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## Two Approaches for Tangible Navigation in Virtual Environments

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## Kurzfassung

Dieses Paper präsentiert zwei Vorgehensweisen zur Entwicklung intuitiver physikalischer Interfaces zur Navigation in virtuellen Umgebungen. Das erste der beiden vorgestellten Interfaces - die Virtual Balance - beruht auf der leicht vorstellbaren Idee mit einem Snowboard einen Berg herunterzufahren. Dieses Interface ist realisiert als eine Plattform, die auf die Körperbewegung und Gewichtsverlagerung des Benutzers reagiert, der auf ihr steht. Die Position des Benutzers in einer virtuellen Umgebung, durch die er navigiert, wird entsprechend der Sensordaten aktualisiert, die von der Plattform an den Computer geschickt werden. Das zweite Interface nutzt elektrostatische Feldsensoren für gestische Navigation in virtuellen Umgebungen. Dieses Interface basiert auf der Abhängigkeit von Parametern elektrischer Oszillatoren zur Nähe der Hand des Benutzers zur Antenne des Oszillator Kondensators. Beide Methoden funktionieren verkabelt, erfordern also kein unbequemes Equipment.

## Schlagworte

Virtual Balance, Intuitiv, Interface, Spürbare Navigation, Gestische Navigation, Elektrostatische Feld Sensoren, drahtlos.

## Keywords

Virtual Balance, Intuitive, Interface, Tangible Navigation, Gestural Navigation, Electrostatic Field Sensors, Wireless



# Two Approaches for Intuitive Navigation in Virtual Environments

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## Abstract

This paper presents two approaches for development of intuitive physical interfaces for navigation in virtual environments. The first discussed interface called “Virtual Balance” borrows the ideas from well-known and immediately understandable to everyone principles of steering of a snowboard down a mountain. This interface is realized as a platform that reacts on the body movements of the user which is staying on it. The position of the user in the virtual environment is updated in accordance with the data from that platform.

The second interface uses electrostatic field sensors for gestural navigation in virtual environments. This interface is based on the dependence of parameters of electrical oscillator on the proximity of the user’s hand to the antenna connected to the oscillator’s capacitor.

Both approaches do not require wearing or keeping uncomfortable equipment.

## 1 Introduction

In order to examine the meaning within the framework of mediated reality, we need interfaces which allow the user a high degree of natural freedom of movement. For this reason, research in recent years has been increasingly devoted to the development of human-computer interfaces which avoid the use of limiting apparatuses and attempt to most effectively allow a complete freedom of movement of the body.

Virtual Environments still suffer from input and output devices that work against the human body and mind. The body with its communication channels (skin, eyes, ears, voice) opens imagination spaces. Body motion is fundamental to learning and living. Interaction and feedback intensify capabilities of perception.

The authors’ main interest is to develop systems that focus on the linking of real and virtual environments and the users sense of presence. This aim is also reflected in earlier works: *The Spatial Navigator* [2] uses a treadmill where the viewer walks through a virtual castle. *The Responsive Workbench* [3] has put the conventional dialogue concepts for human-computer communication into a user-oriented shape. Virtual objects and tools are projected stereoscopically on a real workbench as a virtual design environment. The com-

puter art installations *Rigid Waves* [4], a mirror based on image processing and *Liquid Views* [4], a water surface based on a touch screen stride new ways in human-computer communication, where the interface is tangible to support the users perceptual process.

This paper presents two approaches for development of intuitive physical interfaces for tangible navigation in virtual environments.

We describe our recent improvements and investigations of the interface Virtual Balance (VB) [5]. This interface is realized as a platform that reacts on the body movements of the user which is staying on it. The position of the user in the virtual environment is updated in accordance with the data from that platform.

The second interface uses electrostatic field sensors for gestural navigation in virtual environments. The free user’s hand moving in the vicinity of antennas affects the parameters of the complex electrical circuit that includes those antennas and the hand grounded through the user’s body. The changes of those parameters are mapped to the parameters of the user’s viewpoint in the virtual environment.

