US 20170303805A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2017/0303805 A1**

Boudreaux (43) **Pub. Date: Oct. 26, 2017**

(54) **METHOD AND APPARATUS FOR SIMULATING THE WRIST PULSE PATTERNS FOR PULSE DIAGNOSIS**

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(21) Appl. No.: **15/134,683**

(22) Filed: **Apr. 21, 2016**

Publication Classification

(51) **Int. Cl.**

A61B 5/024	(2006.01)
A61B 5/00	(2006.01)
A61B 5/00	(2006.01)
A61B 5/00	(2006.01)
A61B 5/00	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 5/02438*** (2013.01); ***A61B 5/6824*** (2013.01); ***A61B 5/7225*** (2013.01); ***A61B 5/0015*** (2013.01); ***A61B 5/4854*** (2013.01); *A61B 2562/02* (2013.01)

(57) **ABSTRACT**

A method and an apparatus are disclosed for simulating the wrist pulse patterns to be used for teaching and practicing pulse diagnostic techniques in traditional Chinese medicine (TCM) and other alternative medicines. The method represents the wrist pulse patterns and artery responses by use of six characteristic qualities: width, depth, strength, rhythm, length, and propagation. One embodiment of the invention uses a processor to drive three solenoids. The three plungers of the solenoids produce time-varying forces that simulate the wrist pulse waves felt by the user's fingers when evaluating pulse patterns in humans or animals. Via a force sensor, the processor detects the compression force from the palpating fingers and classifies said force into one of the three ranges (shallow, middle, and deep). A purity of pulse waveforms representing the various pulse patterns defined in TCM are pre-programmed into the processor in terms of their characteristic qualities and compression forces. The width of the artery is represented by either a width-adjustable plunger head or a multi-lumen tube placed on top of the plungers. Once the user selects a specific pulse pattern, the device continuously generates the pulse waveforms that change dynamically in response to the compression force.

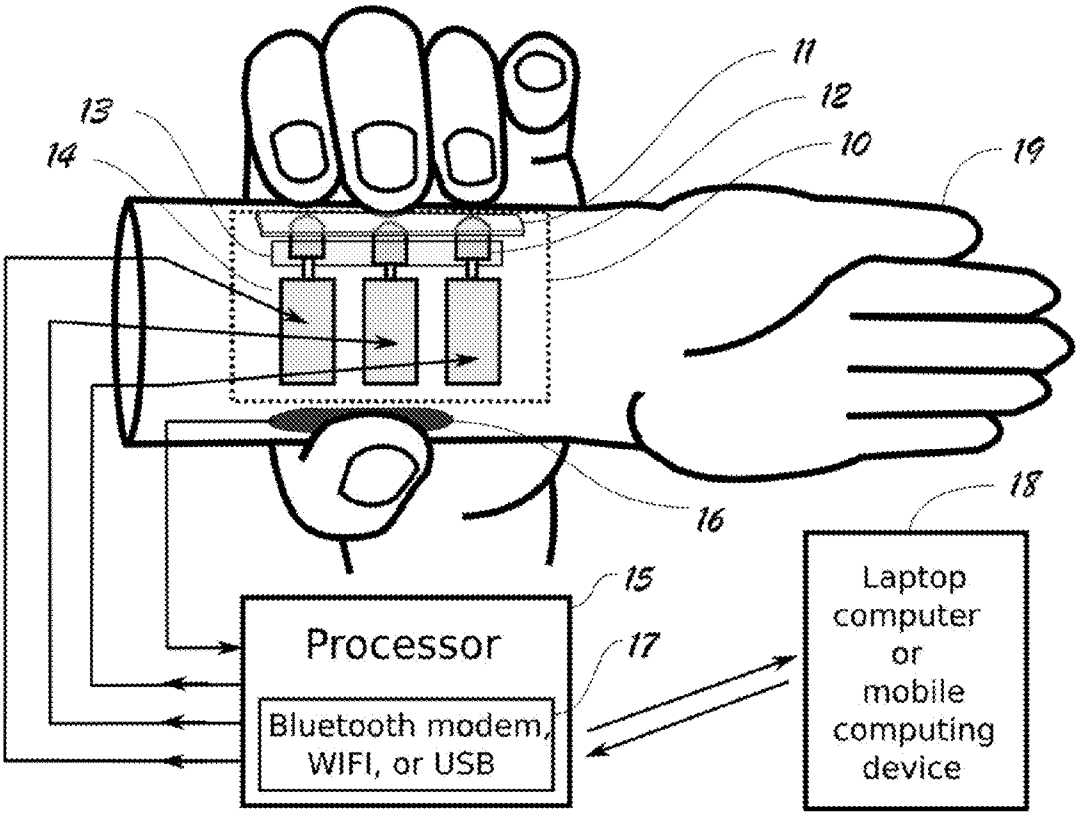


TABLE 1A

	Pattern	Interpretation	Comments
Category 1. Floating Pulses	**1** Floating pulse [*fumai*]	A pulse that is palpable by light touch and grows faint on hard pressure, usually indicating that the illness is in the exterior portion of the body.	The circulation of qi and blood is focused in the body's surface to deal with an external pathogenic agent. The internal circulation is temporarily sacrificed to assure that the pathogen is eliminated before it can enter more deeply and cause serious problems at the visceral level. Debilitated patients may show a floating pulse that is feeble, indicating the inability to retain the qi and yang in the interior due to the deficiency of the vital organs.
	2 Surging pulse [*hongmai*]	A pulse beating like dashing waves with forceful rising and gradual decline, indicating excessive heat.	Excess heat syndromes are rarely difficult to detect, so this pulse type adds little information. The force of the pulse indicates that the condition is pathologically excessive; the gradual decline shows that the syndrome is primarily one of heat (qi excess) rather than fluid excess. The pulse is sometimes described as a "full pulse" indicating the excess condition.
	3 Soggy pulse [*ruanmai*]	A superficial, thin, and soft pulse which can be felt on light touch like a thread floating on water, but grows faint on hard pressuring.	This pulse is similar to the fine and weak pulses, indicating deficiency conditions or damp retention. The thready pulse sensation felt on light touch gives the impression of being easily moved, as if floating on water; hence, it tends to indicate spleen-qi deficiency with accumulation of dampness. It is sometimes referred to as the "soft pulse."
	4 Scattered pulse [*sanmai*]	An irregular pulse, hardly perceptible, occurring in critical cases showing exhaustion of qi.	These are cases where the patient is critically ill, perhaps near death; such patients are normally hospitalized (or sent home to die) and their diagnosis is usually well-established. The pulse only tells that the patient is severely debilitated; it diffuses on light touch and is faint with heavy pressure.
	5 Hollow pulse [*koumai*]	A pulse that feels floating, large, soft, and hollow, like a scallion stalk, occurring in massive loss of blood.	Massive blood loss can easily be reported. This pulse is felt lightly at the superficial level and lightly at the deep level, but barely felt at the intermediate level. The light pulse is like the flexible scallion material, with a hollow center. It means that there is still some flow of qi at the vessel surface, but not much blood.
	6 Tympanic pulse of Hard pulse [*gemai*]	Bowstring and large (wide) with an empty center; feels like the head of a drum. Felt with light pressure. Floating, large, and hard and resistant to pressure.	Indications include hemorrhage, spermatorrhea, abortion, excessive menstrual flow, xu cold. The qi becomes detached and floats to the exterior; the healthy qi is failing to store sperm and blood.
Category 2. Sinking Pulses	**7** Sinking pulse [*chenmai*]	A pulse that can only be felt by pressing hard, usually indicating that the illness is located deep in the interior of the body.	The circulation of qi and blood from the internal viscera to the surface is weak; it is usually confined to the interior as part of the body's attempt to deal with a serious disorder threatening the viscera. Sometimes referred to as the deep pulse.
	8 Hidden pulse [*fumai*]	A pulse that can only be felt by pressing to the bone, located even deeper than the sinking pulse, often appearing in syncope or severe pain.	This pulse is quite extreme, in that one can barely detect it except by applying deep pressure; it gives the sense that the pulse is hidden in the muscles. If there is little musculature, it is as if it is resting on the surface of the bone. The conditions for which it is typical, syncope (fainting) and severe pain, can easily be determined without taking the pulse.
	9 Firmed pulse or Confined pulse [*laomai*]	Pressed superficially or moderately, it does not respond, but can be obtained by heavy pressure. Hard, firm, not changeable, replete, large, bowstring, and long.	Indications include internal cold, perhaps hernia, abdominal masses. It can also indicate wind epilepsy, inflexibility, and cramping, hard accumulations hidden in the interior, running piglet and sudden violent counterflow. The pathogenic factors are steady; there is interior cold and decline of yang qi.
	10 Weak pulse [*ruomai*]	A pulse feeling deep and soft, usually due to deficiency of qi and blood.	This pulse is similar to the fine pulse, but has a softer quality. Usually, this indicates a weakness of the spleen qi, leading to deficiency of both qi and blood. In the system of pulse taking, it serves as the opposite of the replete pulse.

