

INCENTIVE SPIROMETRY SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority under 35 U.S.C. § 119 to U.S. Provisional Application No. 63/581,691 entitled “INCENTIVE SPIROMETER DEVICE, SYSTEM, AND METHOD” filed on September 11, 2023, which is hereby expressly incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure describes systems, devices, and methods for spirometry, such as incentive spirometry systems and methods. The systems, devices, and methods described herein facilitate patient interaction, consistent use, and tracking of patient progress and quantifiable results.

BACKGROUND

[0003] Incentive spirometers can be used to help users improve lung function by strengthening the lungs and facilitating lung expansion. Incentive spirometry is utilized for patients who have had any surgery that may affect respiratory function, including surgery to the lungs, cardiac surgery, or other surgery that may involve prolonged in-bed recovery.

[0004] While diagnostic spirometers can measure the volume of air exhaled out of the lungs, incentive spirometers measure the volume of the air inhaled into the lungs during inspiration. Volume-oriented devices measure the volume of inspiration whereas flow-oriented devices measure the flow rate of inspiration. Incentive spirometers can include target breath volumes that are manually set (e.g., via a slide) by a medical provider.

SUMMARY

[0005] This disclosure describes systems, devices, and methods for spirometry, such as incentive-based spirometry system. The systems, devices, and methods described

herein facilitate patient interaction, consistent use, and health care provider tracking of patient progress and quantifiable results. In particular implementations, the systems, devices, and methods described herein can include an airflow assembly with a pressure sensor that facilitates obtaining sensor data from a plurality of inspiration repetitions (e.g., when a patient or user interfaces with a mouthpiece).

[0006] While incentive spirometry has been shown to reduce risk of post-operative pulmonary complications, shorten hospital stay lengths, and decrease readmission rates, a number of shortcomings prevent the potential benefits of incentive spirometry from being fully realized, including issues with patient adherence and significant monitoring requirements that create time-burdens for healthcare providers.

[0007] Some embodiments described herein include an incentive spirometer system. The system includes a housing including a display screen an airflow assembly, the airflow assembly including: a first end configured to connect to the housing; a second end opposite the first end; an air inlet in a top surface of an airflow housing at the first end; an air outlet at the second end; an air flow chamber including an inlet portion, a constriction portion, and an outlet portion, the constriction portion having a constriction diameter smaller than a diameter of the inlet portion and the outlet portion, the constriction portion having a lateral opening; a pressure sensor connected to the lateral opening of the constriction portion. The housing also includes a mouthpiece configured to connect to the second end of the airflow assembly, the mouthpiece including a one-way valve that permits air flow from a mouthpiece inlet connected to the second end of the airflow assembly to a mouthpiece outlet opposite the mouthpiece inlet; where the one or more storage devices store instructions that are operable, when executed by the one or more processors, to cause the one or more processors to perform operations may include: obtaining sensor data from the pressure sensor, the sensor data including data obtained from a plurality of inspiration repetitions; generating one or more inspiration signatures using the sensor data, the one or more inspiration signatures including an air flow rate and air volume for each of a plurality of inspiration repetitions; providing a result of the

one or more inspiration signatures to each of (i) the display screen; (ii) a user device; and (iii) a provider device.

[0008] Such a system can include one or more of the following optional features.

The incentive spirometer system where the operations may include simultaneously displaying the one or more inspiration signatures in real time at the user device. The operations may include receiving a treatment protocol from the provider device. The operations may include sending alerts to the user device according to the treatment protocol. A plurality of inspiration signatures are obtained according to the treatment protocol, and the operations include may include sending the plurality of inspiration signatures to the provider device. Air flow is prevented from entering the housing. The housing may include an electrical port that interfaces with the first end of the airflow assembly. The airflow assembly and the mouthpiece are disposable. The housing is re-useable. The air inlet may include laser-cut letters. Implementations of the described techniques may include hardware, a method or process, or computer software on a computer-accessible medium.

[0009] Some embodiments described herein include an incentive spirometry method. The incentive spirometry method also includes connecting an airflow assembly to a housing of an incentive spirometry device, the airflow assembly including: a first end configured to connect to the housing; a second end opposite the first end; an air inlet in a top surface of the airflow assembly at the first end; an air outlet at the second end; an air flow chamber including an inlet portion, a constriction portion, and an outlet portion, the constriction portion having a constriction diameter smaller than a diameter of the inlet portion and the outlet portion, the constriction portion having a lateral opening; a pressure sensor connected to the lateral opening of the constriction portion. The method also includes obtaining sensor data from the pressure sensor, the sensor data including data obtained from a plurality of inspiration repetitions; generating one or more inspiration signatures using the sensor data, the one or more inspiration signatures including an air flow rate and air volume for each of a plurality of inspiration repetitions; providing a result of the one or more inspiration signatures to each of (i) a display screen of the

incentive spirometry device; (ii) a user device; and (iii) a provider device. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0010] Such a method can include one or more of the following optional features. The incentive spirometry method may include simultaneously displaying the one or more inspiration signatures in real time at the user device. The simultaneous display includes motivational icons. May include receiving a treatment protocol from the provider device. The incentive spirometry method may include sending alerts to the user device according to the treatment protocol. The incentive spirometry method may include sending the one or more inspiration signatures from a plurality of inspiration spirometry devices to the provider device. The plurality of inspiration signatures are obtained from a plurality of patients. Implementations of the described techniques may include hardware, a method or process, or computer software on a computer-accessible medium.

[0011] Some embodiments described herein include an incentive spirometer device. The incentive spirometer device also includes a housing including a display screen, a power source, one or more processors, and one or more storage devices; an airflow assembly, the airflow assembly including: a first end configured to connect to the housing; a second end opposite the first end; an air inlet in a top surface of the airflow assembly at the first end; an air outlet at the second end; an air flow chamber including an inlet portion, a constriction portion, and an outlet portion, the constriction portion having a constriction diameter smaller than a diameter of the inlet portion and the outlet portion, the constriction portion having a lateral opening; a pressure sensor connected to the lateral opening of the constriction portion. The device also includes a mouthpiece configured to connect to the second end of the airflow assembly, the mouthpiece including a one-way valve that permits air flow from a mouthpiece inlet connected to the second end of the airflow assembly to a mouthpiece outlet opposite the mouthpiece inlet; where the one or more storage devices store instructions that are operable, when executed by the one or more processors, to cause the one or more processors to perform operations

may include: obtaining sensor data from the pressure sensor, the sensor data including data obtained from a plurality of inspiration repetitions; generating one or more inspiration signatures using the sensor data, the one or more inspiration signatures including an air flow rate and air volume for each of a plurality of inspiration repetitions. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0012] Such a device can include one or more of the following optional features. The incentive spirometer device where air flow is prevented from entering the housing. The airflow assembly and the mouthpiece are disposable. Implementations of the described techniques may include hardware, a method or process, or computer software on a computer-accessible medium.

