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Strange Vibrations: The Evolution of the Theremin

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Introduction

Can you imagine an instrument which is played without physically touching it? Leon Theremin not only imagined it, he made it a reality. This project will examine the unusual and versatile instrument known as the theremin. It will look at the history and development of the instrument as well as the story of its Russian inventor, Leon Theremin, and notable performer Clara Rockmore. The physics behind the instrument will be briefly examined. Several prominent uses of the theremin in popular culture/media will be studied including its use in science fiction movies of the 1950s. Also examined will be the electro-theremin, a simplified version of the instrument which is used as a distinguishing feature of the 1966 music of the Beach Boys in "Good Vibrations." Additional instruments inspired by the theremin will be explored. An experimental robotic theremin player will be discussed. This paper will focus on the creation and evolution of the theremin and the usage thereof in the music industry, the movie industry, and the scientific community.

History and Development of the Theremin

The theremin was invented in 1920 by Leon Theremin. It was developed during the civil war in Russia while he was working on radio equipment and proximity detectors. During his work on these items, he discovered that moving his hands near the equipment affected the capacitance and resonant frequency of the circuitry. He thought such resonance could be used to tune oscillators and produce various sounds. This was the birth of the first musical instrument to be played without touching it (Nikitin 252).

Theremin with his original vacuum tubes (cathode relays) instrument ~ circa 1920 {*photo source Dan Burns}*

He initially called his device the aetherphone because it was producing music from the "ether;" at this point in history ether was believed to permeate all space, where it served as a travel medium for light. His amazing invention soon became known by his name: the theremin (Nikitin 253). He gave a demonstration of a prototype musical instrument in 1921 at the 8th Electrical Engineering Congress in Moscow, and by the late 1920s three different companies were already commercially producing the instrument to a limited extent. RCA, as one of three companies, built and sold approximately 500 units (Skeldon et al. 946).

At this point, Theremin made some improvements to his instrument per the recommendations of his friend and thereminist Clara Rockmore. At her behest, Theremin built a more sensitive device with an expanded range, covering five octaves instead of three. Per the suggestion of pianist and fellow inventor Josef Hofmann, Theremin also made the case more compact so Rockmore's hands would be more visible to the audience when she performed (Gray).

There were two main reasons why the theremin was not a commercial success for home use: the instrument was prohibitively expensive and extremely difficult to play (Hiser). In 1930, a radio set cost about $30 while a theremin (with speakers) cost $230, which is over $3,000 in today's money (Nikitin 253). It was the beginning of the Great Depression, and the theremin would have been considered a luxury item for any household. The other main reason for the theremin's commercial lack of success was RCA's claim that anyone could play it easily and without practice or musical knowledge. I know from personal experience how difficult it is to play the theremin. Unless the hands are held extremely still, the pitch will drift. The instrument's range is vast and only one very specific position will produce the desired note. This blatant falsification of the instrument's exponential learning curve was a serious marketing mistake by RCA (Hiser). In fact, during World War II, RCA scrapped its remaining stock of theremins to provide materials for the US war effort ("Leon Theremin").

Not everyone was a fan of the theremin or thought it should have a place with "serious" musical instruments. During the 1930s and 1940s, some early music critics thought the theremin to be irritating and that performers overused vibrato and portamento. Music reviewers from the *New York Tribune* and *Modern Music* compared the sound of the theremin to a yowling cat, and "fifty mothers all singing lullabies to their children at the same time" (Hiser). In 1937 John Cage, a pioneer in electroacoustic music, expressed his dissatisfaction with the theremin. He complained thereminists were taking a brand new technology, with unheard of potential, and doing their utmost to make it sound like an ordinary cello. He also took issue with the literature selection of the theremin players. He thought they should explore new possibilities rather than playing old classics, and he considered doing so a form of censorship. He stated, "thereminists act as censors, giving the public those sounds they think the public will like. We are shielded

from new sound experiences." Clara Rockmore, theremin virtuoso, defended the classical repertoire as a way to confer legitimacy to the theremin as a serious instrument (Hiser).

After WWII (in 1954), a 14-year-old high school student and electronics enthusiast named Robert Moog began building theremins from plans printed in *Electronics World* magazine. He built about ten theremins in all and went on to publish several articles about the building process. He also sold theremin kits for people to assemble at home, which helped him pay his way through college and graduate school. Moog also credits the theremin as inspiration for his own invention: the Moog Synthesizer (Martin). Moog's interest in the theremin helped keep the quirky instrument from fading into obscurity.

