Sensing Human Activities With Resonant Tuning

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Abstract

Designing new interactive experiences requires effective methods for sensing human activities. In this paper, we propose new sensor architecture based on tracking changes in the resonant frequency of objects with which users interact.

Keywords

sensors, embodied interfaces, resonant frequency.

ACM Classification Keywords

H5.2 Information interfaces and presentation: User Interfaces --- Input devices and strategies; B.4.2 Input/output and data communication: Input/Output Devices --- Channels and controllers.

General terms

Design, Measurement.

Introduction

Development of technologies for sensing human activities has a profound impact on user interface design enabling new styles of interaction with devices and environments; inspiring new applications and products and, in some cases, launching entirely new areas of human-computer interaction (HCI) research and development. Therefore, inventing new sensing technologies and exploring their interactive properties and applications is an important research direction in the field of HCI [1].

This paper presents some initial results of a new technique for sensing human activities. It is based on continuous tracking of changes in the electromagnetic resonant properties of conductive objects caused by the interaction between the human and the object. In other words, by measuring how the electromagnetic resonant frequency changes when a user does "something" with an object, we can understand what that "something" was.

Although the fundamental physical principles behind our development are well known, they have not been exploited in designing sensors and input devices for human-computer interaction. This is, perhaps, due to the high computational cost that has made such sensors unfeasible until now. The proposed sensing approach, however, has exciting properties that allow any conductive object to be a touch-sensitive device that can detect both touch and the area of touch; allow objects to be tagged and changes in their internal configuration tracked; and measurement of very small deformations when twisted wires are stretched and bent in new types of interactive fabrics and smart materials. At the same time, the resulting sensors are simple and reliable, do not require instrumentation of the user, and can be connected to any object with a single wire. They provide very high resolution, high sensitivity, are self-calibrating, and resistant to electrical noise. We believe that the proposed sensing architecture has a wide range of uses from making new types of touch-sensitive and embodied interfaces to developing new interactive materials for wearable and ubiquitous computing.

Background and Related Work

A sensor is simply a transducer that converts a physical stimulus, such as light or motion, into a signal that can be measured. In user interfaces, humans supply the stimulus to sensors that can be located in input devices, worn by the user, or embedded into objects or environments. The details of the interface implementations depend strongly on what physical phenomenon is measured by the sensors – e.g. *resistance* is used in knobs and resistive touch panels, *light* intensity is used in cameras, the direction and intensity of *magnetic fields* is used in proximity sensors (e.g. [3][4]), *acceleration* is used to measure motion, and the amount of *electrical charge* is used in multi-touch capacitive input devices [5].

We propose use of yet another physical phenomenon in the design of user interfaces, the frequency of *electromagnetic resonance*. Electromagnetic resonance has been widely used to tune and filter oscillator circuits in radio communication as well as in tagging and identification devices [2]. These devices, however, assume that the resonant characteristics are known *a priori* and that the user manipulates a *specific* tag or identification card. We, on the other hand, view *any* system of conductive objects, including humans, as a large resonant circuit. If we assume that the electrical properties of the objects do not change, then *any changes in the resonant properties of the system can happen only because of the user actions*. Thus, we can identify human activities by tracking changes in the resonant characteristics of the entire system. We are not aware of previous research in HCI that has attempted to design user interfaces based on this approach to sensing.

