walks : walking over an iced virtual lake or a snowy virtual terrain.

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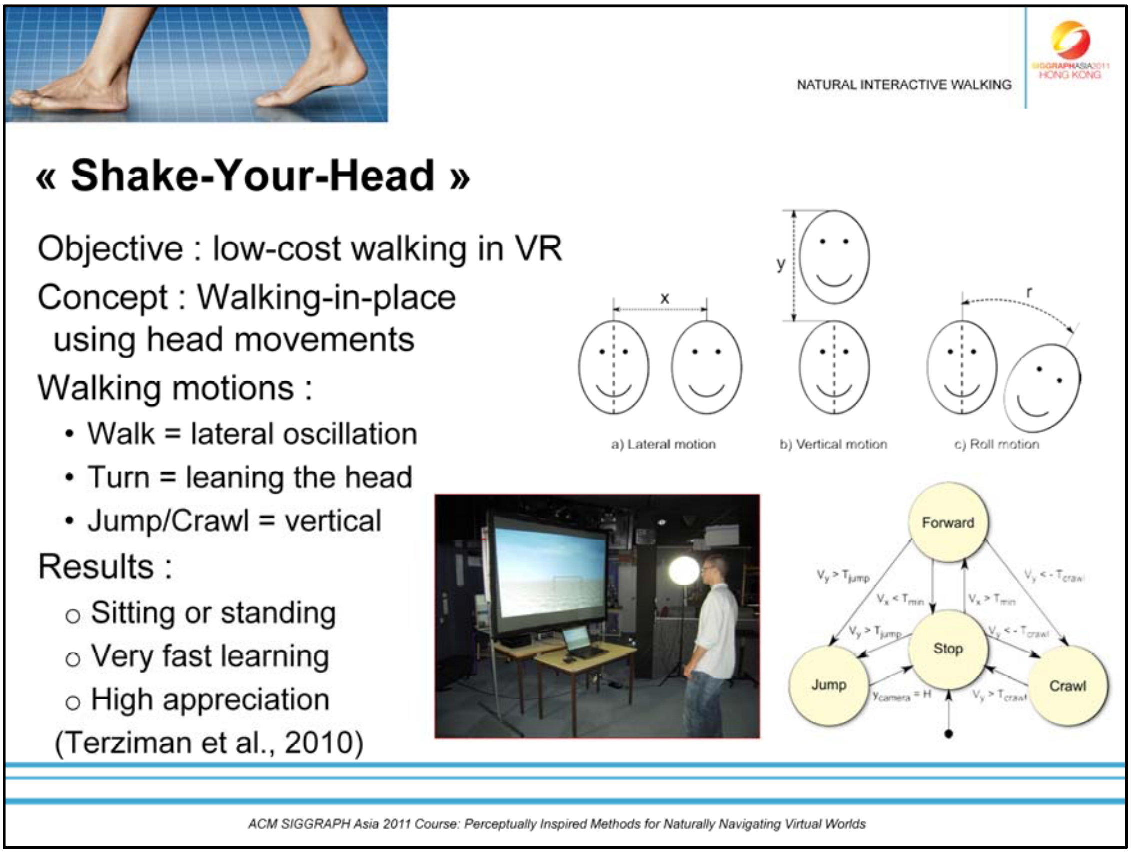
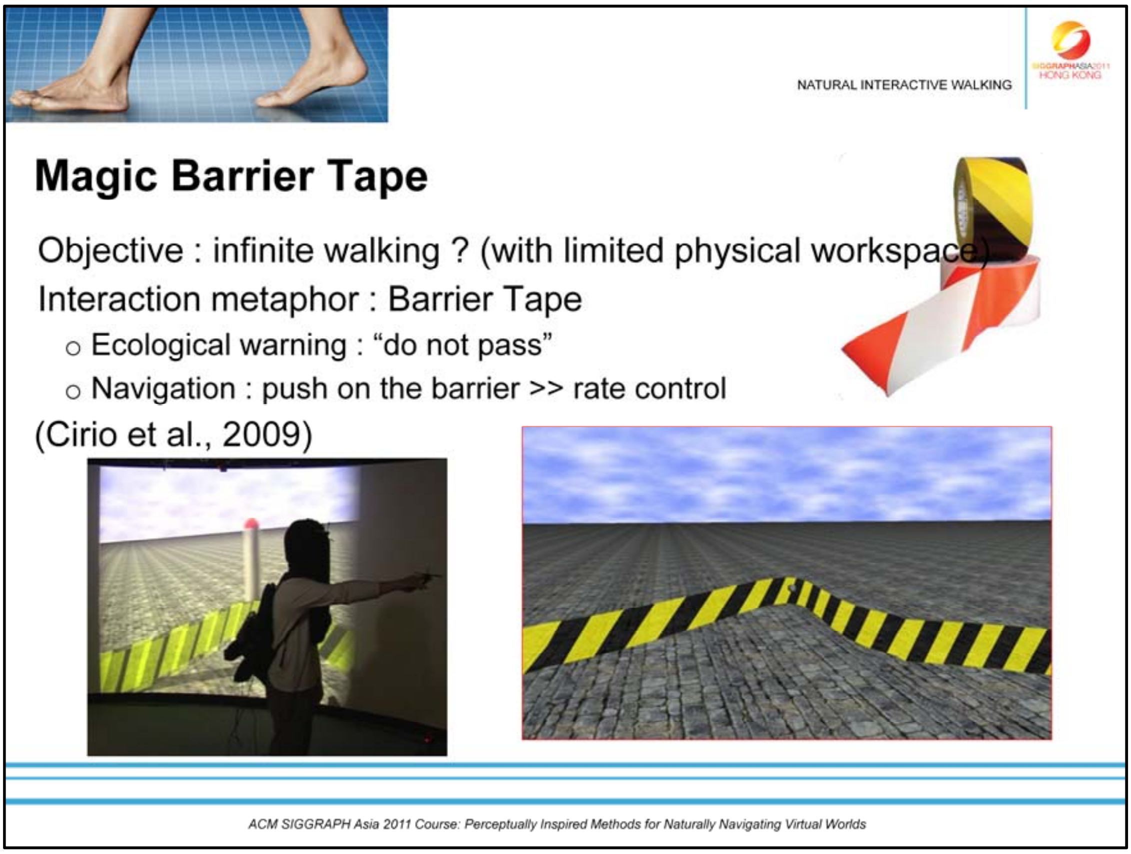