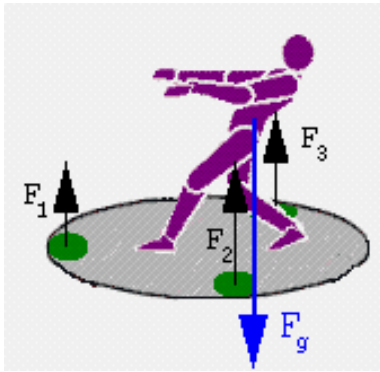
For each interface we discuss physical principles, underlying ideas, actual implementation and operation of the interfaces and mapping of data.

## 2 Navigation with the Virtual Balance

### 2.1 Physical principles, underlying ideas

The interface VB is based on man-machine interaction by movements of the human body on a platform. The platform consists of two circular plates (disks) with three weight sensors arranged in triangular form between these disks. The sensors receive changes of weight distribution on the upper disc and transmit them to an analysis unit which in turn controls the position and orientation of the user’s viewpoint in the virtual environment. The number of the sensors and their location are derived from the well-known fact that any plane is stabilized by three force vectors  $F_1$ ,  $F_2$ ,  $F_3$  against a contradictional force vector  $F_g$  (i.e. the weight of the object). It is quite obvious that the point on the upper disk to which user’s weight is applied at the given moment can be unambiguously calculated from three numbers from the sensors,

as it is shown on the Figure 1.



**Fig.1.** The physical principles of the VB.

## 2.2 Implementation

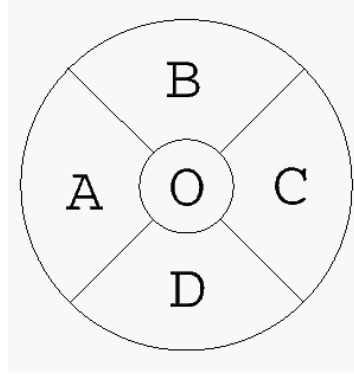
We use a personal computer as an intermediate stage between input signal measurement (weight sensors) and SGI's graphics workstation. The signal from the weight sensors are sampled via three I/O ports. From these separate signals the barycenter coordinates of the user's body on the platform (the location of the point on the disk to which the user's weight is applied) are calculated and sent to the SGI's graphics workstation over a fourth I/O channel for rendering of the new scene. The data sent from the PC to the graphics workstation as input for scene rendering consist of two coordinates for the barycenter on the navigation platform and total weight measured by three sensors. From these data the current position, speed and orientation of the user's viewpoint are calculated in accordance with the chosen mode of navigation.

## 2.3 Mapping of data from the VB

To navigate through large architectural models like the models of ancient cities (see Applications) the user must be provided with the opportunity to change the position of the viewpoint in the 3D space, to change its orientation on the horizontal plane, to move with different speed to see more or less details of the virtual environment. At the same time when choosing the appropriate mapping one should consider the following facts:

- 1) The VB provides only two independent streams of data (coordinates on the disk's plane)
- 2) Untrained user must not undertake special complex actions to change the parameters of the motion in the virtual environment.

In our current implementation the data from the VB are mapped in the way described below and depicted on the Figure 2.



**Fig.2.** Mapping of data from the VB.

For the simplicity we will call the position of the point on the VB's upper disk to which the user's weight is applied 'the position of user's weight'.

If the user's weight is applied to the central area O no parameters of the user's viewpoint are changed. This is neutral area.

When the user's weight is applied to the area A or C correspondingly to the left and to the right from the central area the user's viewpoint turns in the virtual environment with angular velocity increasing linearly with the distance from the position of the user's weight on the disk to the center of the disk. So with the given speed of the motion in the virtual environment the user's weight has to be closer to the left or to the right border of the VB's disk to fit to a turn with smaller radius in accordance with the well-known formula from mechanics  $\vec{v} = [\vec{\omega}, \vec{r}]$ .