[0013] Among other benefits, some systems and methods described herein can advantageously provide a hygienic and reusable system that includes modular components where some of the components (e.g., the airflow assembly and mouthpiece) can be disposable while other components (e.g., the housing) can be re-useable and remain hygienic. Additionally, some embodiments described in more detail below can digitally integrate components such as one or more sensors and communication systems that facilitate real-time tracking of patient outcomes, patient performance, adherence and administration of customized treatment protocols, improved patient interaction and frequency of use, which lead to improved patient outcomes. Additionally, some embodiments described in more detail below can facilitate an efficient and informed allocation of medical resources, personnel, treatment, and time in clinical and non-clinical environments. For example, the systems, devices, and methods described herein can facilitate the efficient allocation of medical staff (e.g., nurses, doctors, therapists, others) that are responsible for ensuring patient adherence to treatment protocols, along with identifying patients that are most at risk for postoperative pulmonary complications (PPCs).

[0014] The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0015] FIG. 1 is a schematic diagram that includes an incentive spirometry system, consistent with some embodiments of this disclosure.

[0016] FIG. 2 is a perspective exploded view of an incentive spirometry device, consistent with some embodiments of this disclosure.

[0017] FIG. 3 shows a side view of an example airflow assembly of the incentive spirometry device of FIG.2.

[0018] FIG. 4 shows a top view of the airflow assembly of FIG.3.

[0019] FIG. 5 shows a perspective view of the airflow assembly of FIG.3.

[0020] FIG. 6 shows a side view of an airflow insert of the incentive spirometry device of FIG.2.

[0021] FIG. 7 shows a top view of the airflow insert of FIG. 6.

[0022] FIG. 8 show a side view of another example airflow insert compatible with the incentive spirometry device of FIG.2.

[0023] FIG. 9 shows a top view of the airflow insert of FIG. 8.

[0024] FIGS. 10A-F show an example mouthpiece, consistent with some embodiments of this disclosure.

[0025] FIG. 11A shows an example calibration mouthpiece, consistent with some embodiments of this disclosure.

[0026] FIG. 11B shows exemplary testing results, consistent with some embodiments of this disclosure.

[0027] FIG. 11C shows an example calibration and testing process, consistent with some embodiments of this disclosure.

[0028] FIG. 12 shows an example switch panel, consistent with some embodiments of this disclosure.

[0029] FIG. 13 shows an example housing, consistent with some embodiments of this disclosure.

[0030] FIG. 14 shows a schematic circuit diagram of the incentive spirometry device of FIG. 1.

[0031] FIG. 15 is a schematic diagram illustrating data transmission, consistent with embodiments of this disclosure.

[0032] FIGS. 16-19 show example user interfaces of a user device, consistent with some embodiments of this disclosure.

[0033] FIGS. 20-21 show example user interfaces of a provider device, consistent with some embodiments of this disclosure.

[0034] FIGS. 22-24 show example user interfaces of a user device, consistent with some embodiments of this disclosure.

[0035] FIG. 25A shows another example inspiration spirometry system, consistent with some embodiments of this disclosure.

[0036] FIG. 25B shows an example airflow insert of the inspiration spirometry system of FIG. 25A.

[0037] FIG. 26 shows the airflow insert of FIG. 25B.

[0038] FIG. 27 shows an example mouthpiece, consistent with some embodiments of this disclosure.

[0039] FIG. 28 shows an example housing, consistent with some embodiments of this disclosure.

[0040] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0041] FIG. 1 shows an example of an incentive spirometry system 100 that includes an incentive spirometry device 102. The incentive spirometry system 100 includes the incentive spirometry device 102, a user device 104, and a provider device 106. Generally, the incentive spirometry device 102 can capture data, e.g., using sensors to capture, analyze, and evaluate a user's performance of inhalation when a user

interfaces with a mouthpiece 110 of the incentive spirometry device 102. The analysis and evaluation can include identification of performance parameters such as repetitions, volume, air flow rate, adherence to treatment protocols, among other metrics. The incentive spirometry system 100 can be utilized to improve patient lung function strengthening the lungs and facilitating lung expansion. For example, some embodiments of the incentive spirometry system 100 and incentive spirometry device 102 can be implemented to improve patient lung function strengthening the lungs and facilitating lung expansion in a post-surgery recovery of a patient. Some examples of such surgeries include and are not limited to: spinal surgery, abdominal surgery, and hip/knee replacements, colorectal resections of both the small and large bowels, and some pediatric and non pediatric indications that do not involved surgery such as sickle cell disease and long COVID-19 are indications for incentive spirometry that have the highest prevalence and rate of post-operative pulmonary complications

[0042] The incentive spirometry system 100 facilitates communication (e.g., using wireless or wired signals) of data throughout the system and between each of the incentive spirometry device 102, the user device 104, and the provider device 106. In some embodiments, the incentive spirometry device 102, the user device 104, and the provider device 106 can be in communication with each other. For example, the incentive spirometry device 102 can communicate sensor data obtained during one or more user repetitions using the incentive spirometry device 102 to either or both of the user device 104 and the provider device 106. In some embodiments, the incentive spirometry device 102 can communicate the sensor data (e.g., including one or more inspiration signatures) to the user device 104, and the user device 104 can communicate the sensor data (e.g., including one or more inspiration signatures) to the provider device 106. In some embodiments, the incentive spirometry device 102 can send the sensor data to both the user device 104 and the provider device 106.

[0043] The incentive spirometry device 102 can facilitate a user (e.g., a patient) performing repetitions that include inhaling air into the user's lungs through the incentive spirometry device 102. For example, a patient can position their mouth over the

mouthpiece 110 and inhale air into their lungs. The incentive spirometry device 102 directs air through an air inlet 130 in an airflow assembly 112, past at least one sensor and out the mouthpiece 110 to the patient. As will be described in more detail below, the incentive spirometry device 102 can include at least one sensor that records sensor data throughout each of the user's repetitions. The sensor data can include air flow rate, volume, pressure, and other data for each repetition. Inspiration signatures are generated for each repetition to reflect the results of each repetition.

[0044] The user device 104 can be a personal device of a user (e.g., a patient device). Non-limiting examples of the user device 104 can include a smartphone, a wearable device, a tablet, a laptop, a computer, an external display, or other user devices. The user device 104 can be in communication (e.g., wired or wireless) with the incentive spirometry device 102 and the provider device 106. The user device 104 can display various parameters and controls related to the incentive spirometry device 102, as will be described in detail below. In some embodiments, the user device 104 can display sensor data to a user before, during, and after the user interfaces with and performs repetitions with the incentive spirometry device 102. For example, the user device 104 can simultaneously display one or more inspiration signatures to a user while the user is using the incentive spirometry device 102. The simultaneous displaying of inspiration signatures (e.g., generated based on the sensor data) can facilitate real-time displaying of results to the user and improve the user experience. For example, the real-time display can encourage patient performance when the patient sees a volume measurement below a target, prescribed, or recommended volume measurement for each repetition. This can encourage and gamify the user's interaction with the incentive spirometry device 102 to facilitate improved adherence, performance, and patient outcomes.