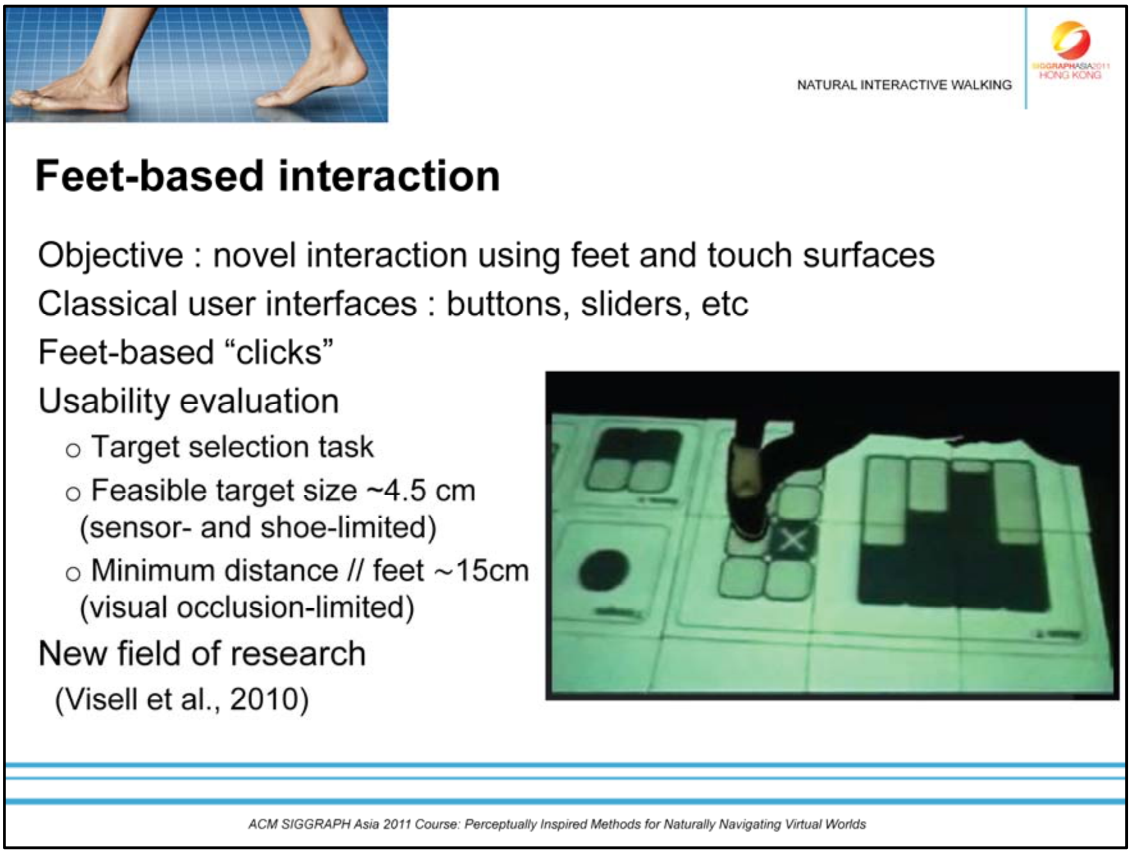
We will now talk about new kinds of interactive technique meant for improving and extending natural interactive walking in virtual environments.