TABLE 1B

Category 3. Slow Pulses	**11** Slow pulse [*chimai*]	A pulse with reduced frequency (less than 60 beats per minute), usually indicating endogenous cold.	A slow pulse may also indicate a person at rest who normally has a high level of physical activity, so must be interpreted in light of other diagnostic information.
	12 Moderate pulse [*huanmai*]	A pulse with even rhythm and moderate tension, indicating a normal condition.	This is similar to the loose pulse, above (and the Chinese name is the same), except that it has a better tension, showing that the qi is adequate. As a normal pulse, it indicates that the disease condition being treated is localized and has not disturbed or been caused by disturbance of the viscera.
	13 Hesitant pulse or Choppy pulse [*semai*]	A pulse coming and going choppily with small, fine, slow, juggling, jostling tempo like scraping bamboo with a knife, indicating sluggish blood circulation due to deficiency of blood or stagnation of qi and blood.	This has a more irregular pattern than the knotted pulse that also shows stagnation of qi and blood. The severity of the blood disorder is greater. As the knife scrapes across the bamboo, it vibrates and irregularly moves forward, yielding a choppy sensation with brief hesitations or interruptions in movement.
	14 Knotted pulse [*jiemai*]	A slow pulse pausing at irregular intervals, often occurring in stagnation of qi and blood.	Qi and blood stasis represent a traditional diagnostic category that does not have a direct correlation with modern diagnostics. In this pulse, the irregularity and slowness are due to obstruction.
Category 4. Rapid Pulses	**15** Rapid pulse [*shoumai*]	A pulse with increased frequency (more than 90 beats per minute), usually indicating the presence of heat.	The rapid pulse is quite a bit more rapid than a normal pulse, and usually occurs only when there is a serious illness and mainly when there is a fever. The pulse can become rapid from activity prior to pulse taking.
	16 Hurried pulse [*cumai*]	A rapid pulse with irregular intermittence, often due to excessive heat with stagnation of qi and blood, or retention of phlegm or undigested food.	This is the excess version of the knotted pulse. it is sometimes called the "running" or "abrupt" pulse. The rapidity indicates heat and the irregularity indicates the blockage caused by stagnation and/or accumulation.
	17 Racing pulse or Swift pulse [*jimai*]	Very rapid, over 120 bpm (beats per minute), or 7-8 beats per breath.	Indications include excess of yang and exhaustion of yin; impending exhaustion of primary qi can also be due to Heart Palpitations. Exhaustion of yin in the lower body and excess of yang in the upper parts. Often accompanies high temperatures. Swift and wiry indicate not enough true yin, overabundance of yang. Swift and forceful indicate primary yang will be exhausted.
	18 Moving pulse or Throbbing pulse [dongmai]	Slippery, rapid, forceful, feels like a bean--strong and throbbing abruptly. "Without head or tail" This is most distinguished at the Guan position, and is a subcategory of the short pulse.	Indications include pain, fright, and shock. Conflict between yin and yang, disturbance of ascending and descending, leading to faster circulation of qi and blood which makes it appear smooth, rapid, and forceful, yet palpable over a narrow region.