[0045] The provider device 106 can be a device controlled by and/or accessible to a physician or other medical care provider. Non-limiting examples of the provider device 106 can include a smartphone, a wearable device, a tablet, a laptop, a computer, an external display, or other provider devices. The provider device 106 can be in communication (e.g., wired or wireless) with the incentive spirometry device 102 and the

user device 104. The provider device 106 facilitates communication of one or more treatment protocols to the user device 104 and/or the incentive spirometry device 102. The treatment protocols can be prescribed, recommended, or otherwise sent from the provider device to the user device 104 and/or the incentive spirometry device 102. The user device 104 can display one or more notifications or alerts to a user according to the treatment plan to remind or encourage the user to perform repetitions with the incentive spirometry device 102. In some embodiments, the repetitions performed at the incentive spirometry device 102 can be logged according to the treatment protocol received from the provider device 106. Additionally, the inspiration signatures logged to the treatment protocol can be transmitted to both of the user device 104 and the provider device 106.

[0046] FIG. 2 shows an exploded view of the incentive spirometry device 102. The incentive spirometry device 102 includes the mouthpiece 110, airflow assembly 112 that includes an airflow insert 114 and an airflow housing 116, a housing 118 including a display 120 and a button 122, a shroud 124, a switch panel 126, and a rear housing 128. In some embodiments, the airflow assembly 112 and the mouthpiece 110 can be disposable components that can be utilized by a single patient (e.g., for one or more treatment sessions that can include one or a plurality of repetitions per treatment sessions). For example, the airflow assembly 112 and the mouthpiece 110 can be connected and disconnected from the housing 118 for rapid assembly and disassembly of the incentive spirometry device 102. In some embodiments, the housing 118, shroud 124, switch panel 126, and/or the rear housing 128 can be re-useable components.

[0047] Referring to FIGS. 2-9, the airflow assembly 112 can include the airflow insert 114 that can be received within the airflow housing 116. The airflow assembly 112 includes a first end 132 that is configured to connect to the housing 118. For example, the first end 132 can include a female connector that interfaces with one or more male connectors of the housing 118. In some embodiments, the first end 132 can connect to the housing 118 via a mechanical pronged or press fit connection that enables the parts to be easily connected and separable. In some embodiments, the first end 132 can connect to the housing 118 via a magnetic connection. The airflow assembly 112 can include a

second end 134 that is positioned opposite the first end 132. The second end 134 can be configured to connect to the mouthpiece 110. For example, the second end 134 can include a male connector that can be received within the mouthpiece 110 to facilitate a connection therebetween.

[0048] The airflow assembly 112 includes the air inlet 130 and an air outlet 136. The air inlet 130 can be positioned in a top surface of the airflow assembly 112, and can introduce air into the airflow chamber 138 (see e.g., the flow pattern 140 shown in FIG. 5). For example, as the patient inhales with their mouth positioned around the mouthpiece 110 (and the mouthpiece 110 connected to the airflow assembly 112), air is drawn into the airflow chamber 138 through the air inlet 130. In some embodiments, the air inlet 130 includes one or more laser-cut letters that define a plurality of openings through the airflow housing 116 to connect to the airflow chamber 138.

[0049] The airflow chamber 138 can extend through the airflow assembly 112 from the inlet 130 to the second end 134 and into the mouthpiece 110. The airflow chamber 138 can be a venturi flow chamber that has an inlet portion 142, a constriction portion 144, and an outlet portion 146. The constriction portion 144 can have a constriction diameter D_2 that is smaller than a diameter D_1 of the inlet portion 142 and the outlet portion 146. In some embodiments, the diameter D_1 of the inlet portion 142 and the outlet portion 146 can be the same. In other embodiments, the diameter D_1 of the inlet portion 142 can be larger than the diameter of both the constriction diameter D_2 and the outlet portion diameter D_3 . In other embodiments, the diameter D_3 of the outlet portion can be larger than the diameter of both the constriction diameter D_2 and the inlet portion diameter D_1 . The inlet portion 142 can include a tapered region 142a and the outlet portion 146 can include a tapered region 146a that gradually constrict the diameter of the airflow chamber 138 to the constriction portion 144.

[0050] The constriction portion can include a lateral opening 149 and a sensor 150 in the lateral opening 149. The sensor 150 can be positioned at or near a center of the constriction portion 144. The sensor 150 can seal the lateral opening 149 and maintain an airtight airflow chamber 138 between the inlet 130 and the outlet. The lateral opening

149 can have a diameter that is between 0.5 and 5 mm, between 1 and 4 mm, between 2 and 3 mm, and about 2.5 mm. In some embodiments, the sensor 150 is configured to collect sensor data from the constriction region 144. For example, the sensor 150 can collect data of an airflow rate, a pressure, a volume (e.g., a flow volume), a temperature, a humidity, among other data. In some embodiments, the sensor 150 can be an absolute pressure sensor, an accelerometer, an impeller sensor, a turbine flow meter, a flow meter, a thermal sensor, a differential pressure sensor, a magneto-inductive sensor, among other sensors.

[0051] Referring to FIGS. 6-9, show examples of the airflow insert 114. FIGS. 6 and 7 show the airflow insert 114 having an L-shaped inlet 130. FIGS. 8 and 9 show the airflow insert having a T-shaped inlet 130b. For example, the L-shaped inlet 130 facilitates an increase the stability of the calculated air pressure difference (e.g., pressure at the constriction portion 144 vs. a pressure between the constriction portion 144 and inlet 130) as the inlet 130 is facing perpendicular to the air flow channel 138 that the sensor 150 samples from. The laser cut letters at the inlet 130 and through the housing 116 also makes it more difficult for users to (i) place their mouth or any other wind generating device covering the letter openings to generate false inhale records, (ii) accidentally covering up the inlet while holding the device and not being able to generate measurements. In some embodiments, the T-shaped inlet 130b further stabilizes the air pressure measurements, by making it much more difficult to generate any airflow past the sensor 150 other than inhalation at the mouthpiece 110. Any blowing at the laser cut letters (e.g., at the inlet 130b) would pass through the short end of the T shaped inlet 130b, and would not disturb airflow along the tube with the sensor 150. The additional holes also make it harder for users to accidentally cover air flow openings when using the device 102. Additionally, the L-shaped inlet 130 and the T-shaped inlet 130b can provide different levels of resistance to a user's inhalation. The different resistance levels can be implemented in a treatment protocol as a patient progresses, or can be used for different patient's at different stages in their recovery. In each of the L-shaped inlet 130 and the T-shaped inlet 130b, the inlet 130, 130b and outlet 136 are not parallel to each other. In

some embodiments, the inlet 130, 130b and outlet 136 are perpendicular to each other. In some embodiments, the inlet 130, 130b and outlet 136 are perpendicular to each other with multiple outlet openings. Some embodiments include the inlet 130, 130b and outlet 136 in a non-parallel arrangement between parallel and perpendicular to each other (E.g., any angle between 1 and 89 degrees).