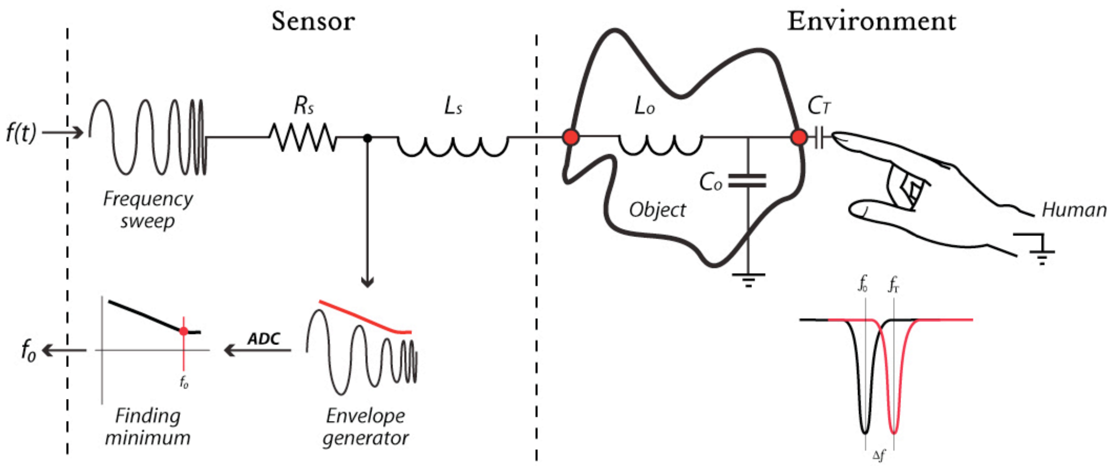

Figure 1: The basic architecture of the resonant tuning sensor.

Sensing by Resonance

The overall principles of sensing are presented in Figure 1. In this section, we discuss the details of sensor design and its basic properties.

Physical principles

We can illustrate the basic idea behind the sensor design using the following familiar example. A slight strike on a crystal glass produces a characteristic ringing sound at the resonant frequency of the glass. A crack in the glass material or water poured into the glass would change the resonant frequency and the pitch of the sound. Therefore, we can estimate the internal state of the glass by measuring *only* the pitch when the glass is vibrating at its resonant frequency.

Similarly, any electrical system that includes capacitive and inductive elements will have a unique frequency at which an alternating current flowing through the system will oscillate – i.e. its resonant frequency. As with the crystal glass, we can "strike" our system with an impulse signal and then estimate its resonant frequency by measuring the frequency of ripples in the system response. A more practical approach is to *force* electrical oscillations by exciting the system with a periodic electrical signal at different frequencies – e.g. by performing a *frequency sweep*. At the resonant frequency, the amplitude of the alternating current reaches its maximum[1].

Similar to the example with the crystal glass, any alterations or interactions that affect the reactive properties of the system will change its resonance frequency. If we assume that the properties of the system do not change, then any changes in resonant frequency will happen only because of *the user interacting with the system*. Therefore, we can infer user actions by tracking changes in the system resonant frequency.

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[1] We consider only series resonant circuits.

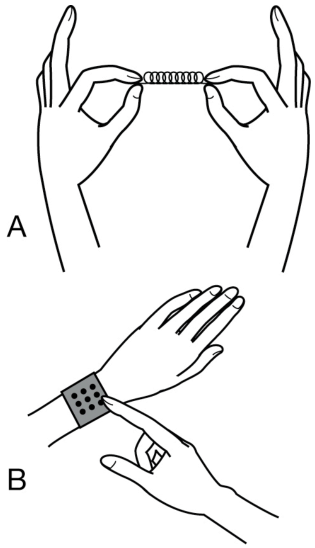

Figure 2: Categories of interactions a) *Inductive interactions*: stretching and deformations b) *Capacitive interactions*: touching and rigid manipulations.

What do we sense?

The resonant frequency can be calculated as:

$$f_0 = \frac{1}{2\pi\sqrt{L \cdot C}}, \text{ (Eq. 1)}$$

where L is inductance and C is capacitance of the system. Therefore, the resonant frequency of the system changes only when its *inductance* and *capacitance* are affected. The design of sensors should afford physical interactions that allow users to alter the system reactance and change its resonant frequency.

As it happens, most real-world conductive objects have capacitances and inductances that exist naturally due to specifics of the object's mechanical structure (C_0 and L_0 on Figure 1). For example, links in the wristwatch bracelet would naturally form capacitive links and a pair of twisted copper wires would create an inductive element.

For most objects, these parasitic capacitances and inductances are very small and the resonant frequency is extremely high, approaching infinity, making it impossible to measure using low-power microcontroller-based devices. To shift the resonant frequency into a lower range we selectively control either the inductance or capacitance of the system while keeping other parameters unchanged. For example, if we would like to track capacitive changes in the system by adding a large biasing inductor L_s (Figure 1), we can effectively shift the resonant frequency into a lower, measureable range. Indeed, Figure 3 shows resonant frequency curves for various values of biasing inductors. We can see that as we increase the inductance, the resonant frequency shifts into a lower range where it can be reliably measured even for very small capacitances. We can measure small inductive changes similarly.

