A New Continuous Multimodal Musical Controller Using Wireless Magnetic Tags

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ABSTRACT

We describe a new kind of musical interface based on magnetic tagging technology that can turn essentially any object into a continuous controller with both contact and noncontact degrees of freedom. Our system responds to magnetically-coupled resonant tags (simple inductor/capacitor combinations or magnetostrictor strips) that are within range of the reader (8"-2 feet, depending on the tag). The "ID" of the tag is defined by the center-frequency of the resonance and the breadth of the reader's frequency sweep, allowing up to roughly 30 independent objects to be distinguished simultaneously by our current system, without the need for anticollision procedures. The reader produces a serial data stream that updates the parameters of all detected tags 30 times per second. These include the center frequency, resonance width, and integrated coupling amplitude for each detected tag. The latter provides an indication of the tag's distance from the reader and their mutual orientation, enabling continuous noncontact control. Tactile parameters may also be acquired by making the resonance frequency parametric with pressure. We demonstrate the musical possibilities of such an interface via mapping software that assigns different continuous musical behavior to an array of 13 toylike objects, enabling performance through their manipulation.

1) Introduction

A variety of noncontact, wireless, free-gesture musical instruments have been developed [1] ever since the invention of the Theremin eight decades ago, exploiting a several sensing technologies. Some, such as the Theremin, are based on electric field sensing [2]; others are active optical trackers [3], sonars [4], or vision-based systems [5]. The vision approaches yield the richest data, enabling many different objects or body parts to be independently tracked [6] without requiring special hardware to be worn or embedded in the targets. Although they are improving, vision-based systems are still often slow and fragile, becoming confused by changes in lighting or dynamic optical clutter.

All of these devices are essentially line-of-sight, including the capacitive-sensing approaches, since the electric fields that are finding hands, for example, can be blocked by any conductive surface, including other parts of the body. This drawback is somewhat overcome by the magnetic tracking systems [7] that determine the 6-axis position of a set of receiving coils relative to an array of fixed transmitting coils via their mutual inductance, which is a function of their relative orientation and position. As magnetic fields at these frequencies pass freely through the body, these systems are widely used by the motion capture and virtual reality communities. Although these trackers are able to locate many simultaneous points, each sensing location must be defined by a receiving coil, which still needs to be wired to a central RF transponder (devices are now emerging that mount a battery-powered RF link right at each coil). Because of their complex design, these systems are also somewhat expensive.

Although the Theremin has developed its share of virtuoso performers, a purely noncontact instrument can provide limited capacity for precise musical expression. Several hybrid devices have been built to explore combinations of tactile and free gesture [8]; essentially all are battery-powered circuits, frequently of non-negligible size, weight, complication, and current drain.

2) Magnetically-Coupled Tags

Magnetically-coupled "tags" provide a potential solution to many of the drawbacks sketched above. They are small, minimal circuits or simple strips of material that can be remotely excited by a fixed reader coil. Their coupling strength is determined by their distance and orientation, and as their resonance frequency [9] and Q [10] can be made parametric with local parameters (e.g., pressure, temperature, etc.), they can also act as sensors, hence tactile controllers. Because of their small size, low cost, and nonreliance on battery power, they can be permanently embedded into essentially any object (provided the reader's magnetic flux isn't shunted by large amounts of magnetic material or conductors that carry eddy currents). This enables essentially any object to serve as an interface device [11] or, in this example, as a musical controller.

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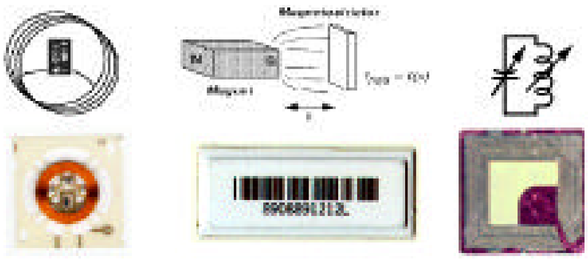

Figure 1: Common types of passive magnetic tags

Figure 1 shows typical examples of the three common classes of passive, magnetically-coupled tags, with associated schematics above. At left is a standard Radio Frequency Identification (RFID) tag, incorporating a simple, low-power CMOS integrated circuit bonded onto a receiver coil. These chips are generally merely simple state machines, powered up by the energy conveyed into the tag's antenna coil by a reader located up to several feet away in the more sensitive systems; after reaching adequate charge, the tag broadcasts its ID and associated data back through its antenna to the reader.