[0052] FIGS. 6 and 8 illustrate exemplary dimensions (in mm) for various components of the airflow insert 114 shown in FIGS. 2-9. For example, the constriction portion 144 (e.g., diameter D2) can be between 1 and 10 mm, between 2 and 8 mm, between 3 and 5 mm, or about 4 mm. The constriction portion 144 can have a length between 10 and 30 mm, or about 20 mm. The inlet portion 142 and the outlet portion 146 can have a diameter between 8 and 20 mm, between 10 and 17 mm, between 12 and 15 mm, or about 14 mm. The lateral opening 149 can have a diameter between 0.1 and 5 mm, or about 2.6 mm. These dimensions are non-limiting and are shown as example dimensions that can be implemented in some embodiments of the airflow insert 114. Other embodiments include different dimensions.

[0053] Referring to FIGS. 2 and 10A-F, the mouthpiece 110 is configured to connect to the second end 134 of the airflow assembly 112. The mouthpiece 110 can be configured to interface with a mouth of a user. For example, the user can position their lips around the outlet end 160 of the mouthpiece during repetitions with the inspiration spirometry device 102. The mouthpiece 110 can continue the airflow chamber 138 from the airflow insert 114 to communicate the air from the air inlet 130, through the airflow chamber 138, into the mouthpiece 110, and to the user. The mouthpiece 110 can including a one-way valve 162 that permits air flow from a mouthpiece inlet 164 connected to the second end 134 of the airflow assembly 112 to the outlet end 160 opposite the mouthpiece inlet 164.

[0054] FIG. 10F illustrates exemplary dimensions (in mm) for various components of the mouthpiece 110. For example, the mouthpiece inlet 164 can have a width between 10 and 20 mm, between 11 and 15 mm, or about 13 mm. The outlet end 160 of the mouthpiece 110 can have an internal opening between 4 and 15 mm, between

5 and 12 mm, or about 7 mm. The outlet end 160 of the mouthpiece 110 can have an outer dimension between 5 and 20 mm, between 7 and 13 mm, or about 10 mm. These dimensions are non-limiting and are shown as example dimensions that can be implemented in some embodiments of the mouthpiece 110. Other embodiments include different dimensions.

[0055] FIG. 11A shows an example calibration connector 170. The calibration connector 170 can connect to the airflow assembly 112 and the inspiration spirometry device 102 at the same location as the mouthpiece 110. For example, the mouthpiece 110 can be removed and the calibration connector 170 can be connected to the airflow assembly 112. The calibration connector 170 can be connected as an adapter so that the inspiration spirometry device 102 can be calibrated before or after use. For example, the calibration connector 170 can facilitate a connection to a syringe as shown in FIGS. 11B-C for testing and calibration.

[0056] FIG. 11B shows exemplary testing results 171, consistent with some embodiments of this disclosure. In some embodiments, the testing results 171 can illustrate testing and validation of the efficacy of the incentive spirometry system 100 and incentive spirometry device 102. The testing results 171 confirmed that the incentive spirometry system 100 and incentive spirometry device 102 accurately measures lung volumes, conforming to ISO 26782 standards. Specifically, ISO 26782 standards require that the maximum permissible error is 75mL for the 3L syringe. The device was tested using a 3L ISO certified syringe to simulate various breathing volumes, with a specific focus on evaluating the accuracy of the measurements. The primary focus of the testing protocol was on the repeatability of the device's measurements. To assess precision, a known volume of 3L was aspirated by the syringe through the spirometer for a total of 12 samples at 3 different air flow rates (200mL/s, 400mL/s, 600mL/s), and the volumes recorded by the spirometer were documented for analysis. The order of each trial with differing target flow rates was randomized. The recorded volumes from the spirometer can be found in Table 1 below. The mean of these measurements was calculated to be 3.009L and a 99% confidence interval of 2.956L to 3.063L, which falls within the

maximum permissible range of 2.925L to 3.075L. Table 2 displays the mean and standard deviations across different target flow rates. We find there is no significant difference of measurements between different flow rates as shown in Table 3.

Table 1. Measurement data for the Incentive Spirometer. Volume aspirated was exactly 3000 mL for all trials.

Trial #	Target Flow Rate (mL/s)	Target Time to 3L (s)	Real Time to 3L (s)	Real Average Flow Rate (mL/s)	Device Average Flow Rate (mL/s)	Device Volume (mL)
1	400	7.50	7.92	378.8	327.4	2958.88
2	600	5.00	5.09	589.4	633.4	3018.2
3	200	15.0	14.46	207.5	253.0	3028.43
4	400	7.50	7.31	410.4	492.0	2965.81
5	200	15.0	12.50	240.0	268.2	3009.4
6	600	5.00	5.12	585.9	651.4	2990.73
7	400	7.50	8.60	348.8	410.0	2996.95
8	400	7.50	7.41	404.9	441.6	3067.63
9	600	5.00	5.28	568.2	670.8	3014.42
10	200	15.0	13.64	219.9	284.2	3067.7
11	200	15.0	13.90	215.8	249.0	3045.62
12	600	5.00	5.08	590.6	636.6	2938.13

Table 2. Mean, standard deviation, and confidence intervals across all target flow rate groups for the Incentive Spirometer.

ISO 26782 standards maximum permissible error: $\pm 2.5\%$ (75mL) for a 3-L syringe					
Target Flow Rate (mL/s)	Device Average	Device Volume Standard	Device Volume 99% Confidence	Device Volume 95% Confidence	Device Volume 90% Confidence

	Volume (mL)	Deviation (mL)	Interval (mL)	Interval (mL)	Interval (mL)
200	3037	24.83	± 32.0	± 24.33	± 20.4
400	2997	49.71	± 64.0	± 48.71	± 40.9
600	2990	36.89	± 47.5	± 36.88	± 30.3
Overall	3009	41.11	± 53.0	± 40.3	± 33.8

Table 3. Single factor ANOVA shows no significant difference between groups of different flow rates.