User interactions, inferring user actions

When the resonant frequency is used to estimate human activities, all interactions can be separated into the following two groups: *capacitive* and *inductive* (Figure 2).

Capacitive interactions change the capacitive properties of the system. For example, a user touching a conductive object, such as a button, forms a capacitive link to the ground increasing the overall capacitance and decreasing the resonant frequency. Another example of capacitive interactions is the physical reconfiguration of the object such as opening or closing a drawer in a metal cabinet. Such reconfiguration leads to changes in parasitic capacitances and changes the resonant frequency.

Inductive interactions change the inductive properties of the overall system. For example, stretching a metal spring will change its inductive reactance, since the

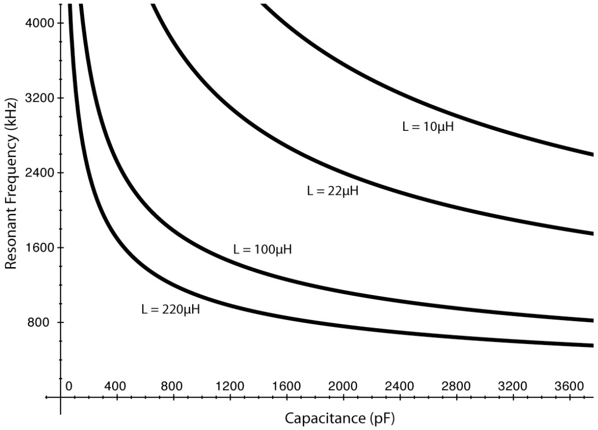

Figure 3: Resonant frequency versus capacitance for fixed values of inductance.

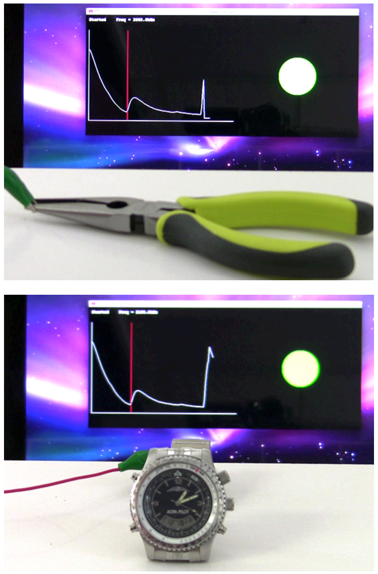

Figure 4: Measuring the self-resonant frequency of everyday objects.

inductance of a coil depends on the distance between its turns.

Both capacitive and inductive interactions change a single physical property – i.e., the resonant frequency. To infer user actions from changes in a single measurable parameter, we must establish a one-to-one correspondence between user actions and parameter changes. While this is a general design problem for each particular sensing configuration, in most basic scenarios, we need to be able to block the effect of either capacitive or inductive interactions. Doing so will allow us to be sure that changes in the resonant frequency are the result of changes in one, but not both, types of interactions. For example, if we are measuring the stretching of twisted wire, which is an inductive interaction, we would like to remove the influence of the user touching the wire, which is a capacitive interaction that would affect the measurements.

Blocking the influence of alternative interactions can be accomplished by adding a biasing capacitor or inductor. As we can observe in Figure 3, with increased capacitance, the resonant frequency becomes less sensitive to small variations while sensitivity to inductive changes is not affected, as long as inductance is very small. Therefore, by including a large biasing capacitor, we can effectively block the influence of capacitance. In the example above, blocking the capacitance will allow us to be sure that any changes in the resonant frequency are from wire stretching only.

Resonant signatures of everyday objects.
Being able to measure the resonant frequencies for very small capacitances and inductances allows us to "tag" and recognize everyday objects. Indeed, we can measure and record their unique resonance frequencies, e.g. *self-resonant frequencies*, by simply touching them with the sensor. We can later match the resonant frequency of an object with which the user interacts to the previously recorded values. If the new measured value matches the stored value, the object can be identified. We demonstrate this technique in the next section.

Case Design: Making Everyday Objects Touch-Sensitive

We have discussed the basic principles of designing sensing solutions based on measuring resonance. In this section, we describe a case design for a sensor that adds ad-hoc touch sensitivity to everyday objects.