A couple of other things also kept the theremin in the public's mind. Moog and Rockmore went on to work together to record an album of theremin music which was released in 1977 when Rockmore was 66 years old (Flanagan). This was a collection of classical music by well-known composers, but it was not a financial success for Moog or Rockmore, as Delos Music, the record company kept the profits. However, the album did have an important function in keeping interest in the theremin alive, as it attracted the attention of filmmaker Steve M. Martin. His documentary, *Theremin: An Electronic Odyssey* (1993), triggered a dramatic resurgence in the popularity of the theremin (Shokin). The documentary included historical footage of Theremin and Rockmore and described the instrument's development, evolution, and connections to the other instruments it inspired (Gray).

Today, it is possible to buy kits or ready-built instruments from a variety of different vendors including Moog, Burns Theremins, Theremin World, and Theremaniacs. RCA offers a kit which utilizes vacuum tubes instead of solid state electronics. I built my theremin from a kit I purchased from PAiA Electronics.

A *YouTube* search will display over 100,000 results of people playing the theremin. Some play badly, but there are also some with great artistry and musicianship. The instrument did not fade into obscurity with the passage of time. Rather, it is seen as the original electronic musical instrument.

Brief Bio of Leon Theremin (a.k.a. Lev Termen)

Leon Theremin was born with the name Lev Sergeyevich Termen on August 24, 1896 in St. Petersburg, Russia (The Editors of the Encyclopaedia Britannica). His name was "Americanized" to Leon Theremin in 1927 when he traveled to New York (Nikitin 252). As a young man he studied physics and astronomy in St. Petersburg at the university. He also studied cello at the conservatory (Nikitin 252), which perhaps influenced the design of the instrument he would eventually invent.

During the first World War, Theremin was drafted and graduated from the Officers' Electro-Technical School for military officers. Later, in 1917, he worked on equipment for some of Russia's first radio stations. Two years after that, Russia went through a revolution and Theremin spent 1919-1920 in prison due to accusations of counter-revolutionary activity. Upon his release, he joined the Ioffe Physical Technical Institute. There, he became the head of a new experimental lab and began work on high-frequency measurement techniques (Nikitin 252). These experiments eventually led to the 1920 invention of his gesture-controlled musical instrument (The Editors of the Encyclopaedia Britannica). The same capacitance-based proximity detection technology was also used by Theremin to develop an alarm system, and he also developed an early mechanical television (Nikitin 253). In 1922, Theremin showcased his inventions including the theremin to Vladimir Lenin at the Kremlin. In 1927, he showed them to Albert Einstein in Berlin (The Editors of the Encyclopaedia Britannica).

Later that same year, Theremin traveled to New York where his instrument was a sensation (Nikitin 253). The next year, he applied for and received US patent #1,661,058 for the theremin ("Leon Theremin"). In 1930, Theremin gave a concert in Carnegie Hall featuring 10 theremins and returned there in 1932 to conduct the first electronic orchestra. During his stay in America, Theremin continued his inventing. In 1930, he built a drum machine in collaboration with Henry Cowell. The device was called a "Rythmicon" and was designed to produce multiple complex rhythmic sound patterns (Martin). He patented an electronic security system used in prisons (The Editors of the Encyclopaedia Britannica), and in 1936 he received his third patent for a DC powered electrical clock (Nikitin 253).

In 1938, Theremin was living at 37 West 54th Street in New York City when he was forcibly spirited out of the country by the KGB. He was literally snatched off the street. The Russian government wanted him for working on secret military projects and his electronic knowledge was exploited for espionage (Martin). When he was initially returned to the Soviet Union he was sent to a Gulag Labor Camp in Magadan, Kolyma. In 1940, during WWII, he was transferred to a military research and development prison/lab where he worked on tracking systems to locate ships and submarines (Nikitin 253). During his stay in prison, he invented a compact listening device for the KGB. This device would come to be known as the Great Seal Bug and earned Theremin the Stalin Prize (The Editors of the Encyclopaedia Britannica). In 1945, Soviet Young Pioneers (equivalent to the Boy Scouts of America) presented a large decorative seal to the US ambassador in Moscow. This wall hanging contained the Great Seal Bug which was used for years to eavesdrop and was not discovered until 1952 (Nikitin 253). In 1947, Theremin was released from prison and moved to Moscow. There, he continued his work as a KGB scientist. In 1964, he became Professor of Acoustics at the Moscow Conservatory (The Editors of the Encyclopaedia Britannica).