SUMMARY						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
200 ml/s	4	12151.15	3037.7875	616.506225		
400 ml/s	4	11989.27	2997.3175	2471.382225		
600 ml/s	4	11961.48	2990.37	1360.6862		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	5246.010617	2	2623.005308	1.768884765	0.2249572643	4.256494729
Within Groups	13345.72395	9	1482.858217			
Total	18591.73457	11				

[0057] The results of statistical analyses indicate that the incentive spirometry system 100 and incentive spirometry device 102 demonstrate a high level of accuracy and consistency in measuring lung volumes. The mean volume of 3.009L is close to the expected 3L, with minimal deviation. The accuracy of the incentive spirometry system 100 and incentive spirometry device 102 suggests that it is reliable for repeated use in measuring lung volumes, which is advantageous for both clinical settings and patient self-monitoring. No significant discrepancies were observed, and the incentive spirometry system 100 and incentive spirometry device 102 performance meets the precision standards as outlined by ISO 26782.

[0058] Regarding FIG. 11B, the testing results 171 also include the following:

Best-fit values	
Slope	1.061 ± 0.07359
Y-intercept	22.09 ± 31.19
X-intercept	-20.82
95% Confidence Intervals	
Slope	0.8974 to 1.225
Y-intercept	-47.39 to 91.58
X-intercept	-101.1 to 39.04
Goodness of Fit	
R square	0.9541
Sy.x	38.03
Data	
Number of XY pairs	12
Equation	$Y = 1.061 * X + 22.09$

[0059] FIG. 11C shows an example calibration process 172. Experimental flow rate denotes the flow rate value our device outputs. The real flow rate denotes the true flow rate obtained by pulling the syringe within a certain amount of time. The example results show a slightly better fit at lower flow rates than faster flow rates, which can advantageous in use because patients using the inspiration spirometry device 102 typically have constrained use of their lungs. The overall RMSE is 18.6 mL/s and the R-squared value is 0.985 which suggests a very accurate system, at a much greater precision than the standard of care.

[0060] A model of a patient's lung was generated to validate that our design could effectively measure lung vital capacity and flow rate. The calibration and testing process 171 can include utilizing a 500mL syringe with graduations which is connected to the Venturi tube via tubing. The end closest to the "lung" is sealed air tight with a stopper, where the patient's mouth would be, while the end of the Venturi tube remains open to air. To collect data that serves as the control, an Arduino circuit was constructed that upon a button press started/stopped a timer. Once weight is added to the syringe

handle, the plunger is pulled down at a constant velocity, using the button press, and measurements were recorded of the rate and volume of airflow of the “breath”. The pressure sensor placed in the constriction was able to measure the change in pressure and turn that into flow rate and vital capacity calculations (experimental data). After conducting multiple trials, a linear regression on the experimental flow rate values versus the control group yielded a slope of 0.999 and an R² of 0.989 suggesting that design accurately measures flow rate and can be used to calculate lung vital capacity.

[0061] FIG. 12 illustrates the switch panel 126 according to some embodiments. The switch panel 126 can include one or more processors or engines, memory storage devices, power sources, wireless transmitters, among other features. The switch panel 126 can facilitate wireless communication with the user device 104 and/or the provider device 106. The switch panel 126 can also store instructions (e.g., treatment protocols, operating instructions, or other instructions) that facilitate the operation of the inspiration spirometry device 102 and the inspiration spirometry system 100. The switch panel 126 can include one or more power sources (e.g., batteries such as a rechargeable battery) that power the inspiration spirometry device 102. In some embodiments, the connection between the rear housing 128 and switch panel 126 facilitates access and utilization of the switch panel 126 by clinicians/providers and hidden from patients if needed. The switch panel 126 can include switches such as turning off exercise reminders (for example, the device buzzes and vibrates every X number of minutes to remind patients to complete exercises), resetting the microcontroller, and turning on/off power.

[0062] Referring to FIGS. 2 and 13, the housing 118 includes a display screen 120, a button 122, a power source 181, one or more processors 182 (or engines), and one or more storage devices. Airflow through the incentive spirometry device 102 can be prevented from entering the housing 118 based on the connection of the airflow assembly 112 to the housing 118. The airflow assembly 112 can facilitate the air flow path while the housing 118 can be closed off from the air flow path. The housing 118 can be re-useable and sterilization of the housing 118 may not be necessary. In some embodiments, the airflow assembly 112 can be sterilized and the housing 118 can be cleaned (and does

not necessitate sterilization due to the lack of airflow). The housing 118 can be re-useable. The housing 118 includes an electrical port 183 that interfaces 132 with the first end of the airflow assembly 112. For example, the first end 132 of the airflow assembly 112 can include one or more electrical contacts that facilitate the connection of the sensor 150 to the electrical components of the housing 118. In some embodiments, the switch panel 126 is integrated within the housing 118. The button 122 can be a power button and/or a start/stop button that facilitates a user turning on the inspiration spirometry device 102 and starting/stopping of a repetition and/or exercise session.

[0063] FIG. 14 shows an example schematic diagram of an electrical assembly 190 of the inspiration spirometry system 100. In some embodiments, the electrical assembly 190 can be housed within the inspiration spirometry device 102. Each of the components can be connected to the microcontroller 182 (or other suitable processor programmed with code stored on a non transitory computer-readable medium, execution of which performs the operations of the device). Additional electronics may also be incorporated into the main body of the device, including LEDs, a vibrating motor 185 for haptic feedback, a memory 189 (e.g., optionally including an SD reader), and/or a speaker 187 that may be used to remind patients when to perform exercises, read what is on the electronic screen, and/or otherwise interact with the patient.

[0064] FIG. 15 shows an example embodiment of data transmission from the microcontroller 182 (e.g., of the inspiration spirometry device 102) to the user device 104 and/or one or more databases or other storage media. Pressure data collected by the pressure sensor 150 is calculated into volume and flow data in the microcontroller 182 and is sent to the user device 104 (e.g., an application which is resident on a smartphone, tablet or other device) using an MQTT messaging protocol. Then the application can send some or all of the collected data to a cloud-based database using an HTTP protocol, specifically, flow rates and volumes during the measurement and the time of the measurement. The mobile app references the cloud-based database when displaying patients' previously recorded exercise data. In embodiments, data may be sent directly from the incentive spirometry device to the cloud-based database. In embodiments,

collected data is automatically transmitted for inclusion in a patient's electronic medical records.

[0065] FIGS. 16-19 illustrate example user interfaces 200 at the user device 104. For example, the user interfaces 200 can reflect various screens of a companion application that can be stored and accessible at the user device 104 and the provider device 106. The user interfaces 200 facilitate controlling, tracking, and displaying the results of the inspiration spirometry system 100. For example, the user interfaces 200 can facilitate the starting of an exercise session (e.g., one or more repetitions at the inspiration spirometry device 102). The interfaces 200 can display inspiration signatures in real time at the user device 104 while a user is performing repetitions at the inspiration spirometry device 102. The interfaces 200 can show progress reports, exercise history, metrics for a current or past repetition(s), and treatment protocols including schedules, times, targets, etc.