In addition the user's viewpoint rotates around the vector of the speed in the virtual environment on an angle increasing linearly with the distance from the user's weight to the center of VB's disk.

These functionalities provide more immersion for the motion in the large architectural models and simulates well known mechanical effect which motobikers and skiers experience when trying to fit on the high speed to a turn with rather small radius. They have to lean very close to the ground to displace the center of gravity closer to the center of the turning. This action decreases the force of friction from the ground and prevents the person from the breakdown.

Figure 3 illustrates these principles.



**Fig.3.** Making a turn with the VB. The top view of the model of Aztec city is shown on the left top corner.

When the user's weight is located in the area B or D (Figure 2) before or behind the central area of the disk the user changes the height of his viewpoint in the virtual environment: decreasing (area B) or increasing it (area D). In addition, the orientation of the user's viewpoint turns around the axis parallel to the horizontal plane and perpendicular to the vector of the speed of the motion in the virtual environment. The angle of the turning is increased linearly with the distance from the user's weight to the center of the disk. This feature simulates the following effect. When the user is on the back side of the disk, the forward part of the virtual platform on which the user flies in the virtual environment is going up, and the height is being increased. In the same manner when the user is on the forward part of the VB's disk the forward part of the virtual platform is going down and the height is being decreased.

The data provided by the VB are not enough to change the speed of motion in the virtual environment in the same intuitive manner. We propose two solutions to this problem.

1) The speed depends on the height of the user's viewpoint in the virtual environment. In the large architectural models all information is located on the ground. So it makes sense to move with relatively small speed on the ground to see the model in details and to fly with a larger speed in some height from the ground where the opportunity to see more details is not important.

2) The change of the mode of the mapping of data from the VB through some predefined actions of the user on the VB's platform. One can use the areas B and D on the disk not only for increasing and decreasing the height of the user's viewpoint in the virtual environment but also for increasing or decreasing the speed of motion. We implemented the following way of the change of the mode of the mapping of data from the VB. If the user wants to increase the speed of motion he goes back on the platform (so his weight is located in the area D) and immediately goes forward (his weight now is located in the area B). The time between these two events must not be greater than 1 second or another small predefined value, otherwise the change of the mode does not occur (Figure 4).



**Fig.4.** The change of mode of the VB through predefined actions of the user on the VB's platform.

Until the user's weight is located in the area B the speed of the motion in the virtual environment is being increased

depending on the distance from the user's weight on the VB's platform to the center of the disk. Once the user's weight leaves the area B, the mode of the mapping of data returns to its usual state when areas B and D are used for changing the height. In the same manner the user can decrease the speed of the motion in the virtual environment.

However testing of this feature with different people showed that such actions can not be considered as intuitive and some time is required for adaptation to this functionality.

We use the first mentioned method of changing of the speed of motion in the virtual environment in our public demonstrations when our visitors navigate through large architectural models (see the next section).

## 2.4 Applications

Our numerous tests with different users show that the interface VB is well suited for investigation of large architectural models, like reconstructed models of ancient cities. We use the model of the Roman village Colonia Ulpia Traiana (100 a.o.t) created from archaeological data by joint work of architects, civil engineers, archaeologists and computer scientists. Body navigation determines height and speed. Depending on the navigator's distance from the virtual objects, different levels of detail (LOD) are activated. To help the user to navigate through a large model that is spread over a rather large area we introduced the top view with a cursor showing the current user's position in the virtual environment as well as the current orientation of the user's viewpoint (Figure 3). We use as the top view the 2D image created beforehand to save computational resources. Depending on the available computational resources one can use in our framework a virtual mirror to give the user a notion of the entire environment surrounding him. However one should use the virtual mirror with care since the use of it assumes recalculation of all normals of the virtual environment, resulting in a very small frame rate.