When Theremin disappeared from the United States in 1938, his friends and colleagues appealed to Washington, D.C. for help in finding him, but to no avail. He was presumed dead. In Steven M. Martin's film *Theremin: An Electronic Odyssey,* Clara Rockmore explains that it was not until she and her husband were visiting Russia 7 years later when they found out differently. They had encountered a fellow scientist and when asked if he ever knew what happened to Leon Theremin, he said they'd just had lunch together that day! Due to fear of the KGB, a clandestine meeting was set up in a subway station and Rockmore and Theremin were briefly reunited. It wasn't until 1991 when director Steven M. Martin traveled to Moscow and found Leon Theremin to bring him back to the United States (for the first time since 1938) that Rockmore and Theremin saw each other again (Martin).

In 1989, Theremin was venerated as a pioneer in electronic music (at a festival thereof) in France (The Editors of the Encyclopaedia Britannica). He also received the Stanford Centennial Medal during a weekend long festival honoring him and other electronic music pioneers at Stanford University in 1991 (Martin). Theremin died November 3, 1993 in Moscow, Russia. He was 97 years old (Nikitin).

Brief Bio of Clara Rockmore, Notable Theremin Performer

Clara Rockmore displayed musical talent from the very beginning. She was born on March 9, 1911 in Vilnius, Lithuania to the Reisenberg family. At the young age of two, she was already showing signs of having perfect pitch and could play simple melodies on the piano (Gray). By the time she was four, she became the youngest violinist to ever be accepted to the Saint Petersburg Imperial Conservatory. She was, in fact, so small she had to stand on a table to audition (McGoogan). At the age of five, she began training under the tutelage of Leopold Auer (Gray).

Rockmore was still a child when her family left Lithuania because of the Russian Revolution. Her sister, pianist Nadia Reisenberg remembers, “It was a long journey. We had to cross many borders illegally, and we traveled without knowing whether or not we would ever reach a country from which we could get a visa to the U.S.” Rockmore was able to help support her family on their journey by giving concerts. Finally, in 1921 the Reisenberg family made it to the United States (Gray).

In America, Rockmore enrolled at the Curtis Institute of Music in Philadelphia. Unfortunately, as a teenager, Rockmore developed a palsy in her hands that eventually made playing the violin all but impossible (PAiA). It was at this point in her life that she met fellow immigrant Leon Theremin and was introduced to the instrument which bears his name. A friend invited Rockmore to a party at the Plaza Hotel in New York City. Theremin was there demonstrating his invention and invited seventeen-year-old Rockmore to try it (Shokin).

Because of her background in violin, as well as her perfect pitch, she was innately skilled at playing the theremin. In her own words, “I was fascinated by the aesthetic part of it, the visual beauty, the idea of playing in the air, and I loved the sound.” Leon Theremin gave Rockmore the gift of an RCA model theremin (Gray). As in the photo below, Rockmore always placed the speaker behind herself. This was so she could hear the note she was about to play while it was still too quiet for the audience to hear, thus giving her a split-second opportunity to fine-tune the pitch. Rockmore developed “aerial fingering” to have more precise control over the instrument. This technique involved adjusting the positions of individual fingers (rather than hands or arms) so as to make extremely fine pitch adjustments (PAiA).

Clara Rockmore playing the Theremin ~ circa 1920 {*photo source Andrew Flanagan}*

During the subsequent years, she performed in Philadelphia, Toronto, and New York, where she premiered a piece written especially for her by Anis Fuliehan, which was conducted by Leopold Stokowski (Gray). She toured the United States multiple times, and she and Theremin sold out Carnegie Hall on several occasions (Flanagan). Rockmore inarguably helped Theremin to promote and popularize his instrument (Nikitin 253).

Although they remained lifelong friends, and Theremin proposed several times, they never married. Rockmore instead married a lawyer named Robert Rockmore (Gray). In 1938, the working relationship of Theremin and Rockmore came to an abrupt halt when he was abducted by Soviet agents and returned to Russia. Rockmore continued to play the theremin in hundreds of concerts before her collaboration with Robert Moog (Gray). After reuniting in 1992 when Theremin was 95 and Rockmore was 80 years old as part of the documentary Theremin: An Electronic Odyssey, they remained friends until the end of their lives. Of all the accolades

she received, her favorite came from Theremin. He wrote to her, “Clarionek, You played like an angel” (Gray).