The sensor continually tracks the resonant frequency of any conductive object attached to it, such as a wristwatch or pliers as seen in Figure 4. In each tracking cycle, we excite objects with a 500 Hz – 3 MHz frequency sweep. We use a biasing inductor $L_s = 400\mu\text{H}$ (Figure 1) in order to shift the object's resonant frequencies into a low range and block inductive effects. A small resistor R_s is added to convert the alternating current into a voltage, which is then converted into a time-varying DC signal using a simple envelope-detector circuit. The signal is sampled using an analog-to-digital converter (ADC) and the first local minimum, which corresponds to the resonant frequency of the current tracking cycle, is computed.

Figure 4 presents measurements of the resonant frequency for a pair of pliers and a watch. The real-time graph of the DC voltage versus frequency is displayed behind the objects and the red vertical line indicates object's resonant frequencies. In Figure 4, the resonant

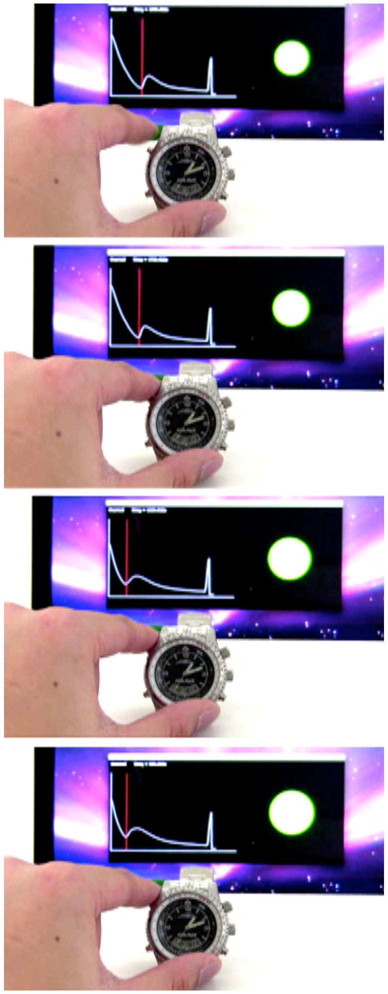

Figure 5: The wristwatch resonance frequency decreases when the user is touching it and the frequency shift depends on area of touch.

frequencies are 2 MHz and 2.1 MHz for the pliers and the watch, respectively[2].

When the user is touching an object, his/her finger forms a capacitive link increasing the overall capacitance and decreasing the resonant frequency. In fact, the user's finger forms a *variable capacitor* – i.e., as he/she presses harder, the skin stretches increasing the area of touch and increasing the capacitance. Figure 5 illustrates this phenomenon showing that, as the user presses harder, the vertical red line, which indicates the current resonant frequency, shifts from 2.1 MHz[3] to 900 KHz. In the current implementation, we sweep the frequency in 1 kHz increments giving us 100 distinct steps of touch sensitivity, which is extremely sensitive.

This design demonstrates some of the following interesting properties of our sensing approach: any conductive object can become touch-sensitive just by attaching a single wire; the sensing is continuous with high sensitivity to changes in the area of touch; and we can identify objects depending on their natural self-resonant frequency and consequently "tag" and recognize them later. A variety of novel applications are possible even with this simple proof-of-concept sensor.

Future Work

This paper presents our early investigation of a new approach for sensing human activities and describes the design of a novel touch sensor developed as a proof-of-concept. This work is still in its early stage with several technological hurdles that must be overcome – e.g. reducing the size of the sensor, increasing the update rate, and improving precision. Investigating new sensing configurations and implementing our approach is also a very important direction of future work. This includes, but is not limited to, designing sensors for stretching; investigating possibilities for 2D touch-sensors and multi-touch; designing sensors for tracking internal changes in an object's configuration; and many more potential research directions. The approach that we describe in this paper can be used to sense a very broad range of human activities. Therefore, we believe that it will lead to the design of many new sensing solutions and exciting interactive experiences that were not possible before.

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[2] Note that these frequencies have been adjusted with a biasing inductor L_s. The *actual* resonant frequencies of these objects are in the gigahertz range.

[3] 2.1 MHz is the self-resonant frequency of the wristwatch.