[0066] FIGS. 20 and 21 illustrate example user interfaces 202 at the provider device 106. The interfaces 202 can display results for one or more patients using one or more inspiration spirometry devices 102. The user interfaces 202 can be configured to manage the connections with each patient and/or inspiration spirometry device. For example, the interfaces 202 can facilitate the programming or prescribing of treatment protocols to one or more patients. The treatment protocols can include a number of repetitions, a volume per repetition, treatment schedules, among other parameters.

[0067] FIGS. 22-24 illustrate example user interfaces 204 at the user device 104. Like user interfaces 200, user interfaces 204 facilitate user interaction with and control of the inspiration spirometry device 102. Some embodiments of the user interfaces 204 can include simultaneous displaying of results of the user performing one or more repetitions with the inspiration spirometry device 102. For example, the interfaces 204 can gamify the user experience to display motivational icons and graphics to encourage a user to perform repetitions or to increase the effort exerted in each repetitions. For example, a rocket icon can be shown to encourage a user to exert additional effort on their repetitions. The larger the inhale, the higher the rocket icon will rise on the screen, thereby providing

a reward to the user while they perform exercises. In another non-limiting example, the interfaces 200, 204 can include the gamification of collecting medals/trophies when users achieve the target goal or target number of inhales/repetitions for their exercise.

[0068] In some embodiments, the gamification and guidance provided at the interfaces 200, 204 can be provided both via the app (e.g., via interfaces 200, 204) and on the device itself (e.g., at the display 120) as visual, auditory, and haptic cues. Guided exercises (with or without gamification) facilitate improved patient outcomes by effectively coaching and training desired specific inhalation rate ranges that many patients do not adhere to. For example, patients may try to breath in as fast as possible to reach the target goal ($>1200\text{ml/s}$), and the interfaces, guidance, and gamification approaches described herein facilitate adherence to beneficial speeds such as between $200\text{-}800\text{ml/s}$. The systems, devices, and methods described herein provide guidance and cues (e.g., at the display 120 and/or application via the interfaces 200, 204 and the user device 104) based on real time flow rate measurements (for example, "breathe slower").

[0069] FIGS. 25A-B illustrate another example incentive spirometry system 2500. The incentive spirometry system 2500 can share features with the incentive spirometry system 100 described above. The incentive spirometry system 2500 can include an incentive spirometry device 2502 that includes: (1) a detachable and disposable mouthpiece that the user places their mouth over 2510; (2) a detachable and disposable Venturi tube insert 2512, which serves as the main airflow channel in the device; (3) a lid 2524 with an on/off push button; and (4) the main body 2518 of the device housing all electronics, including but not limited to the pressure sensor 2550 and a digital display screen 2520. When a patient inhales from the assembled device to perform incentive spirometry exercises, the pressure sensor, housed within the main body and operatively coupled to the Venturi tube insert, takes pressure readings in the tube insert to derive airflow rates and inhalation volumes.

[0070] FIG. 26 illustrates an airflow insert 2512 of the incentive spirometry system 2500. The airflow insert 2512 can share features with the airflow assembly 112 described above (e.g., including the air chamber, the pressure sensor, etc.).

[0071] FIG. 27 illustrates the mouthpiece 2510. The mouthpiece 2510 can share features with the mouthpiece 110 described above. For example, the mouthpiece 2510 can attach to a one-way valve before being inserted into the incentive spirometry device 2502 to prevent excessive moisture from entering the airflow insert 2512. In embodiments, the valve is a one way valve disposed within the mouthpiece 2510 itself so that the mouthpiece can stand alone as a one-way mouthpiece. Air flows from the narrow end to the wide end of the mouthpiece as the patient inhales.

[0072] FIG. 28 illustrates the main body 2518 of the incentive spirometry device 2502. The main body 2518 can share features with the housing 118. The main body 2518 can house electronic components, including: (1) the pressure sensor, (2) the digital screen, (3) the microcontroller or engine (or other suitable processor), and (4) push button, which is coupled to the lid of the main body. The airflow tube is inserted in the rectangular opening on the side of the main body, and there are openings at opposite ends for air to flow through. There are also openings for the digital screen and a USB-C charging port.

[0073] Inhalation volume and flow measurements can be collected by the digital pressure sensor (e.g., sensors 150, 2550) in the airflow tube and displayed on the device screen. Alternatively or additionally, in embodiments, the volume and flow measurement data is relayed wirelessly, such as via WiFi, Bluetooth®, NFC or other wireless communication technology and protocol, to the companion iOS (or Android®, or other) mobile app. It should also be appreciated that in embodiments, this data can be transmitted through a wired connection. The paired app (e.g., at user device 104) has features to increase patient compliance and provide clinicians (e.g., at provider device 106) with easily accessible compliance data. The patient side of the app includes tutorials on how to perform exercises, exercise reminders and notifications, a measurement view that displays guidance during exercises, a view where patients can track their exercise completion progress over time, and a game for gamified exercises. The clinician side of the app displays summaries of all of their patients' exercise performance and compliance,

and alerts them of patients that are not compliant or whose exercise performance declines.

Example Instructions

[0074] The incentive spirometry systems 100, 2500 and incentive spirometry devices 102, 2502 can utilize a microcontroller (e.g., processor 182 and/or engine) with the pin-out shown below to take in readings from the differential pressure sensor (e.g., sensor 150, 2550) and convert them simultaneously to flow rate and lung vital capacity measurements. In some embodiments, the initial pressure is set as 1 atm given the constriction is open to the room and measure the pressure at the constriction using the aforementioned pressure sensor. The velocity of airflow at the constriction facilitates the calculation of the flow rate, which can then be integrated to calculate the volume of air inhaled or the lungs vital capacity.

[0075] Variables:

[0076] Points 1 and 2 are points along the same streamline inside and outside of the constriction in the Venturi tube.