Although chip-based RFID systems are capable of providing many bits of information and ID, they currently have several shortcomings for musical controller applications. Many of these systems update their list of detected ID's slowly, requiring many 10's or 100's of msec between detections. The situation worsens when several tags are simultaneously within range of a single reader. In this case, most tagging systems either stop working or implement iterative anticollision schemes that introduce even more delay. In addition, commercial RFID products seldom provide an indication of detected signal strength, corresponding to tag position and orientation (a very useful interface parameter).

The tags that we have chosen are simple, magnetically-coupled resonances, such as used for anti-shoplifting Electronic Article Surveillance (EAS) systems. At the frequency range used here (40-400 kHz), these are of two types; simple inductor and capacitor series (LC) circuits (Fig. 1 right) or metallic glass "magnetostrictor" strips (Fig. 1 middle), such as the mechanical resonators used in Sensormatic's UltraMax [12] EAS system. As the ID of each tag is determined by the center frequency of the resonance, the number of unique ID's is limited by the swept frequency range and the width (Q) of the resonances. In the system described below, we are able to easily incorporate circa 30 uniquely ID'ed objects. Although this is far fewer than possible with chip tags, these analog tags can be read out much faster (our current system can update the tag parameters at over 30 Hz) and all tags can be read simultaneously without additional delay or complication. The tags are inexpensive and easily fabricated by either choosing an inductor and capacitor (their resonant frequency is determined by $[2\pi\sqrt{LC}]^{-1}$) or trimming a magnetostrictor strip to the appropriate length. In addition, by making the capacitance, inductance, damping, or mechanical resonance a property of an environmental parameter (pressure, temperature, etc.), these tags may be used as sensors, e.g., as in [9,10].

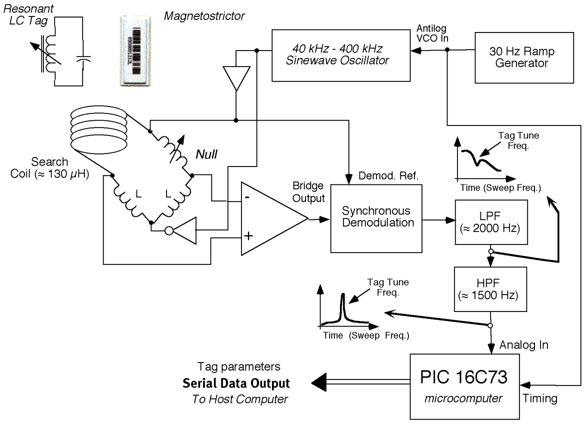

Figure 2: Block diagram of swept tag reader

3) Swept-Frequency Tag Reader

Fig. 2 shows a diagram depicting the tag reader that we are using in our current demo projects. Although other (e.g., transmit/receive) arrangements may provide more sensitivity, our present circuit uses an inductive bridge, where a search coil (currently 12 turns of magnet wire around a 11.5" diameter frame, giving roughly 130 μH of inductance) is balanced against a set of reference inductors. The bridge excitation is a 20-volt sinusoid, sweeping linearly from 40 to 400 kHz at a 30 Hz repetition. The bridge imbalance is synchronously demodulated and low-pass filtered to attenuate noise background. A high-pass filter then enhances abrupt changes in the bridge's null, caused by current drawn by the search coil when resonant tags are traversed. The entire sweep is monitored by a PIC 16C73 microcomputer that logs the center frequency, width, and integrated height (e.g., proximity or coupling strength) of each detected peak and transmits them to a host PC through a serial connection after each sweep. Related architectures are used to detect LC shoplifting tags [13] at higher frequencies, such as depicted at right in Fig. 1.