## 3 Gestural navigation with electrostatic field sensors (EFS)

### 3.1 Underlying ideas

The operation of this interface is based on the same underlying principles as they were used in the musical instrument called Theremin which was invented by the Russian scientist Lev Termen (Leon Theremin) in the early 1920's. Figure 10 shows the design of a classic Theremin. The main parts of the device are two LC oscillators with very close own frequencies. One of them has fixed capacitance and inductance, the second has an external antenna connected to its capacitor. By moving a hand into the vicinity of the antenna the user actually adds the capacitance  $C_{h1}$  to the oscillator. Since the user's hand is grounded through his/her body the capacitor  $C_{h1}$  is connected in parallel with the capacitor  $C_0$ .

As the user varies the distance of his/her hand from the antenna, the capacitive coupling and the resulting frequency  $\omega_1$  is changed according to the formula  $\frac{1}{\sqrt{L_0(C_0+C_{h1})}}$ . Because the capacitance  $C_0$  is usually very small (typically below a picofarad), this oscillator must be run well above audio frequencies (typically 100 kHz to 1MHz) to attain significant coupling and dynamic range. The radio-frequency wavelength is approximately 3 km at 100 kHz, therefore most Theremins and devices based on their principles of operation should be analyzed as a slowly varying electrostatics problem with negligible radiation effects. The hand dependent frequency  $\omega_1$  is then down-shifted to audio band by mixing the  $\omega_1$  signal with a fixed frequency reference  $\omega_0$  and detecting the new frequency beats at  $\omega_0 - \omega_1$ . Theremins usually use a second proximity-variable oscillator/antenna  $\omega_2$  to control the amplitude of the audio signal. The  $\omega_2$  signal is applied to a steep bandpass filter, than the amplitude of its output is detected to determine the gain of a voltage controlled amplifier (VCA) in the audio path. As a hand moves near this volume-controlled antenna,  $\omega_2$  moves into tune with the band pass filter, changing the audio level through the VCA. So one can play music controlling the pitch and the volume of the sound simply moving the hands near the pitch and volume antennas and not touching anything.

The general idea of the Theremin and EFSs, affecting the parameters of the oscillator via user's body motion, can be used in a variety of applications for proximity sensing. In such applications a set of antennas is used to provide more data about space characteristics of matter induced the change of oscillator's characteristics.

In particular, MIT Media laboratory built a set of sensors used for different modes of navigation in the 3D world with free user's hand. Details can be found in [6, 7, 8].

### 3.2 Setup: electrostatic field sensors desktop interface

In our present implementation we use two specially designed EFSs with two spherical antennas connected to each EFS (Figure 5).



Fig.5. Setup of the system of EFSs for navigation in virtual environments.

The EFS circuits have been designed by Martin Nawsrath at KHM-Academy of Media Arts (Köln, Germany). In his device the output can be provided in two forms: usual audio output and digital output that delivers the values of the shift of the base frequency of the audio signal from its "neutral" value at each time of sampling. The basic frequency of the EFS's oscillator when the user's hand is out of the area of the EFS's antenna sensitivity is assumed under the 'neutral' value. The digital output of each device is connected to the serial input of the computer. If this installation is used for navigation in virtual environments, the position of user's viewpoint is updated in accordance with the data arriving at the serial inputs of the computer (Figure 5).

The digital output of each EFS is provided by a microprocessor which performs the Fourier transform of the audio signal. It also sets the pitch to zero when it have not changed during a predefined time (10 s in our application).

Before describing the actual operation of our system and the mapping of data from the EFSs to parameters of the user's viewpoint in the virtual environment, we introduce the physical principles of our implementation.

### 3.3 Physical principles of our implementation

When the user's hand is in the area of sensitivity of the antennas, the equivalent electric scheme presented in the Figure 11 below can be used for describing the physical properties of our application.

