

# COMPOSITON OF VISUAL STIMULI FOR MEDICAL RESEARCH USING VIRTUAL REALITY

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## Abstract

**The vision in humans not only provides information about the surrounding world, but also affects functionality of system responsible for maintaining balance in upright stance. Investigation of role of vision in balance control uses measurement methodologies that require presentation of specifically designed visual stimuli. In this work we will present procedures for design moving stimuli suitable for this field of medical research. Scene composition is based on VRML file format and virtual reality/3D animation capabilities of Matlab's toolboxes. Moving scenes were created by translational and rotational movement of the camera over the static scene - virtual world. We have tested designed stimuli in clinical laboratory. Experiments on force platform showed that proposed stimuli induce measurable imbalance and body sway.**

## 1 Introduction

The vision is one of the most important sensory inputs. It provides information useful to everyday activities and often cooperates with other sensory systems. The brain combines different sensory cues to produce signals controlling human action. Results of the action is sensed and feed back to the brain. A biological system functioning in such a manner can be likened to an engineering feedback control system. Malfunctioning of any component in the control loop deteriorate system performance; can lead to instability and even overall system failure. One of interesting biological feedback system is those responsible for maintaining balance in upright stance in human. The system is inherently unstable, like inverted pendulum, and needs to be stabilized. Stabilizing commands to the musculoskeletal system are formed in the brain that combines visual information with vestibular input (generated in the inner ear) and proprioceptive sensory input (originated from muscles and joints) [1], [2]. In order to study this physiological feedback system, with aim to identify role of its individual components and find its weak points, an experimental system needs to be designed. Experimenter should have control over input signals. Specific stimuli are thus applied to activate or inhibit selected components of the system under investigation. In this work we will concentrate on visual stimulation.

Visual stimuli can be presented to measured subject by means of different technologies, such as head mounted displays or more expensive projection systems. Advanced environments for stimuli presentation, called immersive virtual reality environments, use multiple projectors and mirrors that display scene on several walls surrounding the examined person. Examples of such system include CAVE [3] (recursive acronym stands for CAVE Automatic Virtual Environment), NAVE (NAVE/Non-expensive Automatic Virtual Environment) [4], BNAVE (Balance NAVE) [5]. In our experiments, scenes are presented using commonly available general purpose devices – single PC, projector and rear projection screen. Projection is thus limited to display in one plane and virtual reality concepts serves essentially as a tool for moving scene composition.

In this paper we present the method for composition of moving scene stimuli using Simulink 3D Animation Toolbox, formerly known as Virtual Reality Toolbox. Visual scenes used for moving stimuli creation were composed from 3D objects defined in VRML format (Section 2). Movement of the scene is achieved by translational and rotational movement of the camera over the static scene in the virtual world, controlled by Matlab script (Section 3). Effect of visual stimulation on balance by designed stimuli is measured using force plate, sample measurement results are presented in Section 4.

## 2 Static scene

Static scenes that we have designed as a basis for moving stimuli generation are defined in VRML format (Virtual Reality Modeling Language), VRML97 or VRML 2.0 standard. This file format has been developed for exchange of interactive 3D contents. Although nowadays X3D format supersedes VRML, philosophy of the file content remains almost the same. Matlab and Simulink support VRML files via toolbox Simulink 3D Animation (Virtual Reality Toolbox). Viewer (Orbisnap) and editor of VRML files (Vrealm) are distributed together with this toolbox.

A scene defined in VRML format is built from objects called nodes that include basic geometric shapes, more complex objects can be defined in terms of polygon vertices (IndexedFaceSet node). Textures, lights, elevation grids, sky, ground and even fog allows to compose wide variety of scenes. We can recognize two scene types, that researchers use in balance investigation: natural scenes and patterned scenes.

Natural scenes are characterized by usage of textures, colors, clouds. Real world objects are placed at various distances from the subject. Typical scene consists of a room containing pillars, textured ceiling, floor, surrounded by mountains and sky [6]. Natural scenes often exhibit property called visual polarity. An object has visual polarity, when it contains an identifiable principal axis with one end distinct from the other [7]. Visually polarized objects appear asymmetrical in the vertical plane and have distinct ends that are designated “top” and “bottom”. Visual scene is arranged according to ordinary rules: ceiling of a room is located upward, the floor is located downward. There is experimental evidence that visual polarity can strengthen the sense of vection (self motion) while viewing a dynamic visual scene [7].