TABLE 1C

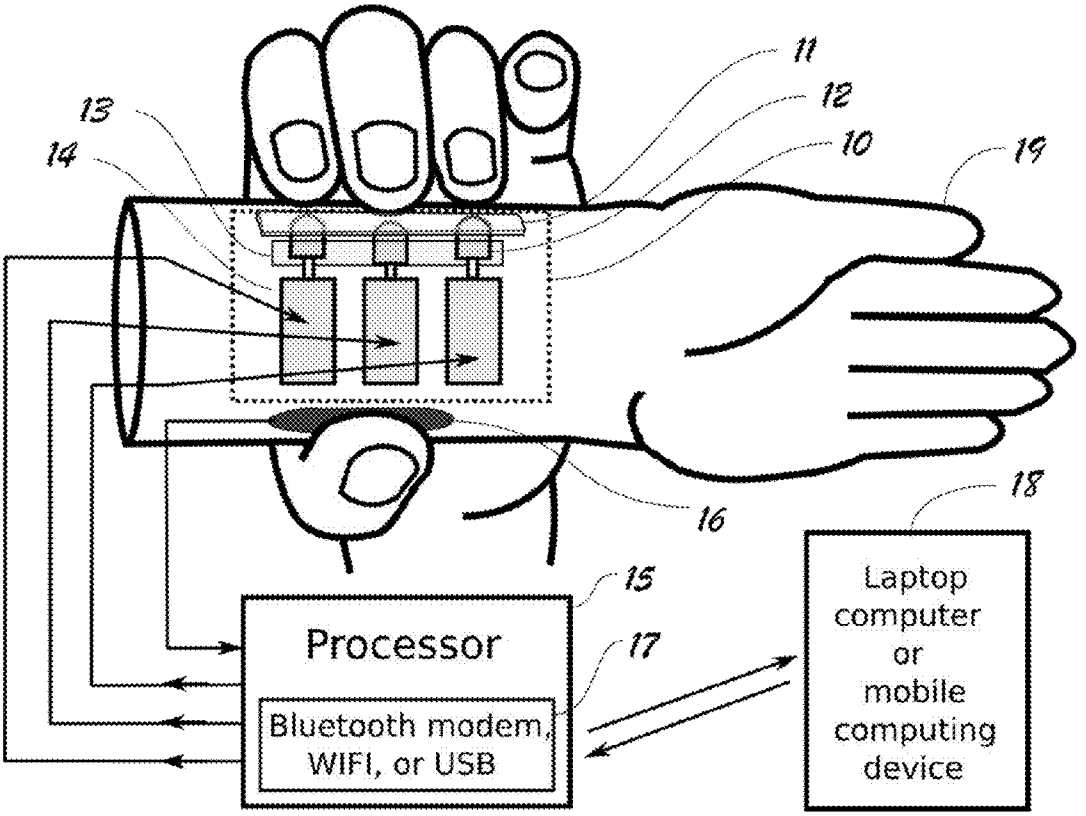
Category 5. Feeble Pulses 虚脉	**19** Feeble pulse [*xumai*] 虚脉	A pulse feeling feeble and void, indicating deficiency of qi and blood or impairment of body fluid.	This pulse is similar to the weak, fine, and faint pulses. It occurs when the deficiency of blood is more severe than in the case of weak and fine pulses, but not so deficient as with the faint pulse.
	20 Faint pulse [*weimai*] 微脉	A pulse feeling thready and soft, scarcely perceptible, showing extreme exhaustion.	Extreme exhaustion is obvious to both the patient and the practitioner. The pulse, lacking substance, volume, and strength, simply reveals the exhaustion of the body essences. It is weaker than the thready (faint) pulse.
	21 Fine pulse or Thready pulse [*ximai*] 细脉	A pulse felt like a fine thread, but always distinctly perceptible, indicating deficiency of qi and blood or other deficiency states.	Although the deficiency can be easily detected by other means, some patients can show an artificially robust exterior appearance, while having notable deficiency. Essence deficiency, the result of chronic illness, can give rise to this pulse type.
	22 Intermittent pulse [*daimai*] 代脉	A slow pulse pausing at regular intervals, often occurring in exhaustion of zangfu organs, severe trauma, or being seized by terror.	As with the scattered pulse, this pulse Type is usually only seen in cases where the person is hospitalized or otherwise in an advanced disease stage. It is expected to occur, for example, with those having serious heart disease.
	23 Short pulse [*duanmai*] 短脉	A pulse with short extent. A short and forceful pulse is often found in qi stagnation and a short and weak pulse implies consumption of qi.	The short pulse seems to deteriorate from the central pulse position towards the two adjacent pulse positions. It strikes the middle finger sharply and leaves quickly. On the one hand, this can represent contraction of the qi, as in liver qi stagnation, or it can represent deficiency of the qi.

Category 6. Replete Pulses 实脉	**24** Replete pulse or Forceful pulse [*shimai*] 实脉	A pulse felt vigorously and forcefully on both light and heavy pressure, implying excessiveness.	This pulse gives relatively little information other than that the condition is one of excess; one must further determine the nature of the excess in order to select a therapeutic strategy. This pulse, however, generally rejects the use of tonification strategies, as it indicates that the body resistance is undamaged.
	25 Slippery pulse [*huamai*] 滑脉	A pulse like beads rolling on a plate, found in patients with phlegm-damp or food stagnation, and also in normal persons. A slippery and rapid pulse may indicate pregnancy.	While use of the pulse to indicate pregnancy is no longer of value (as more reliable tests are readily available), and while this pulse, like the long pulse, is often normal (occurring especially in persons who are somewhat heavy), it is a good confirmation of a diagnosis of phlegm-damp accumulation. It is sometimes referred to as a "smooth pulse."
	26 Tense pulse or Tight pulse [*jinmai*] 紧脉	A pulse felt like a tightly stretched cord, indicating cold or pain.	This is similar to the wiry pulse, but not as long. While pain can be easily reported, a cold syndrome is sometimes disguised by localized heat symptoms; this pulse can indicate either exterior or interior chill.
	27 Long pulse [*changmai*] 长脉	A pulse with lengthy extent and prolonged stroke. A long pulse with moderate tension may be found in normal persons, but a long and stringy pulse indicates excess of yang, especially liver yang.	Particularly in young people, the pulse is felt rather easily across all three finger positions, as is characteristic of the long pulse. The prolonged stroke shows that the vessels are both strong and flexible. A stringy quality indicates a certain level of tension, that corresponds with a liver syndrome. In cases of acute disease, a long pulse will occur when there is a strong confrontation between the body's resistance and the pathogenic factor.
	28 Stringy pulse or Wiry pulse [*xianmai*] 弦脉	A pulse that feels straight and long, like a musical instrument string, usually occurring in liver and gallbladder disorders or severe pain.	This is similar to the tense pulse, but longer and more tremulous. While severe pain can be easily reported, the wiry pulse confirms the liver and/or gallbladder as the focal point of the internal disharmony.

TABLE 2

1) width	The magnet-controlled locking rod changes the plungers between the wide mode and narrow mode, which represents the width of the blood vessel. As an alternative, a multi-compartment tube is placed on top of the plungers with width adjusted by inflating all or some compartments.
2) depth	The pressure sensor measures the applied force. The microprocessor generates different waveforms accordingly, representing the depth quality of the pulse.
3) strength	The processor generates a pulse waveform that has a specific magnitude and shape to represent the pulse strength.
4) rhythm	The processor controls the rate of repeating the pulses and can simulate the conditions of tachycardia, bradycardia, and arrhythmia.
5) length	The processor controls the "duty cycle" of the pulse wave, which represents the systolic portion of the pulse wave.
6) propagation	The timing and magnitude of the pulse wave for each of the three solenoids can be set independently to simulate how the pressure wave propagates along the artery.

FIG. 1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15
17
Processor
Bluetooth modem, WIFI, or USB
Laptop computer or mobile computing device