The capacitances  $C_{h1}$  and  $C_{h2}$  between the hand and each of the antennas and the capacitance  $C_A$  between the antennas depend on the current position of the hand. The capacitance  $C_h$  is dominated by the capacitance between the surface of the shoes of the user and the ambient room ground. It is typically much larger than capacitances  $C_{h1}$  and  $C_{h2}$ . Capacitances  $C_{h1}$ ,  $C_{h2}$  and  $C_A$  are always much smaller than  $C_1$  or  $C_2$ . One can show using those assumptions that oscillations with two frequencies are presented in the electrical circuit of the Figure 11:

$$\omega_1 = \frac{1}{\sqrt{L_1 C_1}} \left(1 - \frac{C_A + C_{h1}}{2C_1}\right) \quad (1)$$

$$\omega_2 = \frac{1}{\sqrt{L_2 C_2}} \left(1 - \frac{C_A + C_{h2}}{2C_2}\right) \quad (2)$$

Note, that native frequencies  $\frac{1}{\sqrt{L_1 C_1}}$  and  $\frac{1}{\sqrt{L_2 C_2}}$  of each EFS must differ to a certain amount to allow for following their shift by the microprocessor when the environment near antennas is being changed. Otherwise the microprocessor might mix the frequencies and follow the shift of the second frequency. To avoid this we use EFSs where the native frequencies (655 kHz for the first EFS and 455 kHz for the second one) differ to a significant value.

$C_A$ ,  $C_{h1}$  and  $C_{h2}$  are abstract quantities that do not have real physical sense. One can show that these quantities are easily expressed through capacitance coefficients [9]:

$$C_{11} = C_{h1} + C_A, \quad C_{22} = C_{h2} + C_A,$$

So equations (1,2) can be rewritten in the following form:

$$\omega_1 = \frac{1}{\sqrt{L_1 C_1}} \left(1 - \frac{C_{11}}{2C_1}\right)$$

$$\omega_2 = \frac{1}{\sqrt{L_2 C_2}} \left(1 - \frac{C_{22}}{2C_2}\right)$$

Capacitance coefficients  $C_{11}$  and  $C_{22}$  have simple physical sense. Each of them is equal to the charge on the corresponding antenna provided the antenna is under unit potential and the other conductors in the system are being grounded.

The problem can be stated now as follows. Given the shifts from “neutral” frequency for each sensor and, as a consequence, quantities  $C_{11}$  and  $C_{22}$ , the hand position must be derived from these quantities.

It is known that capacitance coefficients are quite easy calculated for the system of many conducting spheres. For our system this would be the case if we use spherical antennas and treat user’s hand as a conducting sphere.

Thus, for example,  $C_{22}$  can be calculated in the following way (see Figure 6).

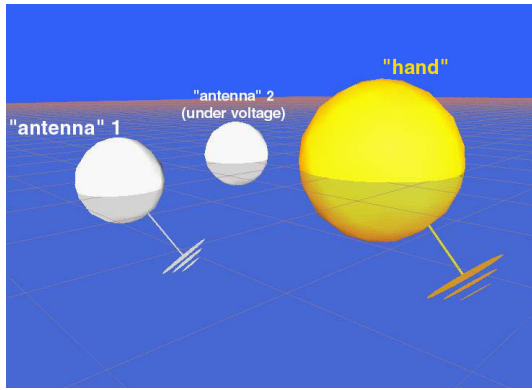


Fig.6. Physical model of our system.

We put a point charge  $q = a$  in the center of the antenna 2, where  $a$  is the radius of the sphere’s antenna; that would raise the potential at this conductor to unit in the absence of the other conductors.

It is known from electrostatics that for the system of a point charge and a grounded sphere with radius  $a$  and located on the distance  $x$  from the charge, the field outside the sphere can be calculated as superposition of the given point charge and an imaginary charge  $q' = -\frac{a}{x}q$  located inside sphere on the distance  $x' = \frac{a^2}{x}$  from the center of the sphere as shown in the Figure 7.

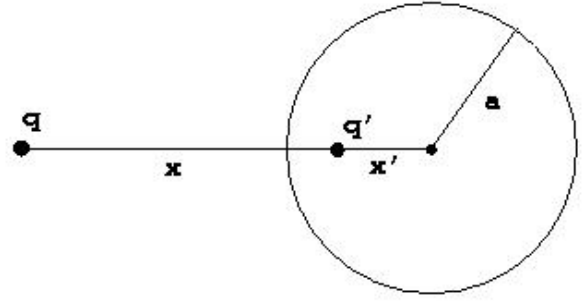


Fig.7. Electrostatic image of a point charge in a conducting grounded sphere.