Second family of scenes covers more abstract scenes, emphasizing effect of optical flow. Spinning pattern, tunnels, moving walls with chessboard textures are some examples of scene used in experiments [8]. These scenes usually have high contrast; they are displayed in levels of gray or in black-and-white.

There are three principal ways how to create VRML file:

1. *Ordinary text editor*

VRML files are written as plain text and ordinary text editor can be used. Understanding of VRML file format is required if user decides to compose scene in general purpose text editor.

2. *Specialized VRML editor*

These editors use VRML as their native format, offer syntax highlighting, interactive work in insertion of nodes and visualization of the scene. Vrealm distributed with Simulink 3D Animation toolbox is an example of such editor.

3. *Export from 3D modeling software*

Advanced 3D modeling program, such as 3dsmax or Blender, support export to VRML format.

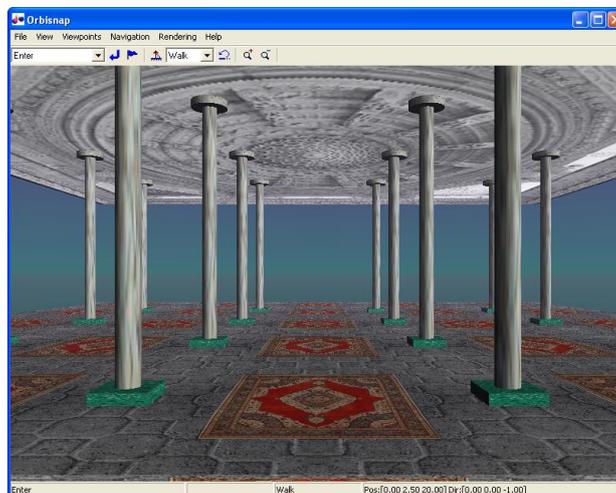


Figure 1: Sample “natural” scene defined in VRML, rendered in Orbisnap

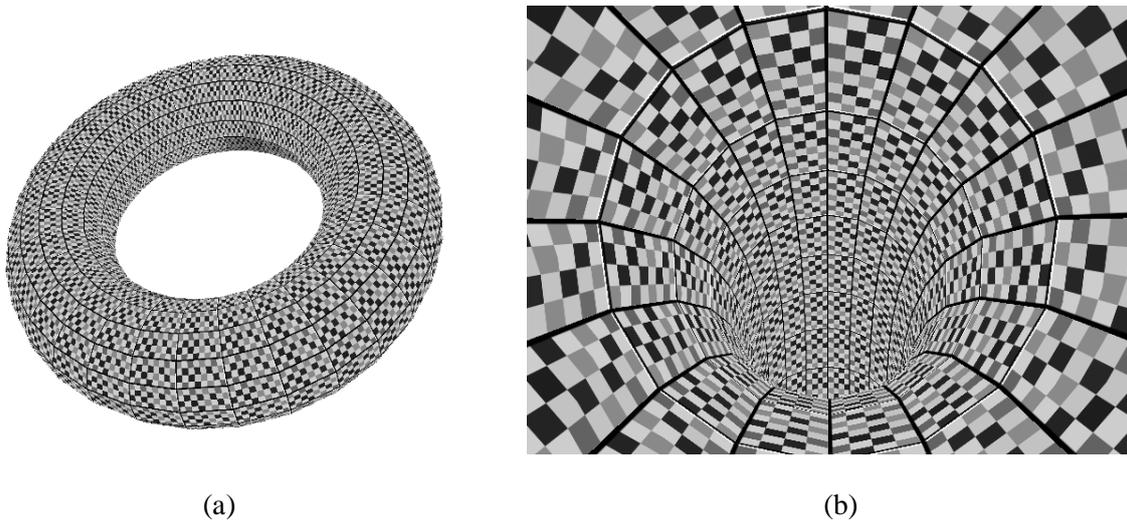


Figure 2: Patterned “tunnel” scene: (a) outside torus, (b) inside the tunnel

Sample scenes are shown in Figures 1, 2. The first scene is composed from basic geometric shapes and natural textures. Second scene uses IndexedFaceset node to define the torus. Look inside the torus resembles tunnel scene.

### 3 Animation of the scene

VRML format is not only static description of a scene, but it supports animation and interaction of the user with the virtual world. Animation is realized by nodes Sensor, Interpolator, and ROUTE command. Figure 3 illustrates steps involved in scene animation.