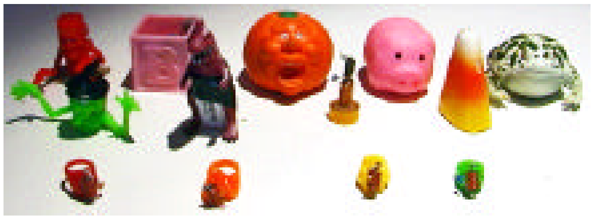

Figure 3: Entire ensemble of tagged objects

4) Tagged Objects

Different types of LC tags were inserted into an array of 13 objects (shown in Fig. 3) in order to explore various possibilities for musical control. As described in the following section, every object produced a different musical event or effect when brought near the reader. Only a single LC tag or magnetostrictor was embedded in most of the objects of Fig. 3, thus a

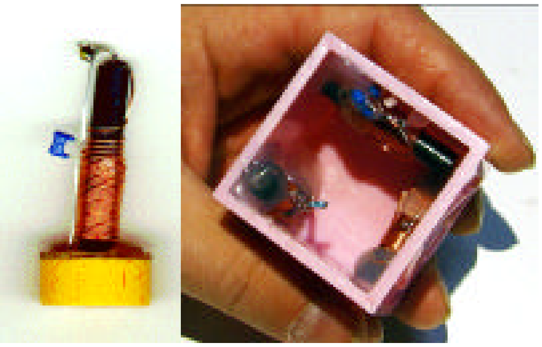

Figure 4: Two multiparameter tagged objects

Figure 5: Ring tags for tracking fingers

resonance seen at a particular frequency indicates the presence of the corresponding object. Two of the tags, however, exploited wider variance in frequency to enable additional degrees of control. These are shown in Fig. 4. In the construct at left, the coil can be moved by the fingers while they are holding the tag, causing a change in the inductance, hence a shift in resonant frequency. This is thus a dual-parameter controller, with the resonance amplitude a function of coupling strength (hence position and orientation) and the center frequency determined by the amount of finger pull. The cube at right has 3 tags mounted along orthogonal axes, thus its orientation can be determined when it is within the reader's range.

Fig. 5 shows our smallest tags, mounted on a set of plastic rings to enable tracking of the fingertips. These rings could be detected up to 8 inches from the search coil, and the net coupling strength indicated the combined proximity and orientation of each finger (the signal is maximal when the ring coil's axis is aligned with the local magnetic field, which tends to run along the search coil's axis). Larger coils were used in the bigger objects, which could be detected two feet from the search coil, giving a good continuous range of sensitivity. Magnetostrictors were also embedded in other objects; the antilog frequency sweep enabled them to be well detected, as they are very high-Q resonators at lower frequency (e.g., 50-100 kHz).

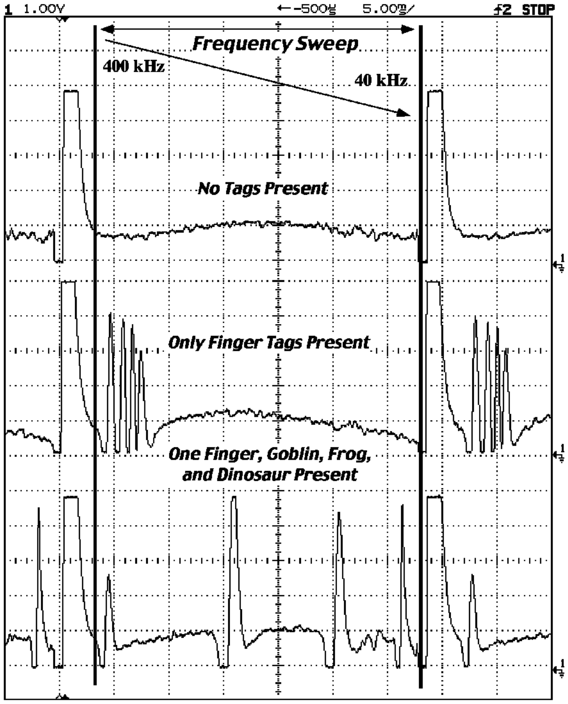

Figure 6: Tag reader analog output vs. sweep freq.