Thus, we need to put additional charge in the other spheres on Figure 6 to compensate for the change of potential due to the charge in the center of the antenna 2. Then, for each sphere we need to compensate for the change of potential due to recently introduced charges in the other spheres. This procedure converges to finite solution and gives the resulting charge in the antenna 2 which is equal to the capacitance coefficient  $C_{22}$ .

Understanding the physical principals of our implementation we are now describing the actual operation of the system.

### 3.4 Operation of the system

We can calculate analytically capacitance coefficients for any position of the sphere representing user’s hand and approximate the function  $C_{ii} = F(x, y)$  with as large number of points as desirable and store these data in the file.

During operation each EFS provides the shift of the frequency from its “neutral” value. For that value an isoline is calculated from the analytical data. The position of the user’s hand is calculated as intersection of the isolines as shown on the Figure 8.

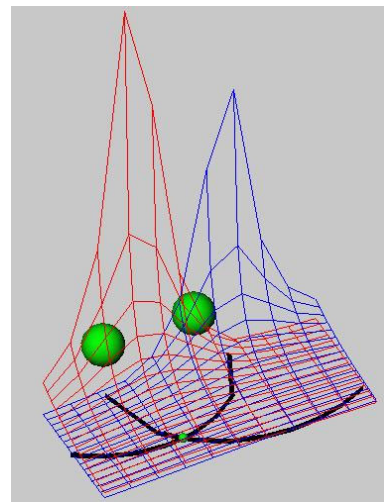


Fig.8. Operation of the system.

### 3.5 Mapping of data and applications

We implemented two commonly used modes of navigation: the “examine” and “walk” modes.

In the “walk” mode the  $y$  coordinate serves for determining the speed of the motion in the virtual environment. The speed depends linearly on the  $y$  and is maximal if  $y = 0$ .

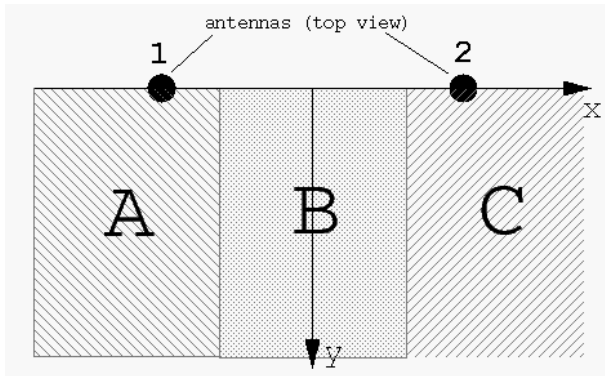


Fig.9. Mapping of data from the EFSs.

If the user's hand is located in the area A or C (Figure 9) the user's viewpoint begins to turn with an angular velocity increasing linearly with the distance from the current hand's location to the border with the area B. The radius of the turn is determined in accordance with the formula  $\vec{v} = [\vec{\omega}, \vec{r}]$ .

We use SGI's Inventor API for mapping the data from the EFSs to the parameters of the user's viewpoint in the virtual environment and for rendering the scene stored in the Inventor file format.

Our numerous tests with different people show that they immediately recognize the described above relations between the position of the hand and the change of viewpoint's parameters in the virtual environment.

### 4 Conclusion. Future work

We have tested the described interfaces with a large number of visitors during our public demonstrations. The first - and probably most important - observation was that virtually all people, disregarding of age and sex, who tried the VB and our EFS' interface, adapted to the system within a minute or less without any adjustment of the system.

It was not surprising for us that both interfaces were requested by disciplines working on the body and the senses (e.g. neurophysiologists, dancers, game industry). Medical researchers identified the VB and electrostatic field sensors as tools for research for handicapped people, e.g. motion control or problems of body balance.