Rockmore died May 10, 1998 at the age of 87. On the 2016 anniversary of her birth, she was honored with an interactive Google Doodle which plays musical tones controlled by the position of the cursor on the screen. The tone is deliberately reminiscent of that produced by a theremin. A total of 12 Google engineers worked on the Doodle in order to capture the unique instrument. Clara Rockmore was unquestionably a master of the theremin and a pioneer in the field of electronic music (McGoogan).

Physics of the Theremin

The theremin is unique in the fact that it is played without any physical contact between the instrument and the performer. The pitch produced by the theremin is controlled by moving one’s hands near a vertical antenna and the volume is controlled through a separate horizontal antenna. Experienced players can estimate the approximate positions required to produce specific notes, but precise control requires the feedback of hearing the tone produced by the theremin and adjusting one’s hands accordingly.

From the outside the theremin generally resembles a box with two antennas sticking out: a straight vertical one and a looping horizontal one. Many modern theremins also have a selection of control knobs on the front panel to adjust various aspects of the instrument’s performance. The box can be made from any non-metallic material. Unlike a stringed or percussion instrument, its composition does not affect the quality of sound produced by the theremin.

Inside the box, Theremin's original device would have contained vacuum tubes and coils. A modern theremin has similar circuitry but uses semiconductors in place of vacuum tubes. Both operate on the same physical principles.

The components themselves are relatively simple. They consist of four oscillators operating in two pairs. Each pair is what is known as a beat frequency oscillator, or BFO. The circuits are composed of an inductor, a resistor, and a capacitor. This is referred to as an LRC circuit. Two of the circuits are fixed and constant (one in each pair), and two of them each use one of the antennas as the capacitor. Any conductive object in proximity to the antenna will alter its capacitance and change the circuit's resonant frequency. The circuits are in pairs so this varying difference between their resonant frequencies causes what is called a "beat frequency" as the waveforms go into and out of phase with each other. The beat is converted from a variance in amplitude to a separate tone of the same frequency, then amplified and sent to the audio output.

In the article "Physics of the Theremin" by Kenneth D. Skeldon et al., a detailed mathematical explanation is provided. I have adapted it below:

The frequency produced is determined by multiplying the two oscillator signals $A_1 \sin \omega_1 t$ and $A_2 \sin \omega_2 t$ to produce the signal

$$V_{\text{out}} = A_1 A_2 \sin \omega_1 t \sin \omega_2 t$$

where ω is the frequency of each oscillator, A is their amplitude, and t is time. One of the oscillators has a fixed frequency ω, and the other incorporates the control antenna. The equation then expands into

$$V_{\text{out}} = \frac{A}{2} [\cos(\omega_1 - \omega_2)t - \cos(\omega_1 + \omega_2)t]$$

in which the A is the product of A_1 and A_2. This will produce two frequencies. One is the difference between the two oscillators, and the other is the sum. Because the oscillators resonate at very high frequencies (on the order of 1 Mhz), the sum is far beyond the human range of hearing and can be ignored. This simplifies the equation to

$$V_{out} = \frac{A}{2} \cos(\omega_1 - \omega_2)t$$

As a thereminist approaches the antenna, they very slightly alter the capacitance of the circuit and change its resonant frequency (Skeldon et al. 945).

This very small influence is why the oscillators resonate at such high frequencies. A very slight change in a large number can produce a significant change in beat frequency. Suppose the fixed oscillator is resonating at 1,000,000 Hz and the variable at 1,000,100 Hz. If the second oscillator changes by 100 Hz, it will have only changed by .01% and yet have doubled the beat frequency (Theremin 50).

It is, of course, important to control volume as well. Without such control, all transitions between notes would have to be portamentos. By using the left hand antenna as volume control, the theremin player is able to separate different notes from one another and play staccato rhythms. It operates on the same basic principle as the pitch control circuitry, but is used to control the amplifier rather than as the signal to be amplified. This gives the thereminist full control over volume, ranging from full volume to mute and all levels in between.