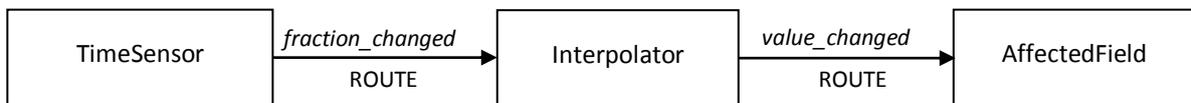


Figure 3: Usage of TimeSensor and Interpolators for scene animation

Animations require a timer to control the scene movement. In VRML, timers are implemented with TimeSensors. A TimeSensor node outputs an event called *fraction\_changed*. This event has a value ranging from 0 to 1, that expresses the fractional amount of time elapsed from the cycle interval. This generating event is linked to the *set\_fraction* event from the receiving interpolator using a ROUTE command. The interpolator subsequently generates the event *value\_changed*, which is routed to the target exposed field of another node. For animation purpose, exposed fields are position and orientation from viewpoint node. Therefore, an animation usually exploits two interpolators: position and orientation.

Sample code that clarifies usage of the interpolator is listed below (Code 1). To make VRML code more readable, static scene is included from external file *staticscene.wrl*. Interpolator can be explained as a table defining how controlled parameter should change as time passes. The field *key* contains list of times normalized to cycle length defined in TimeSensor, *key values* act as ordinates.

Understanding of coordinate system convention in VRML is crucial for correct direction of scene motion. VRML uses Cartesian coordinate system, where Z-axis comes out of screen, X-axis is horizontal and Y-axis is vertical; spatial unit in VRML is meter. Angular units are radians. Rotation (orientation) is described by four numbers. First three define viewing axis, followed by rotation angle (right hand rule). The sample code defines periodic forward-backward movement of the scene. To construct more complex path, several interpolators may be required. Moreover, the camera can be inserted into *transform* node controlled by interpolator.

Code 1: Sample code – usage of position interpolator

```
#VRML V2.0 utf8
Inline {url "staticscene.wrl"}

DEF Camera Viewpoint {
  orientation    0 1 0 0.0
  position 0 2.5 20
  description    "MovingCamera"
}

DEF timer TimeSensor {
  cycleInterval  5
  loop  TRUE
}

DEF pi PositionInterpolator {
  key  [ 0, 0.5, 1 ]
  keyValue [ 0 2.5 20,
            0 2.5 0,
            0 2.5 20 ]
}

ROUTE timer.fraction_changed TO pi.set_fraction
ROUTE pi.value_changed TO Camera.set_position
```

Disadvantage of animation method explained above is that playing animated VRML does not guarantee required frame rate (displayed frames per second). In addition, image rendering is highly hardware and software dependent. Storing video-sequences in movie file alleviates this problem and improves portability of animated scene. In order to assemble stimuli from frames and create avi-file, we have used Matlab's ability to control parameters of the camera in *vrfigure* object. Keystone of the movie generating script is following command

```
set(F, CameraProperty, value)
```

where *F* is *vrfigure* object. Three vectors define camera position and orientation:

1. CameraPosition : Cartesian coordinates in 3D space,
2. CameraDirection: vector defines viewing axis,
3. CameraUpVector: the specified vector projected onto the plane that is normal to the camera direction defines camera up orientation. Orientation specification thus differs from VRML orientation field.

## 4 Results

The body sway when a person quietly stands and perceives stimulus can be measured by force platform. The force platform measures coordinates of the centre of pressure (COP). This quantity is closely related to the centre of mass projected on the ground plane. A force platform is a rigid platform supported in 3 or 4 points. Load cells located in supports produce signals used for calculation of the stabilogram: x- and y- components of COP coordinates.

The measurement system is constituted by force platform, data acquisition card, PC, projector and back projection screen. Whole measurement is controlled from Matlab environment, by means of the program that displays graphic user interface on primary monitor. The secondary monitor is used for playing videostimulus, projected on the translucent screen. The projector is DLP type, with refresh rate of at least 60 Hz for smooth playing fast moving scenes at 60 fps, with native resolution 1024×768 points.