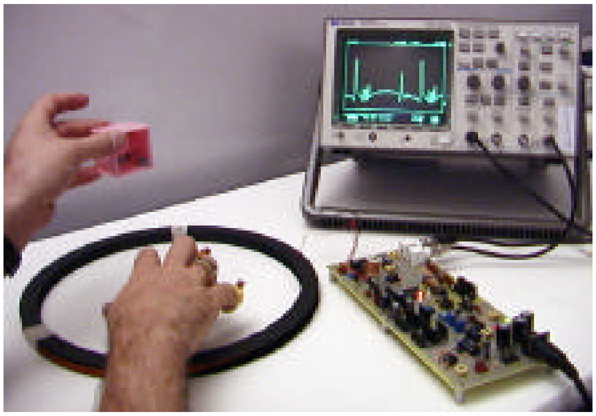

Figure 7: Musical tags in performance

Fig. 6 shows the response of the tag reader analog output (i.e., conditioned bridge unbalance) vs. the sweep frequency. The top trace shows that the bridge is nicely nulled in the absence of resonant tags. The middle trace shows the bridge signal when all 4 finger tags are introduced (these take the highest frequency slots), while the lower trace shows the sweep with a combination of different tags near the reader. Similar signals can be seen on the oscilloscope in Fig. 7, which shows the musical tag system in operation (the swept-frequency tag reader is at lower right).

5) Musical Implementation

We have developed a musical mapping to demonstrate the potential of the tag system as a unique musical interface. We assigned the objects to four categories: harmonic tags, melodic tags, embellishment tags, and additional sound tags. Three of the objects were attached to harmonic events. When these were brought near the coil, harmonic chords were generated.

Each of the three tags had a basic chord associated with it; specifically, in the key of C major, inserting the first tag by itself produced a I chord, the second produced a IV chord, and the third produced a V chord. Due to the ability of the tag reader to sense multiple tags, it was possible to insert multiple harmonic tags simultaneously and sense all of them. The volume of the chord thus produced was dependent on the distance of the furthest sensed harmonic tag from the coil. The quality of the chord was determined according to a harmonic state machine, which provided for relatively smooth transitions between the basic harmonies associated with each of the three individual tags. For instance, if the I tag was inserted, and then the IV was additionally inserted, a vi chord would be played. The premise was that if the I tag was removed, the IV chord could be played to correspond with the IV tag's sole presence, and the vi chord would have served as a suitable transition to the IV chord. Harmonies were thus added to the state machine, with one path through the state machine doing a complete step through the circle of fifths. The physical harmonic tags themselves were attached to somewhat large free-standing objects, so the harmonies could be established and maintained without requiring the user to continue holding them.

The melodic tags supplemented the harmonic tags by playing higher-pitched single melody notes belonging to the chord already being generated by the harmony tags. These were the ring tags of Fig. 5, worn on the fingers of one hand. As the fingers were tilted in and out of the plane of the detection coil, distinct melodic notes could be played, much like the playing of a piano. Velocity could also be sensed for each melodic tag, enabling volume control over the melody notes through finger speed.

Aside from the harmonic and melodic tags, several tags were designed to modify and embellish the sounds. The first embellishment tag was a free-standing tag that continuously slid the pitch of the harmonic chord notes down by up to an octave. The second embellishment tag was a "voice-changer" that produced a brief sound effect and changed the instrument voices playing the harmony and the melody notes. The third embellishment tag added a vibrato effect to the melody notes when inserted into the coil. Finally, the fourth embellishment tag was the most complicated. It was the tag with a manipulable inductor coil (Fig. 4 left), thus two independent effects were possible; inserting the tag into the field transposed the melody notes up by an octave and faded in a choral voice, while stretching the tag's coil added a different choral sound supplementing the harmony being played.

Another pair of objects enabled two additional supplementary sounds to be added. One tag triggered a high-pitched, "wind-chime-like", twinkling sound, whose volume changed with proximity. The other object was the orientation-sensing cube (Fig. 3 right). Inserting the cube triggered a strong synthetic lead sound that could be pitch-bent up and down by several octaves as it twisted.

6) Conclusions

Our simple musical demonstration only hints at the new possibilities enabled by such a musical interface. Future work will explore more complicated mappings with multiple read coils, multi-axis tag tracking, and more sensitive readers.

7) Acknowlegements

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