FIG. 2

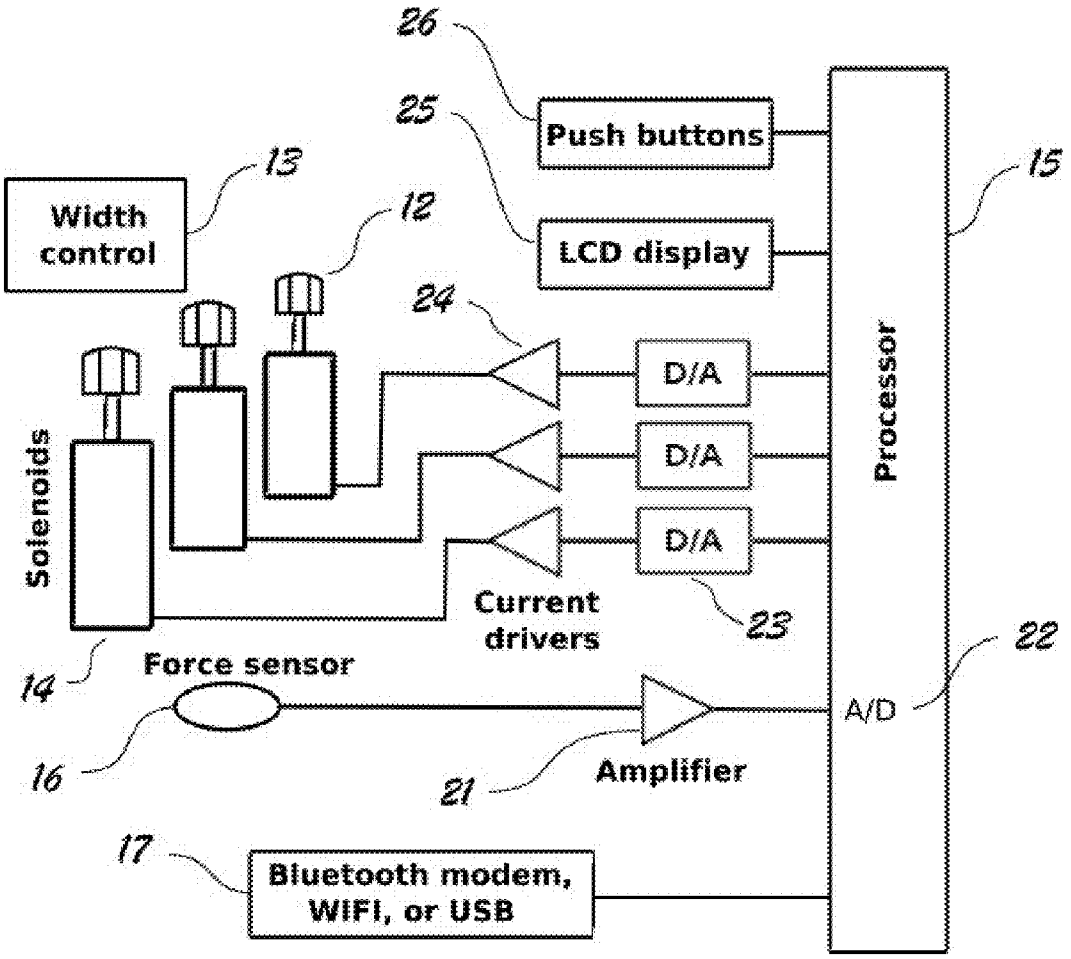

26
Push buttons
25
LCD display
15
Processor
13
Width control
12
24
D/A
D/A
D/A
Solenoids
Current drivers
23
22
14
Force sensor
A/D
16
21
Amplifier
17
Bluetooth modem, WIFI, or USB