Each of 7 participants undergone a measurement protocol, that consisted of presentation 4 scenes (forward, backward; rotation to right, left). We have created animation in such a way that stationary point (e.g. rotation centre) is outside visible area of the moving scene. To achieve this, camera is elevated by angle  $\alpha$  above the ground. Camera position and orientation obey formulas listed in Table 1, where positive numbers  $v_z$  and  $\omega$  denote linear and angular velocities, respectively. Backward scene in table refers to patterns moving outwards screen (towards subject), and vice versa in the case of forward scene. Scenes denoted as right and left are characterized by rotating scene clockwise and counterclockwise, respectively.

Table 1: CAMERA DIRECTION AND ORIENTATION SETTING FOR SCENE ANIMATION

<i>Scene</i>	<i>CameraPosition</i>	<i>CameraDirection</i>	<i>CameraUpVector</i>
F (forward)	$[x_0, y_0, z_0 + v_z t]$	$[0, \tan(\alpha), -1]$	$[0, 1, 0]$
B (backward)	$[x_0, y_0, z_0 - v_z t]$	$[0, \tan(\alpha), -1]$	$[0, 1, 0]$
L (right)	$[x_0, y_0, z_0]$	$[\tan(\alpha) \sin(\omega t), \tan(\alpha) \cos(\omega t), -1]$	$[\sin(\omega t), \cos(\omega t), 0]$
R (left)	$[x_0, y_0, z_0]$	$[-\tan(\alpha) \sin(\omega t), \tan(\alpha) \cos(\omega t), -1]$	$[-\sin(\omega t), \cos(\omega t), 0]$

Each scene was presented 5 times, with randomly changed direction of movement to suppress subject adaptation to the scene. A single measurement starts with 10 s pre-stimulus period (static scene), continued with 10 s stimulation (moving scene) and 30 s post-stimulation period (static scene). Baseline of each measured waveform was corrected by subtraction the time-averaged value computed from pre-stimulus period. Group averaged responses can be observed in Figure 4. Stimulation period is delineated by gray areas. Positive deflections in x and y component of the stabilogram correspond to subject deviation in right and forward direction, respectively.