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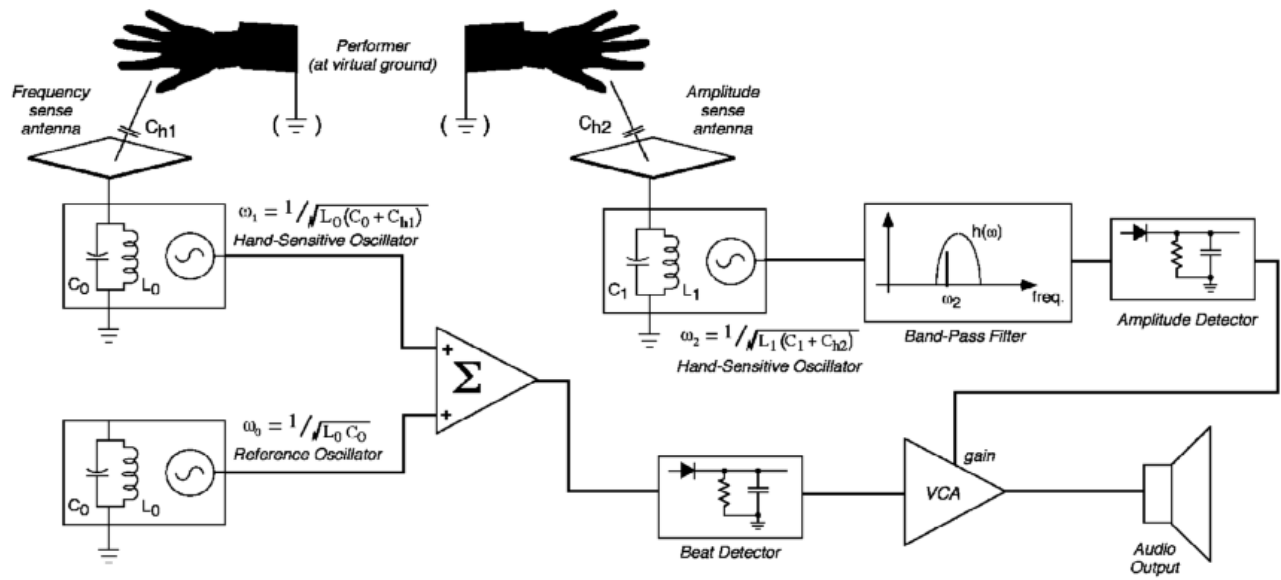


Fig.10. Design of the classic Theremin (the picture from [7]).

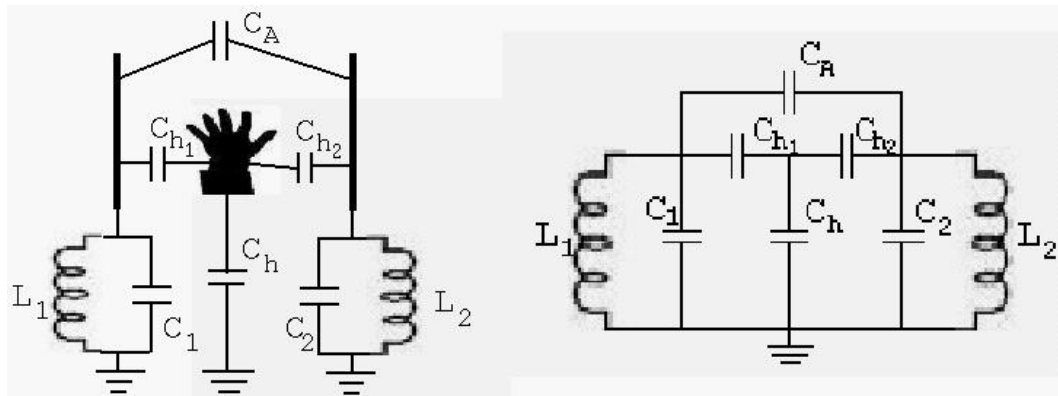


Fig.11. The equivalent electrical scheme in our application.