$p_{1,2}$ = pressure at points 1 and 2

d = density of air

$v_{1,2}$ = velocity of air at points 1 and 2

g = gravitational constant

$H_{1,2}$ = height of points 1 and 2

$A_{1,2}$ = area of cross-section at points 1 and 2

$$(1) \quad p_1 + \frac{1}{2}\rho v_1^2 + \rho g H_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g H_2$$

$$(2) \quad p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2$$

$$(3) \quad A_1 V_1 = A_2 V_2$$

$$(4) \quad V_1 = \frac{A_2 V_2}{A_1}$$

$$(5) \quad p_1 + \frac{1}{2}\rho \left(\frac{A_2 V_2}{A_1}\right)^2 = p_2 + \frac{1}{2}\rho v_2^2$$

$$(6) \quad (p_1 - p_2) = \frac{1}{2}\rho \left(v_2^2 - \left(\frac{A_2 V_2}{A_1}\right)^2\right)$$

$$(7) \quad 2dP = \rho \left(v_2^2 - \left(\frac{A_2 V_2}{A_1}\right)^2\right)$$

$$(8) \quad 2dP = \rho v_2^2 \left(1 - \left(\frac{A_2}{A_1}\right)^2\right)$$

$$(9) \quad v_2^2 = \frac{2dP}{\rho \left(1 - \left(\frac{A_2}{A_1}\right)^2\right)}$$

$$(10) \quad v_2 = \sqrt{\frac{2dP}{\rho \left(1 - \left(\frac{A_2}{A_1}\right)^2\right)}}$$

[0077] The systems, devices, and methods described herein advantageously facilitate at least hygienic reusability, digital integration, customizable parameters, remote monitoring, and data analytics and research. For example, the removable airflow assembly 112, 2512 facilitates easy disinfection or replacement, maintaining a higher level of hygiene between patients. The design of a removable airflow tube also simplifies the cleaning and maintenance process, reducing the burden on healthcare staff. The inclusion of digital technology within the incentive spirometry systems 100, 2500 advantageously facilitates real time data tracking, patient progress monitoring, and integration with electronic health records (EHR) systems. This can enhance patient care and streamline data management. The digital nature of the incentive spirometry systems 100, 2500 facilitates customizable parameters based on individual patient needs or prescribed rehabilitation plans. This adaptability improves the accuracy and effectiveness of therapy. The systems, devices, and methods described herein facilitate the analysis of patient trends in vital capacity and other clinical and demographic factors to better predict

which patients are at the highest risk for a PPC and predict a PPC is going to occur prior to the PPC occurring. Various factors such as (smoking status, incision size, duration of anesthesia, BMI, vital capacity prior to surgery) can be predictive, and the system (e.g., via the user device 104 and provider device 106) can incorporate this data with the sensor data. The digital interface of incentive spirometry systems 100, 2500 provides visual feedback and interactive elements, enhancing patient engagement and motivation during respiratory exercises, leading to improved patient adherence and better outcomes. With the capability for digital data transmission, healthcare providers can remotely monitor a patient's progress and adherence to prescribed spirometry exercises. This feature is additionally beneficial for telehealth and remote patient management when inpatients leave the hospital. The device's digital capabilities facilitate research by facilitating the collection of standardized and consistent spirometry data across different patient populations. The digital spirometer collects and analyzes data over time, providing insights into patient trends and progress. This aids clinicians in making informed decisions and potentially personalized treatment plans or complications intervention. Reuse between patients and the avoidance of disposable components can also lead to cost savings over time.

[0078] Additionally, some embodiments described in more detail below can facilitate an efficient and informed allocation of medical resources, personnel, treatment, and time in clinical and non-clinical environments. For example, the systems, devices, and methods described herein can facilitate the efficient allocation of medical staff (e.g., nurses, doctors, therapists, others) that are responsible for ensuring patient adherence to treatment protocols, along with identifying patients that are most at risk for postoperative pulmonary complications (PPCs).

[0079] In this specification, the term “engine” or “software engine” refers to a software implemented input/output system that provides an output that is different from the input. An engine can be an encoded block of functionality, such as a library, a platform, a software development kit (“SDK”), or an object. Each engine can be implemented on any appropriate type of computing device, e.g., servers, mobile phones,

tablet computers, notebook computers, music players, e-book readers, laptop or desktop computers, PDAs, smart phones, or other stationary or portable devices, that includes one or more processors and computer readable media. Additionally, two or more of the engines may be implemented on the same computing device, or on different computing devices.

[0080] The subject matter and the actions and operations described in this specification can be implemented in digital electronic circuitry, in tangibly-embodied computer software or firmware, in computer hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. The subject matter and the actions and operations described in this specification can be implemented as or in one or more computer programs, e.g., one or more modules of computer program instructions, encoded on a computer program carrier, for execution by, or to control the operation of, data processing apparatus. The carrier can be a tangible non-transitory computer storage medium. Alternatively or in addition, the carrier can be an artificially-generated propagated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal, that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. The computer storage medium can be or be part of a machine-readable storage device, a machine-readable storage substrate, a random or serial access memory device, or a combination of one or more of them. A computer storage medium is not a propagated signal.

[0081] The term “data processing apparatus” encompasses all kinds of apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers. Data processing apparatus can include special-purpose logic circuitry, e.g., an FPGA (field programmable gate array), an ASIC (application-specific integrated circuit), or a GPU (graphics processing unit). The apparatus can also include, in addition to hardware, code that creates an execution environment for computer programs, e.g., code that constitutes processor

firmware, a protocol stack, a database management system, an operating system, or a combination of one or more of them.

[0082] A computer program can be written in any form of programming language, including compiled or interpreted languages, or declarative or procedural languages; and it can be deployed in any form, including as a stand-alone program, e.g., as an app, or as a module, component, engine, subroutine, or other unit suitable for executing in a computing environment, which environment may include one or more computers interconnected by a data communication network in one or more locations.

[0083] A computer program may, but need not, correspond to a file in a file system. A computer program can be stored in a portion of a file that holds other programs or data, e.g., one or more scripts stored in a markup language document, in a single file dedicated to the program in question, or in multiple coordinated files, e.g., files that store one or more modules, sub-programs, or portions of code.

[0084] The processes and logic flows described in this specification can be performed by one or more computers executing one or more computer programs to perform operations by operating on input data and generating output. The processes and logic flows can also be performed by special-purpose logic circuitry, e.g., an FPGA, an ASIC, or a GPU, or by a combination of special-purpose logic circuitry and one or more programmed computers.

[0085] Computers suitable for the execution of a computer program can be based on general or special-purpose microprocessors or both, or any other kind of central processing unit. Generally, a central processing unit will receive instructions and data from a read-only memory or a random access memory or both. The essential elements of a computer are a central processing unit for executing instructions and one or more memory devices for storing instructions and data. The central processing unit and the memory can be supplemented by, or incorporated in, special-purpose logic circuitry.

[0086] Generally, a computer will also include, or be operatively coupled to, one or more mass storage devices, and be configured to receive data from or transfer data to the mass storage devices. The mass storage devices can be, for example, magnetic,

magneto-optical, or optical disks, or solid state drives. However, a computer need not have such devices. Moreover, a computer can be embedded in another device, e.g., a mobile telephone, a personal digital assistant (PDA), a mobile audio or video player, a game console, a Global Positioning System (GPS) receiver, or a portable storage device, e.g., a universal serial bus (USB) flash drive, to name just a few.