Uses of the Theremin in Popular Culture

Most people who have never heard of a theremin would probably recognize the sound produced by one because of its common use in old science fiction movies. But the theremin was in use as a concert instrument well before TVs were popular. During the 1930s and 1940s,

people known as thereminists performed in professional orchestras. There are surviving sound recordings of the emotional expressiveness and sentimentality achieved by these musicians (Hiser). On April 25, 1930 ten theremin players performed together in Carnegie Hall (Nikitin 252). To celebrate the 75th anniversary of that performance, on May 26, 2007 ten thereminists gave a concert at Los Angeles Disney Hall (Jason).

It is unlikely many Americans would have been familiar with the first films to utilize the theremin because they were produced in Russia. *Alone* was produced in 1931, and *Komsomol: The Patron of Electrification* was produced in 1934. But Americans would have been familiar with a radio program from 1936 called *The Green Hornet* which used a theremin to indicate the presence of the title character. The public might also have enjoyed a radio broadcast during the 1930s and 1940s of a theremin concert featuring Clara Rockmore or Leon Theremin himself (Wierzbicki 127).

It wasn't until 1944 that a theremin was used in an American film, *Lady in the Dark.* This film was about a woman with mental illness, and the theremin's quavering, unstable quality was used as a sound effect to represent mental instability (Wierzbicki 128). In 1945, director Alfred Hitchcock's movie *Spellbound* utilized a theremin to indicate when the movie's male lead, played by Gregory Peck, fell under a potentially murderous trance. Hitchcock and producer David O. Selznick had never heard a theremin but asked composer Miklós Rózsa for "something unusual" (Wierzbicki 128). When looking for someone to play the theremin for their movie, they first asked Clara Rockmore, who refused to make "silly noises" for Hollywood. The role was eventually filled by Samuel Hoffman. After Rózsa and Hoffman won an Academy Award for best score, the theremin was established in Hollywood as an interesting musical option for adding a unique twist to a movie's soundtrack (Wierzbicki 128).

According to James Wierzbicki's article "Weird Vibrations: How the Theremin Gave Musical Voice to Hollywood's Extraterrestrial 'Others'," Samuel Hoffman went on to play the theremin in dozens more movies. Before it was used in outer space movies, it was utilized in the 1945 film *The Lost Weekend* to represent dipsomania, a craving for alcohol. In 1946, *The Spiral Staircase* made use of the theremin to indicate the presence of a serial killer. *The Red House* (1947) used the theremin to lend an eerie, suspenseful quality to its score, as did *The Pretender* (1947). That same year the theremin was used in a comedy movie called *The Road to Rio* to lend a zany clue that people were hypnotized. The next year, Hoffman played the theremin for the movies *Corkscrew Alley,* a crime drama, and *Let's Live A Little,* a romantic comedy starring Hedy Lamarr and Robert Cummings. Generally speaking, the theremin was utilized in movies during this time as a representation of anxiety, insanity, drunkenness, and emotional unbalance.

In 1950, science fiction joined the list of Hollywood movie genres using the theremin with the release of *Rocketship X-M* (1950). This was the first time a theremin was used in a science fiction movie, but it certainly was not the last. The theremin's otherworldly hum lent itself to many films including *The Day the Earth Stood Still* (1951), *The Thing from Another World* (1951), and *It Came from Outer Space* (1953). In the 1960s, the theremin was featured on television shows such as *The Jetsons* (1962) and *My Favorite Martian* (1963) (Wierzbicki 129). In popular culture of the 1950s and 1960s, the sound of the theremin was symbolic of contact from another world. During the mid 1960s though, the theremin became less and less common because of the invention of the electro-theremin, a simplified instrument with a mechanical user interface (Miller).

The theremin even played a role in the Apollo 11 mission in which Neil Armstrong first set foot on the moon. On their way back from the moon, about 150,000 nautical miles from Earth, NASA's flight journals show that Armstrong played a recording of an album by Samuel

Hoffman featuring the theremin. Armstrong says, “That's an old favorite of mine . . . It's an album made about 20 years ago, called *Music Out of the Moon*” (“Apollo”). In the 2018 biopic of this epic journey called *First Man,* this same album is featured in the soundtrack.

The Electro-theremin and Other Devices Inspired by the Theremin

Why was it necessary for the theremin to evolve and not just remain as Leon Theremin had created it? Due to its lack of a physical interface, it is inherently difficult to play. Composer Bob Schwimmer says of the theremin, “Having perfect pitch doesn’t mean you’re going to be in tune - it just means you’ll know when you’re out of tune” (Shokin). The modifications that Theremin made to his original device for Clara Rockmore allowed her to express greater artistry at the cost of making the instrument even more difficult to play. With no frets, strings, or keys, and a nigh-infinite range of notes, the aspiring thereminist would find that even taking a deep breath at the wrong moment would produce a tonal error (Rothman).