FIG. 3

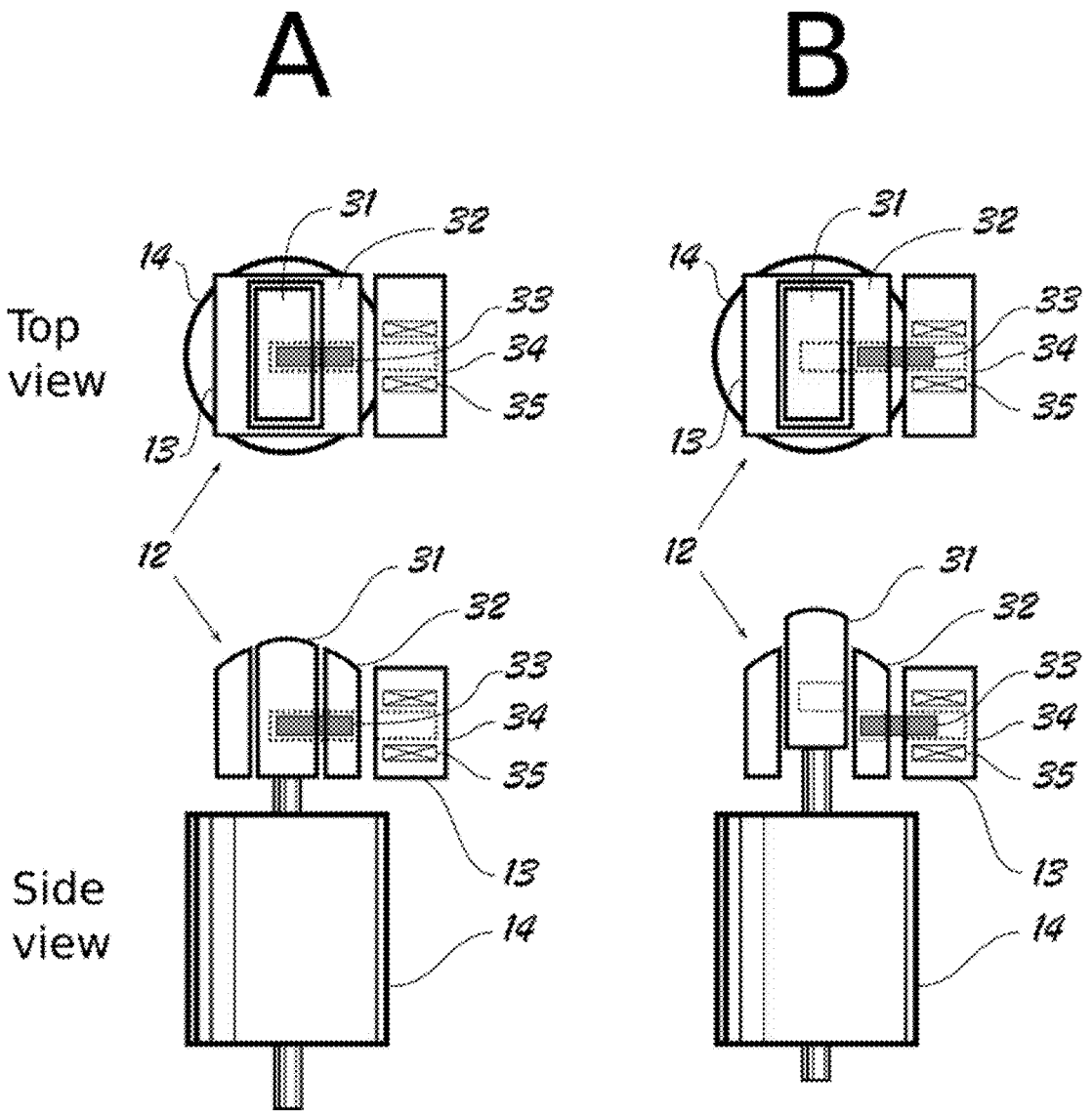


FIG. 4

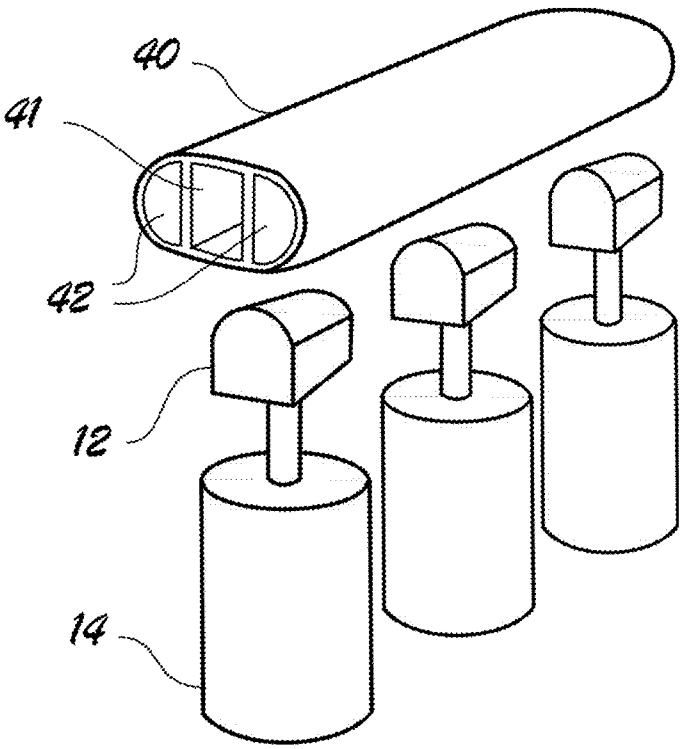


FIG. 5

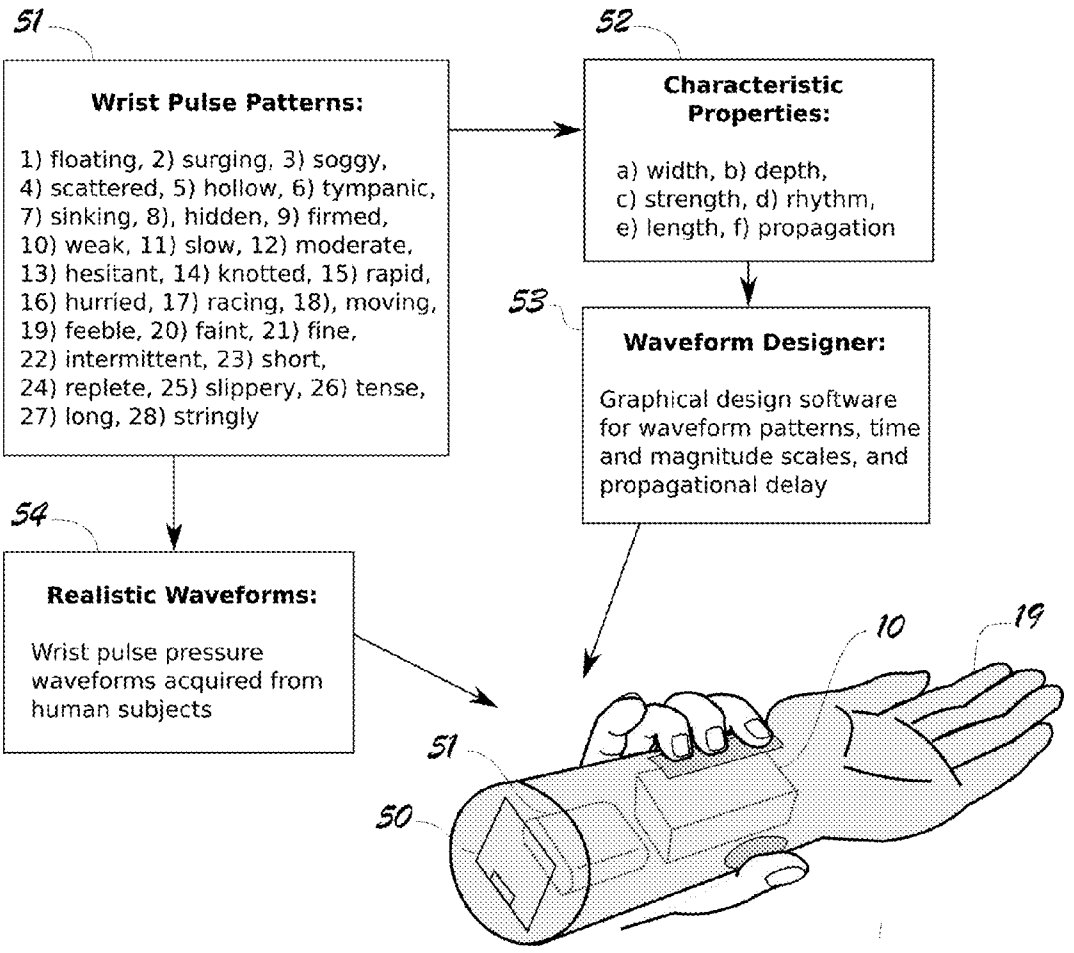

51
Wrist Pulse Patterns:
1) floating, 2) surging, 3) soggy,
4) scattered, 5) hollow, 6) tympanic,
7) sinking, 8), hidden, 9) firmed,
10) weak, 11) slow, 12) moderate,
13) hesitant, 14) knotted, 15) rapid,
16) hurried, 17) racing, 18), moving,
19) feeble, 20) faint, 21) fine,
22) intermittent, 23) short,
24) replete, 25) slippery, 26) tense,
27) long, 28) stringly
52
Characteristic Properties:
a) width, b) depth,
c) strength, d) rhythm,
e) length, f) propagation
53
Waveform Designer:
Graphical design software for waveform patterns, time and magnitude scales, and propagational delay
54
Realistic Waveforms:
Wrist pulse pressure waveforms acquired from human subjects
10
19
51
50