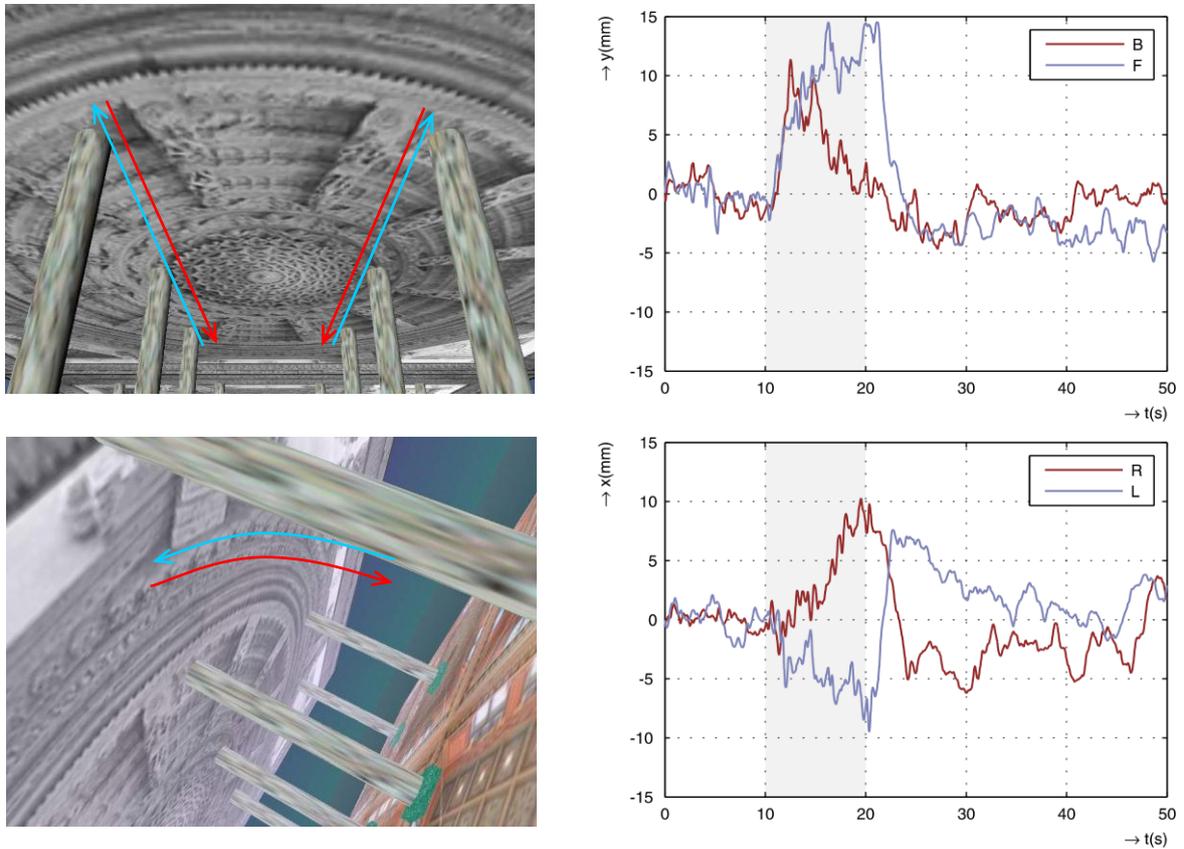


Figure 4: Group-averaged responses to visual stimuli

During stimulation period, subject exhibits increased effort to maintain stability. Coping with stimuli is manifested as increased fluctuations of stabilogram waveforms, as well as increased sway velocity (Figure 5). Effect of stimulation can be expressed quantitatively by parameter called line integral. The line integral (LI [mm]) express length of COP trajectory excursed during the specified time period, consisting of  $N$  samples of the stabilogram

$$LI = \sum_{n=1}^{N-1} \sqrt{(x[n] - x[n-1])^2 + (y[n] - y[n-1])^2} . \quad (1)$$

Statistic analysis (t-test) showed significant difference of the parameter compared to its pre-stimulus value (P-value ranging from  $5.6 \times 10^{-4}$  to  $2.0 \times 10^{-3}$ , depending on scene type). We have observed strongest effect on balance in older diseased subjects. Sample response of the patient is shown in Figure 5.

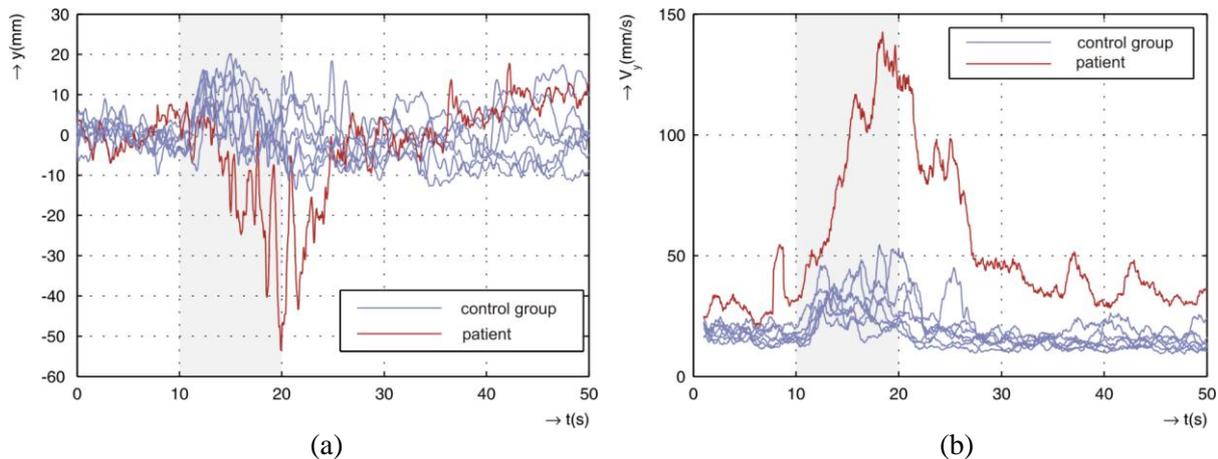


Figure 5: Stabilograms (a) and sway-velocity curves (b) – patient versus control group; scene B

## 5 Conclusion

In this paper, we have presented design of moving visual scenes for investigation of balance control in human. Our scene composition technique relies on VRML file format. Two design approaches have been discussed – animation ability of the WRML format and capability of Matlab toolboxes. Despite low-cost, general purpose hardware used to present stimuli, experiments performed in stabilometric laboratory showed ability of moving scenes to induce body sway and instability. Measurement procedures with visual stimuli can give insight into control mechanism involved in maintaining upright stance. If some components of this control system are altered by disease, injury or aging, or if controller output is inappropriate, a person exhibits instability or even it can fall. Falls can significantly affect quality of life, especially in elderly peoples, that motivates research in this topic.

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