In 1958, an amateur inventor named Bob Whitsell developed the electro-theremin as a simplified version of the theremin. Rather than gesture-controlled antennas, it uses a knob for volume and a slide for pitch. This mechanical interface, while lacking the unique “touchless” aspect of the theremin, makes the electro-theremin far easier to play. Using a mechanical linkage to control an audio oscillator makes the instrument extremely accurate. While the theremin has a much wider range and a richer sound, the electro-theremin has a depiction of a piano keyboard next to the slider so you know exactly where to position the slider in order to produce any given note. While both instruments produce an electronic sound, they are different. The theremin is reminiscent of a cello in the lower tones of its five-octave range and a human voice at higher frequencies. The electro-theremin only produces a pure sine wave without any harmonics and has a three octave range (Polk). It’s likely that Whitsell chose the sine wave to

simplify the construction of the instrument, as the first model was completed mere hours before it was needed to record an album called *Music for Heavenly Bodies* (1958) (Holmes 454). It was the electro-theremin which provided the Beach Boys's "Good Vibrations" (1966) its distinctive sound. The original electro-theremin was sold to a hospital for use in hearing tests in the late 1960s. In 1999, a modern replica of the original electro-theremin was built by Tom Polk and Paul Tanner. Called the Polk Tannerin, it is the instrument currently being used by Brian Wilson of the Beach Boys (Miller).

A Tannerian (electro-theremin) ~ 2011 {*photo source Tom Polk}*

Another device inspired by the theremin was created by Robert Moog. As a high school student, Moog was fascinated by the theremin and constructed at least 10 of them. He went on to create multiple other theremin models, each incorporating his own technological improvements. Moog spent a lot of time playing the theremin. He understood what made a good sound and what musicians found useful, thus leading him to eventually develop his synthesizer. The Moog synthesizer, the first voltage controlled modular synthesizer, is important because it gave birth to a multitude of other electroacoustic devices (Martin).

On a connected note, in 1955 American composer Raymond Scott bought a theremin kit from young Moog and used it to develop a keyboard synthesizer and sequencer called the Clavivox. He created it as an easy-to-use keyboard theremin for his daughter, but it eventually evolved into one of the earliest synthesizers (Martin).

Another musical instrument that makes use of modular synthesizers and sounds like a theremin is one created by Swedish musician Martin Molin, part of the folktronica band known as Wintergatan. Because it is made of modular synthesizers and is held and played like a violin, he calls it the modulin. Utilizing a Moog ribbon controller as the interface gives the modulin a distinctly theremin-like quality. And the ten modular synthesizers work together to produce a similar timbre (Maloney).

The Modulin ~ {*photo source Dan Maloney}*

An even more exotic instrument inspired by the theremin is the MultiMultiTouchTouch. Inspired by an April Fool's Day prank video featuring a polyphonic theremin (which is physically impossible), the device uses a microsoft Kinect to track the position of the player's hands and send corresponding control signals to modular synthesizers. Like the original theremin, it is controlled by gesturing in mid-air, but the field covered by the sensor is divided into multiple "instruments," i.e. percussion, windchimes, and other synth sound effects. A wooden frame divided into quadrants gives the musician a literal frame of reference as to where the sensor

field is. It is possible to play as many simultaneous notes as you have extremities to poke into the sensor field. Unlike a theremin, it is also possible to insert delays, loops, and quantization of pitch and rhythm without the use of external devices. Also unlike a theremin, the player must deal with latency (“A Kinect-Based . . . ”).

The Kinect sensor can respond to your full body rather than just your hands, and this actually relates back to an invention of Leon Theremin’s from 1936. Theremin developed a specialized dance-controlled instrument called the Terpsitone, which he named after the Greek muse of dance, Terpsichore. It functioned on the same capacitance-tuned beat frequency oscillator principle as the theremin, with a metal plate under the dance floor serving as the antenna. The sound was controlled by the movement of dancers standing on the plates, and every gesture affected the sound. It also produced colored lights which changed in time with the music (Mason). Only three terpsitones were ever built, and it remained a novelty with no commercial value due to the extreme difficulty of precise control (Martin).