FIG. 6

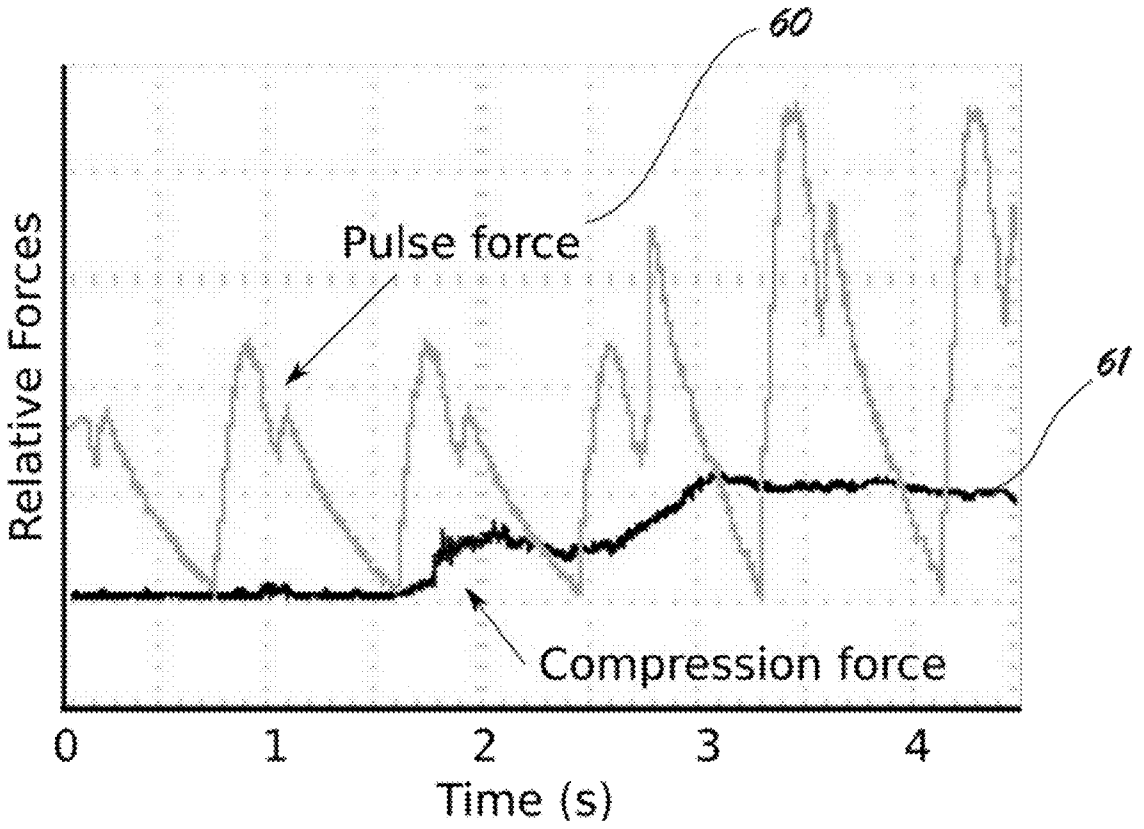
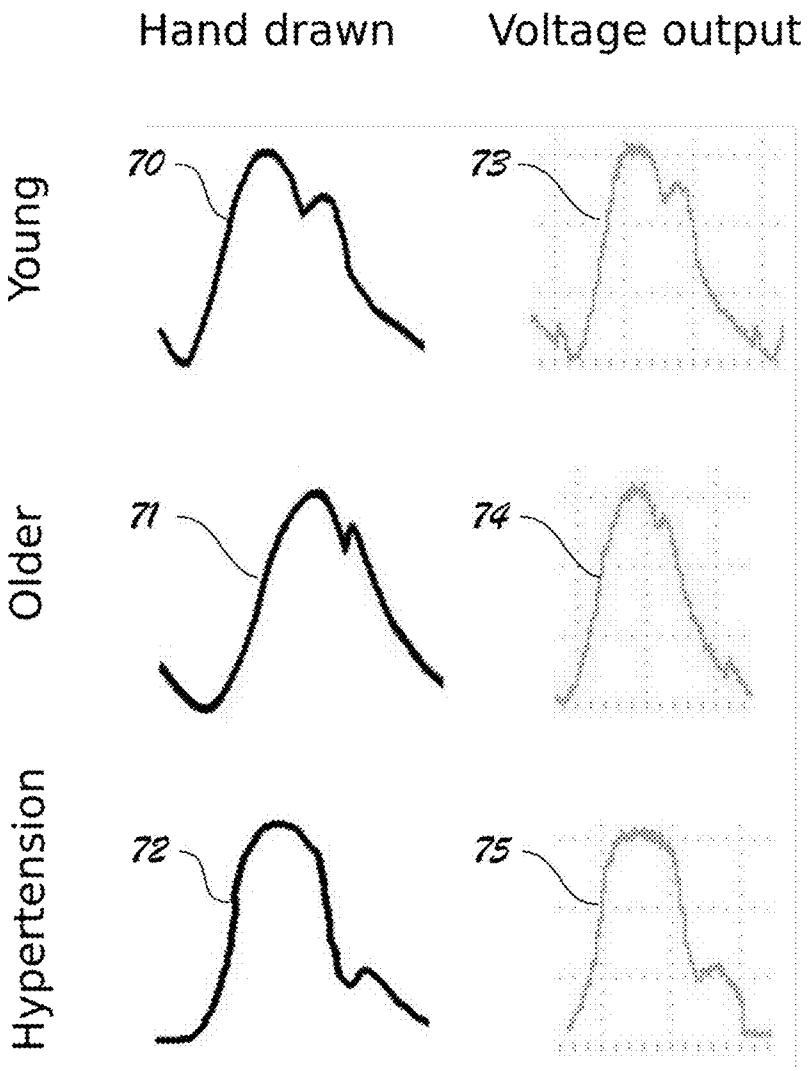

60
Pulse force
61
Compression force
Relative Forces
0
1
2
3
4
Time (s)

FIG. 7


Hand drawn
Voltage output
Young
Older
Hypertension
70
71
72
73
74
75

METHOD AND APPARATUS FOR SIMULATING THE WRIST PULSE PATTERNS FOR PULSE DIAGNOSIS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] Under 37 CFR 1.53 §1.81(a3), this U.S. full utility patent application is hereby converted from the U.S. provisional patent application filed on Apr. 23, 2015 (application no. 62178949) entitled "Method and apparatus for simulating the wrist pulse patterns for pulse diagnosis" by inventors Mona Boudreaux, Ying Sun, and G. Faye Boudreaux-Bartels.

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BACKGROUND OF THE INVENTION

[0008] Pulse diagnosis is an important technique for diagnosing the health conditions and the course of treatment based on pulse patterns detected at the wrist in traditional Chinese medicine (TCM) as well as other alternative medicines, such as ayurvedic medicine, traditional Mongolian medicine, Siddha medicine, traditional Tibetan medicine, and Unani. The pulses are felt by pressing the index finger, the middle finger, and the ring finger against the radial artery at the wrist of the subject. Pulse diagnosis is noninvasive, convenient, inexpensive, quick, and painless. Pulse diagnostic techniques are taught at schools that teach TCM, Ayurveda, and acupuncture. The training of pulse diagnostic techniques is highly hands-on and tactile. It is often difficult to find patients who exhibit a full range of symptoms for students to practice on and learn from. Thus, the purpose of the present invention is to provide a method and a simulation device for training people how to perform pulse diagnosis.

[0009] In the USA there are over 45,000 acupuncturists who use pulse diagnosis to find where there are problems with the flow of energy in the body. Each year 3,500 students of TCM undergo licensing exams administrated by organizations such as the National Certification Commission for Acupuncture and Oriental Medicine (NCCAOM). Naturopaths, napropaths, medical doctors, chiropractors, and veterinarians also perform acupuncture and pulse diagnosis. There are many more practitioners of TCM in other parts of the world, especially in Asia. The present invention leads to a product to be used by schools, teachers, and students for teaching, learning, and testing the techniques of pulse diagnosis.

DESCRIPTION OF THE RELATED ART

[0010] In Western medicine, the study of the pulse is known as sphygmology. The pulse is palpated over an artery near the surface of the body by pressing a finger or two fingers against a bone. The pulse can be detected from the carotid artery at the neck, the brachial artery on the inside of the elbow, the radial artery at the wrist, the femoral artery at the groin, the popliteral artery behind the knee, the posterior tibial artery near the ankle joint, and dorsalis pedis artery on the foot. A typical clinical pulse palpation is conducted by pressing the index and middle fingers on the radial artery at the wrist or the carotid artery at the neck. A stop watch is used to count the number of pulses for a certain duration, say 15 seconds, and the heart rate in beats per minute (bpm) is given by the count multiplied by 4. The sole purpose of pulse palpation in Western medicine is to measure the heart rate; it is not intended to extract any other health-related information.

[0011] By contrast, in traditional Chinese medicine (TCM) and other alternative medicines, pulse palpation is used to extract much more diagnostic information about the patient's health conditions. The pulse palpation in TCM differs from that in Western medicine in the following respects:

[0012] 1. In TCM, the pulse palpation is always performed at the wrist on humans, and for both the right hand and the left hand.

[0013] 2. In TCM, three fingers instead of two are used to palpate at three different positions. The first position

closest to the wrist is the can (inch), the second guan (gate), and the third pulse position furthest away from the wrist is the chi (foot).

[0014] 3. Furthermore, the pulse is palpated at shallow, middle, and deep levels by changing the compression force with the fingers.

[0015] 4. The conditions of the internal organs are mapped to and reflected at the different positions. On the left hand, the first position represents the heart and small intestine; the second position, the liver and gall-bladder; and third position, the kidney yin and bladder. On the right hand, the first position represents the lungs and large intestine; the second position, the spleen and stomach; and the third position, the kidney yang and uterus or triple burner.