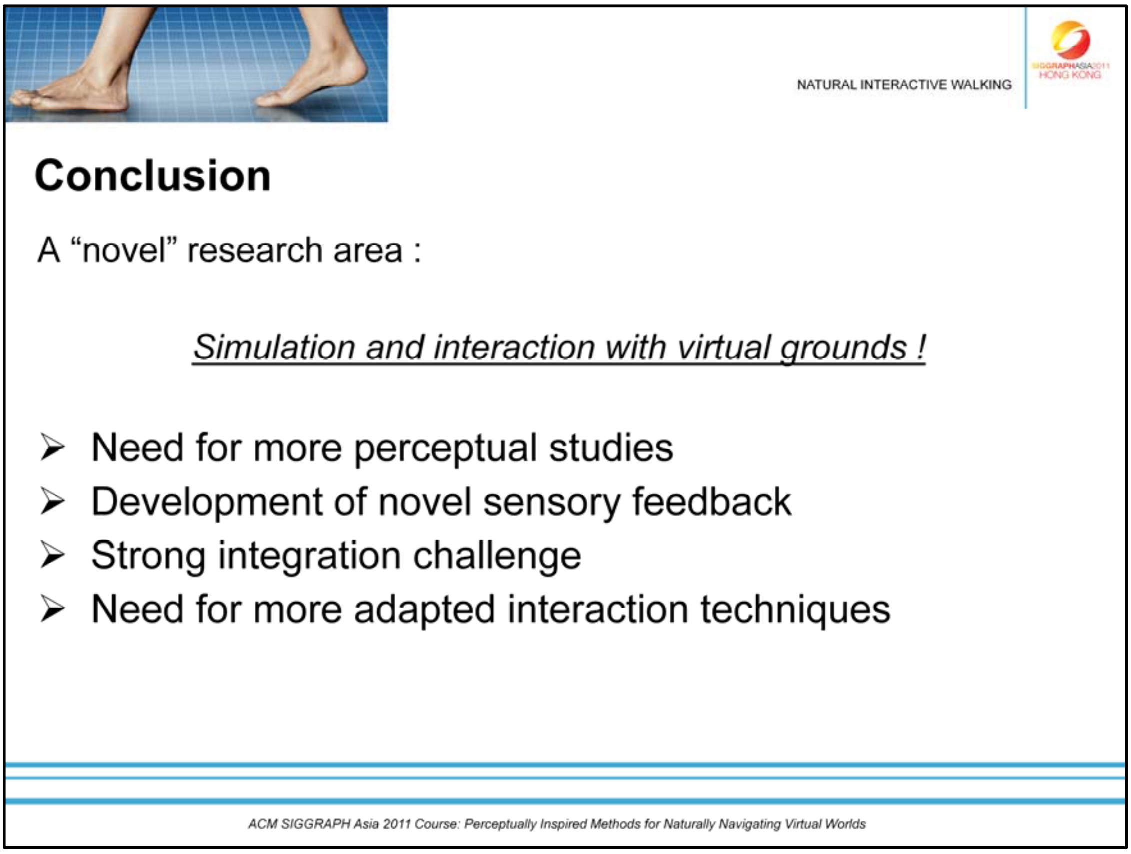
A first topic of research on natural interactive walking techniques concerns techniques dedicated to ‘low-cost’ walking experiences. Walking-in-place is here a good candidate and Terziman et al. show how this technique can be designed and used with low-cost equipments. They use a basic webcam to track user’s head movements and use it to control the virtual walk by “shaking the head”. The system can be used when sitting or standing and proved very appreciated.