The late 1920s also saw other inventors drawing inspiration from Theremin’s work. French musician and scientist Maurice Martenot invented the Ondes Martenot which was similar to a theremin but used a keyboard and a ring attached to a wire which the player wore on their right hand allowing them to produce theremin-like glissandos. With their left hand, players controlled a signal generator which controlled the output transducers. Some well known musicians of the time who made use of this instrument were Olivier Messiaen, Pierre Boulez, and Edgard Varèse (Hiller).

Another instrument inspired by Theremin’s work was the Trautonium, designed in 1930 by a German named Friedrich Trautwein. Similar to the Ondes Martenot, it used a sawtooth-wave signal generator and tuned its oscillators with an exotic keyboard. A notable composer, Paul Hindemith, made use of this instrument in the *Concertino for Trautonium and Strings*

(1931). Due to its lack of continuous pitch control, the Trautonium was made obsolete by the development of modern synthesizers and faded into history (Hiller). The theremin, however, cannot be so easily replicated and remains in use to this day.

The theremin also continues to serve as an inspiration for other similar devices. *Make* magazine published build instructions for a “heliophone,” a tiny theremin-like device which generates a tone when exposed to sunlight. This solar powered theremin utilizes an Altoid tin as its case. The pitch is controlled by tilting the solar panel towards or away from the sun; more light on the panel generates a higher pitch (Cunningham). This novelty does not accommodate volume control and sounds rather buzzy, but it demonstrates continued interest in the theremin.

Experimental Robotic Theremin Player

Dr. Takeshi Mizumoto of Kyoto University states:

> Interaction between humans and robots through music in daily environments is expected to lead to new communication channels apart from spoken language. Because music is independent of a particular language, it should transcend language.

Because of this, he hypothesised that if robots could express “emotions” through music, it would make communications more meaningful to humans.To test his hypothesis, he and a team of fellow researchers programed a robot to play the theremin. They used a theremin because the only thing physically needed to play one is arms, so any robot equipped thusly would be able to do so. Also, because a theremin’s sensor field can be mathematically modeled (as shown in the Physics of the Theremin section), the robots used “feed-forward” to predict where to place their arms before listening to the sound for feedback. This allowed the robo-thereminist to find the correct note much faster than simply listening for it (Mizumoto).

Because a robot can play the theremin, an interesting experiment becomes a possibility: a musical version of the Turing test. During a Turing test, a human judge converses with the test subject without being able to see them. If the subject is a robot but manages to convince the examiner that it is a human, it passes the test. What Dr. Mizumoto and his colleagues set out to do in 2009 was to test whether a robot could recognize music, and play it on a theremin expressively enough to pass for human. If the robot passed the “musical Turing test,” it was considered to have the capability to actually *understand* music (Mizumoto).

Dr. Mizumoto and his team were able to successfully program two different robots (HRP-2 and ASIMO) to play the theremin, albeit in a rigidly mechanical way which would not pass the Turing test. They confirmed robo-thereminists are possible and are continuing to experiment in hopes of making the robots better at playing the theremin. In future work, they hope to make the robots able to implement more advanced playing techniques, such as vibrato (Mizumoto). The theremin played an essential role in this scientific endeavor because of its unique no-touch interface.

Conclusion

The theremin was the original non-contact musical instrument. Leon Theremin’s imagination and engineering expertise allowed him to create a truly unique device. Many people have never heard of a theremin by name but would likely recognise its distinctive sound. Starting in Russia in 1920 as a collection of vacuum tubes and coils, the theremin was showcased throughout the world, evolved, and inspired the development of many other fascinating musical instruments, and it is still in use today. Leon Theremin and Clara Rockmore would no doubt be pleased with its enduring relevance. Although built originally with 1920s-era radio equipment, despite the changes in technology, the physics of the instrument remain the

same. Primarily known for its special effects use in movies of the 1950s, it is capable of so much more as demonstrated by its inclusion in a variety of contemporary films as part of the soundtrack. Despite being extremely difficult to play well, it has the potential for great artistry when played by the right hands. As the theremin evolved into the electro-theremin, it saw use in mainstream popular culture including the music of the Beach Boys. It inspired a variety of other electronic instruments, among them the eponymous Moog synthesizer. The theremin was uniquely suited to be part of a robot-human communication experiment and ultimately a Turing test. In Leon Theremin's own words, "In conclusion, I must express my assurance that electricity, which has had considerable influence on science and engineering, will undoubtedly have a great influence on the precious field of art."

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