[0016] 5. In addition to the rhythm, many other pieces of information related to the strength and other qualities of the pulse are detected.

[0017] William. E. Thornton (U.S. Pat. No. 7,510,398 B1) disclosed an apparatus that uses an electronic tactile pulse simulator to generate pressure pulses simulating arterial pressure pulses discernible by touch. Thornton's invention is useful for teaching pulse palpation in Western medicine. However, it lacks the multiple tactile outputs and the sophistication of representing different pulse patterns for teaching the pulse diagnostic techniques in TCM and other alternative medicines.

[0018] Simulating the wrist pulse patterns for TCM is the inverse problem of detecting the wrist pulse patterns. There exist an abundance of prior art for detecting wrist pulses, for example: U.S. Pat. No. 5,170,796, U.S. Pat. No. 5,381,797, U.S. Pat. No. 6,767,329 B2, U.S. Pat. No. 8,317,716 B2, WO 2003073932 A1, and WO 2009019720 A2. However, there is no prior art of simulating the wrist pulse patterns for TCM that can be found. The classification of the pulse patterns in TCM has not yet been standardized. Generally speaking, experts of pulse diagnosis have described 28 different patterns relating to internal energy flows and various diseases conditions. The present invention is concerned with 1) an effective method for representing the characteristic qualities of the wrist pulse patterns, and 2) a realization of pulse simulator for teaching pulse diagnostic techniques.

BRIEF SUMMARY OF THE INVENTION

[0019] This invention discloses a novel method and a device for simulating the palpation of wrist pulses. All 28 wrist pulse patterns in the traditional Chinese medicine can be represented by use of 6 characteristic qualities: width, depth, strength, rhythm, length, and propagation. These 6 characteristic qualities guide the design of a set of wrist pulse waveforms, which are pre-programmed in a processor to deliver time-varying tactile outputs against the palpating fingers via plungers of three solenoids. The wrist pulse waveforms reacts dynamically to the compression force from the palpating fingers measured with a force sensor. The palpation sense of the artery width is controlled by either width-adjustable plungers or a multi-lumen flexible tube. The field of use of the wrist pulse simulator device includes 1) teaching pulse diagnostic techniques in traditional Chinese medicine and other alternative medicines, and 2) developing and testing automated pulse diagnostic devices.

BRIEF DESCRIPTION OF THE TABLES

[0020] TABLE 1 summarizes the 28 wrist pulse patterns, the interpretations and health relevancies in TCM for the categories of (A) floating and sinking pulses, (B) slow and rapid pulses, and (C) feeble and replete pulses.

[0021] TABLE 2 shows the six characteristic qualities of the wrist pulses and how the simulator represents them.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The following description of the figures may be further understood with reference to the accompanying drawing in which:

[0023] FIG. **1** is an illustrative diagrammatic view of an embodiment of the wrist pulse simulator device that produces tactile outputs via three solenoids under the control of a processor.

[0024] FIG. **2** is a block diagram of an embodiment of the wrist pulse simulator device showing the major components and the signal paths.

[0025] FIG. **3** shows an embodiment for representing the width of the artery by using a magnetically actuated rod to lock the plunger in the wide configuration (A) or in the narrow configuration (B).

[0026] FIG. **4** shows a different embodiment for representing the width of the artery by using a three-lumen flexible tube. A wide artery is represented by inflating all three lumens; a narrow artery is represented by inflating only the central lumen.

[0027] FIG. **5** shows the processes of specifying the pulse waveforms for the various wrist pulse patterns either by using a graphical waveform designer or by acquiring realistic waveforms recorded from human subjects and recording numerical representations of the waveforms.

[0028] FIG. **6** shows experimental data of changing the pulse waveform magnitude in response to the compression force.

[0029] FIG. **7** shows experimental data of three hand-drawn wrist pulse patterns and the corresponding waveforms outputted by the digital-to-analog converters for driving the solenoids.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

[0030] Table 1 summarizes the 28 pulse patterns in TCM, which are classified into 6 categories: floating and sinking pulses (Table 1A), slow and rapid pulses (Table 1B), and feeble and replete pulses (Table 1C). For each pulse pattern, its TCM interpretation and health relevancy are also given in Table 1. The present invention discloses the use of 6 characteristic qualities to represents the wrist pulse patterns and artery responses. These characteristic qualities are as follows.

[0031] a) width: thin or wide artery,

[0032] b) depth: superficial or deep artery,

[0033] c) strength: forceful or forceless pulse,

[0034] d) rhythm: fast or slow rate; rhythmic or arrhythmic pulses,

[0035] e) length: short or long duration of the contraction, and

[0036] f) propagation: delay and magnitude change among the three positions.

[0037] FIG. **1** is an illustrative diagrammatic view of an embodiment of the pulse simulation. The pulse simulator **10**

is a hand-held device that transfers tactile outputs to the fingers via a soft pad **11** made of silicone rubber or a similar material. The three moveable plungers **12** underneath the soft pad are used to simulate the wrist pulses. A width control unit **13** is used to change the width of the plungers, which will be described in more detail later. The plungers are actuated by three solenoids **14**, which are controlled by a processor **15**. The hand-held unit has a force sensor **16** to detect the force applied by the thumb, which indirectly measures the compression force applied by the three palpating fingers against the soft pad.

[0038] The processor system **15** contains a communication unit **17**, which can receive data from or transmit data to a laptop computer or a mobile computing device **18** such as a smartphone or a tablet. The communication unit **17** can be either wireless (Bluetooth or WIFI modem) or wired (USB).

[0039] As an option, the hand-held pulse simulator **10** can be embedded in a life-sized hand-wrist model **19**. The model is anatomically correct in terms of its dimensions and the artery position to provide a more realistic simulation. The three moveable plungers **12** are positioned near the surface and underneath a thin soft pad **11** around the wrist area to deliver the pulses. The user's hand is applied to the pulse simulator with the index, middle and ring fingers pressing onto the three plungers **12**, respectively. The thumb is at the opposite side of the wrist where the force sensor **16** is positioned.

[0040] FIG. **2** further specifies the functional units and signal paths of the pulse simulator in FIG. **1**. The compression force from the user's hand is sensed by a force sensor **16**, which is conditioned by an amplifier **21** and acquired by a processor **15** via an analog-to-digital converter **22**. The compression force is compared to two pre-set thresholds to determine which level (shallow, middle, or deep) the pulse is palpated at. The digital pulse waveforms and parameters pertaining to the characteristic qualities are stored in the processor **15**. The user can select which of the pre-programmed pulse patterns to simulate via a user interface facilitated by an LCD display **25** and push buttons **26**. The pulse waveforms are played back in response to the compression force. The stored digitized waveforms are sent to three analog-to-digital converters **23** that actuate three solenoids **14** via current drivers **24**. The three plungers **12** of the solenoids deliver the tactile outputs to be palpated by the user's fingers. A width control unit **13** provides a means of adjusting the sensation of either a wide artery or a narrow artery.