Another topic of research concerns the extension of natural interactive walking to ‘infinite virtual walks’, i.e., to virtual environments that are larger than the real physical workspace. The Magic Barrier Tape is a good example developed by Cirio et al. to address this need. A virtual barrier tape warns the user about the limits of the physical workspace. He/she can then push on the virtual tape to move further in a rate-control mode (i.e., as when using a joystick).



Novel User Interfaces (UI) could be invented based on natural interactive walking and user’s feet. Visell et al. have notably demonstrated how classical widgets (buttons, sliders, etc) could be activated using feet and touch surfaces. This opens an entirely new and promising field of research for the Human-Computer Interaction community…



This concludes our course on Natural Interactive Walking !

This new field of interactive systems should foresee major outcomes in the incoming years, on different aspects: (1) perceptual studies, (2) input/output devices, (3) interactive techniques, (4) integrated and smart systems.

We hope that this will inspire other students, researchers or engineers who would be ready to follow this path, for an improved natural interactive walking in virtual environments…

Thank you ! For more information you can refer to websites :

NIW project = www.niwproject.eu

Anatole Lécuyer’s homepage = www.irisa.fr/bunraku/anatole.lecuyer

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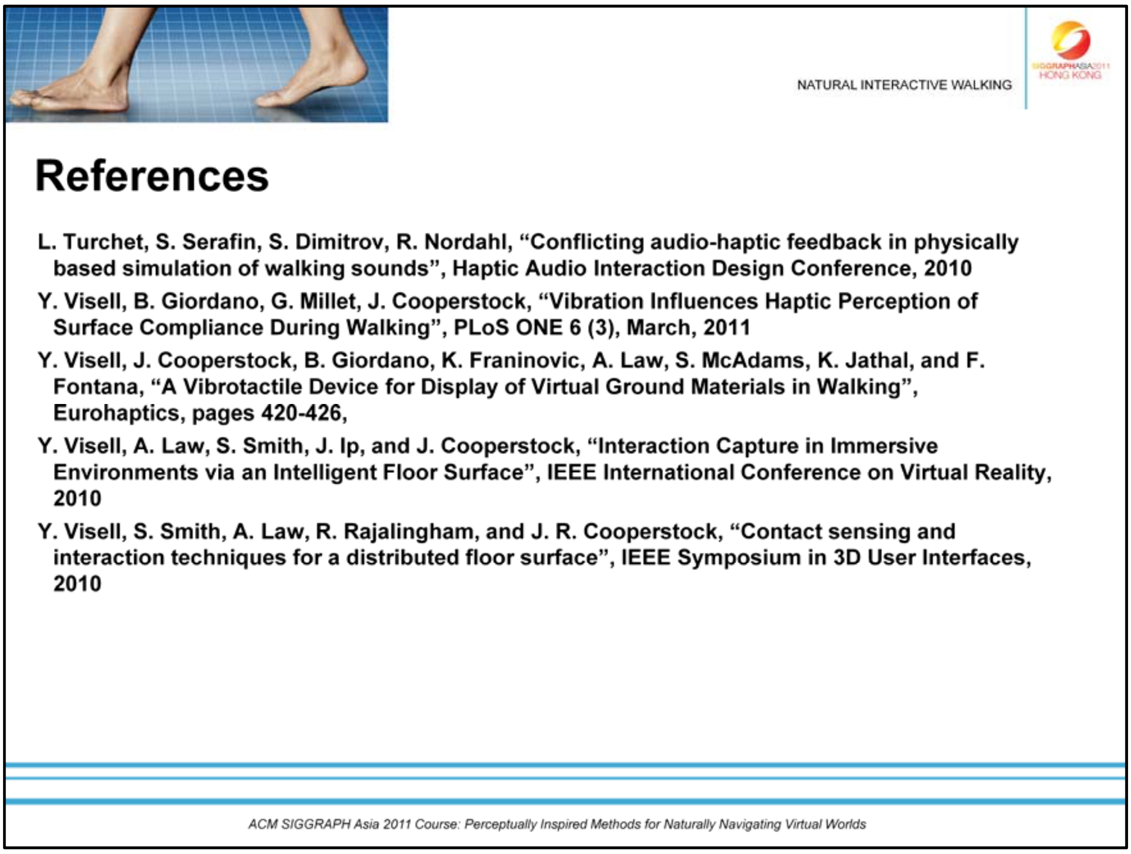
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