[0041] FIG. **3** shows a possible embodiment for adjusting the width sensation. In FIG. **3** top and side views, a plunger consists of a center piece **31** surrounded by a side piece **32**. The plunger assembly is connected to the solenoid **14**, which moves the plunger up and down in proportion to the supplied electrical current. A locking rod **33** can slide through the center piece **31**, the side piece **32**, and a separate actuator unit **33**. The locking rod **33** is made of a ferromagnetic material such that it can be pushed or pulled by changing the polarity of an electromagnet **35** embedded in the actuator unit **34**. FIG. **3**A (left column) shows the plunger in the wide configuration, in which the locking rod **33** is pushed to a position between the center piece **31** and the side piece **32**. With this wide configuration the center piece **31** and the side pieces **32** move up and down together as one unit to simulate the effect of a wide blood vessel. FIG. **3**B (right column) shows the plunger in the narrow configuration, in which the locking rod **33** is pulled back to a position between the side piece **32** and the actuator unit **34**. With this narrow configuration, only the center piece **31** moves up and down to simulate the effect of a narrow blood vessel.

[0042] FIG. **4** shows an alternative embodiment for representing the width of the artery by employing a three-lumen tube **40**. The tube has a center lumen **41** and two side lumens **42**. A wide artery is represented by inflating all three lumens. A thin artery is represented with the center lumen inflated and the two side lumens deflated. The inflation mechanism (not shown) can be either pneumatic (air) or hydraulic (water). The forces from the plungers are transferred to the fingers through the three-lumen tube **40**. Thus, the user can palpate the difference of the simulated width of the artery.

[0043] Table 2 summarizes how the pulse simulator uses the aforementioned hardware and software methods to represent the 6 characteristic quantities of the wrist pulse patterns. For each of the 28 pulse patterns given in Table 1, the simulator stores the following information: 1) a digital waveform or waveforms representing the time course of the pulse, 2) a set of 6 characteristic quantities pertaining to this pulse pattern, and 3) how the pulses react to the shallow, middle, and deep levels of compression.

[0044] FIG. **5** shows the processes of specifying/designing the pulse waveforms to be downloaded to the wrist pulse simulator **10**. The wrist pulse simulator **10** can be incorporated into the wrist-hand model **19** as a single integrated unit. An access trap cover **50** is available for installing/replacing the batteries **51**. The waveform design process begins with the selection of one of the wrist pulse patterns **51**. There are at least two possible ways to design the pulse waveforms. One way is to first extract the 6 characteristic properties **52** for the chosen wrist pulse pattern. Then, a waveform designer **53** is used to design a set of waveforms for the three solenoids and the three levels of the compression force. The waveform designer **53** is a software system that runs on a laptop computer or a mobile computing device. The pulse waveforms can be drawn by hand with a graphical user interface or generated by equations. Additional parameters such as the time delays among the three solenoids and the magnitude/waveform changes in response to the finger compression forces can be specified. This set of waveforms can then be downloaded to the wrist pulse simulator **10** for execution.

[0045] Another way to specify the wrist pulse waveforms is to use an array of pulse pressure sensors and a data acquisition system **54** to record realistic waveforms from human subjects. These waveforms are scaled to the proper magnitude ranges and downloaded to the pulse simulator **10** for execution.

[0046] A functional prototype of the pulse simulator has been built to verify that the design concept and specifications are realizable. FIG. **6** shows the experimental data of changing the magnitude of the pulse force waveform **60** in response to the compression force **61**. This is to simulate the situation of applying different levels of forces (shallow, middle, and deep) through the palpating fingers. The artery reacts to the given compression force and produces the pulse waveform accordingly.

[0047] FIG. **7** shows the experimental data of three hand-drawn wrist pulse patterns by use of the waveform designer representing a young person **70**, an older person **71**, and a person with hypertension **72**. These waveforms were downloaded to the pulse simulator for execution. The correspond-

ing waveforms **73-75** outputted by the digital-to-analog converters for driving the solenoids showed a good resemblance of the original hand-drawn waveforms.

[0048] There are 3 independent claims and 7 dependent claims in this invention. The claims structure is as follows:

[0049] 1. Method for wrist pulse simulation (independent)

[0050] 2. Pulse patterns represented with 6 characteristic qualities

[0051] 3. Processor to play back pulse waveforms through solenoids

[0052] 4. Mechanical means of changing the palpation of the artery width

[0053] 5. Pulse patterns in response to compression force

[0054] 6. Waveform designer and data acquisition for generating wrist pulse patterns (independent)

[0055] 7. Apparatus for wrist pulse simulation (independent)

[0056] 8. Mechanical means of changing the palpation of the artery width

[0057] 9. Adjustment of wrist pulse waveforms in response to the compression force

[0058] 10. Pulse pattern generation system linked to the wrist pulse simulator

What is claimed is:

1. A method for simulating the palpation of wrist pulses that comprises the steps of

a) representing the wrist pulse patterns and artery responses with a set of characteristic qualities;

b) implementing the characteristic qualities with a set for force waveforms delivered by a plurality of solenoids under the control of a processor;

c) changing the palpation of the artery width by mechanical means; and

d) delivering the wrist pulse patterns in response to the compression force of the palpating fingers.

2. In the method for simulating the palpation of wrist pulses according to claim **1**, said characteristic qualities of the wrist pulse patterns and artery responses include width, depth, strength, rhythm, length, and propagation.

3. In the method for simulating the palpation of wrist pulses according to claim **1**, said pulse waveforms are pre-stored in the said processor and selectively played back in real-time via a plurality of digital-to-analog converters to drive said solenoids.

4. In the method for simulating the palpation of wrist pulses according to claim **1**, said mechanical means of changing the palpation of the artery width employs either a plurality of plungers with adjustable width attached to said solenoids or a multi-lumen flexible tube placed between said solenoids and the palpating fingers.

5. In the method for simulating the palpation of wrist pulses according to claim **1**, said compression force of the palpating fingers is sensed by said processor via a force sensor and controls the delivery of said wrist pulse patterns.

6. A method of generating the wrist pulse waveforms by use of either

a) a waveform designer software system to draw the waveforms by hand via a graphical user interface or to generate the waveforms with equations; or

b) a data acquisition system to measure the realistic wrist pulse patterns from human subjects via an array of pulse pressure sensors placed around the wrist area.

7. An apparatus for simulating the palpation of wrist pulses that comprises the components of

a) a processor to store and play back wrist pulse waveforms;

b) a plurality of solenoids to deliver the pulse waveforms to the palpating fingers;

c) a mechanical means of changing the palpation of the artery width;

d) a force sensor to measure the compression forces of the palpating fingers; and

e) a live-sized wrist-hand model to enclose the aforementioned components; and

f) a wrist pulse pattern generation system to design the pulse waveforms by drawing, computing from equations, and/or acquiring realistic waveforms from human subjects.

8. In the apparatus for simulating the palpation of wrist pulses according to claim **7**, said mechanical means of changing the palpation of the artery width employs either a plurality of plungers with adjustable width attached to said solenoids or a multi-lumen flexible tube placed between said solenoids and the palpating fingers.

9. In the apparatus for simulating the palpation of wrist pulses according to claim **7**, an algorithm is implemented in said processor to adjust the outputs of the wrist pulse waveforms in response to the input of the compression force from said force sensor.

10. In the apparatus for simulating the palpation of wrist pulses according to claim **7**, said wrist pulse pattern generation system is implemented on a laptop computer or mobile computing device connected to the processor in the wrist pulse simulator via a wireless or wired communication link.

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