[0087] To provide for interaction with a user, the subject matter described in this specification can be implemented on one or more computers having, or configured to communicate with, a display device, e.g., a LCD (liquid crystal display) monitor, or a virtual-reality (VR) or augmented-reality (AR) display, for displaying information to the user, and an input device by which the user can provide input to the computer, e.g., a keyboard and a pointing device, e.g., a mouse, a trackball or touchpad. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback and responses provided to the user can be any form of sensory feedback, e.g., visual, auditory, speech, or tactile feedback or responses; and input from the user can be received in any form, including acoustic, speech, tactile, or eye tracking input, including touch motion or gestures, or kinetic motion or gestures or orientation motion or gestures. In addition, a computer can interact with a user by sending documents to and receiving documents from a device that is used by the user; for example, by sending web pages to a web browser on a user's device in response to requests received from the web browser, or by interacting with an app running on a user device, e.g., a smartphone or electronic tablet. Also, a computer can interact with a user by sending text messages or other forms of message to a personal device, e.g., a smartphone that is running a messaging application, and receiving responsive messages from the user in return.

[0088] This specification uses the term "configured to" in connection with systems, apparatus, and computer program components. That a system of one or more computers is configured to perform particular operations or actions means that the system has installed on it software, firmware, hardware, or a combination of them that in operation cause the system to perform the operations or actions. That one or more computer programs is configured to perform particular operations or actions means that

the one or more programs include instructions that, when executed by data processing apparatus, cause the apparatus to perform the operations or actions. That special-purpose logic circuitry is configured to perform particular operations or actions means that the circuitry has electronic logic that performs the operations or actions.

[0089] The subject matter described in this specification can be implemented in a computing system that includes a back-end component, e.g., as a data server, or that includes a middleware component, e.g., an application server, or that includes a front-end component, e.g., a client computer having a graphical user interface, a web browser, or an app through which a user can interact with an implementation of the subject matter described in this specification, or any combination of one or more such back-end, middleware, or front-end components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network (LAN) and a wide area network (WAN), e.g., the Internet.

[0090] The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other. In some implementations, a server transmits data, e.g., an HTML page, to a user device, e.g., for purposes of displaying data to and receiving user input from a user interacting with the device, which acts as a client. Data generated at the user device, e.g., a result of the user interaction, can be received at the server from the device.

[0091] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of what is being claimed, which is defined by the claims themselves, but rather as descriptions of features that may be specific to particular embodiments of particular inventions. Certain features that are described in this specification in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple

embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially be claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claim may be directed to a subcombination or variation of a subcombination.

[0092] Similarly, while operations are depicted in the drawings and recited in the claims in a particular order, this by itself should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system modules and components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

WHAT IS CLAIMED IS:

1. An incentive spirometer system, comprising:
 - a housing including a display screen, a power source, one or more processors, and one or more storage devices;
 - an airflow assembly, the airflow assembly including:
 - a first end configured to connect to the housing;
 - a second end opposite the first end;
 - an air inlet in a top surface of an airflow housing at the first end;
 - an air outlet at the second end;
 - an air flow chamber including an inlet portion, a constriction portion, and an outlet portion, the constriction portion having a constriction diameter smaller than a diameter of the inlet portion and the outlet portion, the constriction portion having a lateral opening;
 - a pressure sensor connected to the lateral opening of the constriction portion;
 - a mouthpiece configured to connect to the second end of the airflow assembly, the mouthpiece including a one-way valve that permits air flow from a mouthpiece inlet connected to the second end of the airflow assembly to a mouthpiece outlet opposite the mouthpiece inlet;
 - wherein the one or more storage devices store instructions that are operable, when executed by the one or more processors, to cause the one or more processors to perform operations comprising:
 - obtaining sensor data from the pressure sensor, the sensor data including data obtained from a plurality of inspiration repetitions;
 - generating one or more inspiration signatures using the sensor data, the one or more inspiration signatures including an air flow rate and air volume for each of a plurality of inspiration repetitions;
 - providing a result of the one or more inspiration signatures to each of (i) the display screen; (ii) a user device; and (iii) a provider device.

2. The incentive spirometer system of claim 1, wherein the operations comprise simultaneously displaying the one or more inspiration signatures in real time at the user device.
3. The incentive spirometer system of claim 1, wherein the operations comprise receiving a treatment protocol from the provider device.
4. The incentive spirometer system of claim 3, wherein the operations comprise sending alerts to the user device according to the treatment protocol.
5. The incentive spirometer system of claim 4, wherein a plurality of inspiration signatures are obtained according to the treatment protocol, and the operations include comprise sending the plurality of inspiration signatures to the provider device.
6. The incentive spirometer system of claim 1, wherein air flow is prevented from entering the housing.
7. The incentive spirometer system of claim 6, wherein the housing comprises an electrical port that interfaces with the first end of the airflow assembly.
8. The incentive spirometer system of claim 6, wherein the airflow assembly and the mouthpiece are disposable.
9. The incentive spirometer system of claim 8, wherein the housing is re-useable.
10. The incentive spirometer system of claim 1, wherein the air inlet comprises laser-cut letters.
11. An incentive spirometry method, comprising:

connecting an airflow assembly to a housing of an incentive spirometry device, the airflow assembly including:

a first end configured to connect to the housing;

a second end opposite the first end;

an air inlet in a top surface of the airflow assembly at the first end;

an air outlet at the second end;

an air flow chamber including an inlet portion, a constriction portion, and an outlet portion, the constriction portion having a constriction diameter smaller than a diameter of the inlet portion and the outlet portion, the constriction portion having a lateral opening;

a pressure sensor connected to the lateral opening of the constriction portion;

obtaining sensor data from the pressure sensor, the sensor data including data obtained from a plurality of inspiration repetitions;

generating one or more inspiration signatures using the sensor data, the one or more inspiration signatures including an air flow rate and air volume for each of a plurality of inspiration repetitions;

providing a result of the one or more inspiration signatures to each of (i) a display screen of the incentive spirometry device; (ii) a user device; and (iii) a provider device.

12. The incentive spirometry method of claim 11, further comprising simultaneously displaying the one or more inspiration signatures in real time at the user device.

13. The incentive spirometry method of claim 12, wherein the simultaneous display includes motivational icons.

14. The incentive spirometry method of claim 11, wherein further comprising receiving a treatment protocol from the provider device.
15. The incentive spirometry method of claim 14, further comprising sending alerts to the user device according to the treatment protocol.
16. The incentive spirometry method of claim 11, further comprising sending the one or more inspiration signatures from a plurality of inspiration spirometry devices to the provider device.
17. The incentive spirometry method of claim 16, wherein the plurality of inspiration signatures are obtained from a plurality of patients.
18. An incentive spirometer device, comprising:
 - a housing including a display screen, a power source, one or more processors, and one or more storage devices;
 - an airflow assembly, the airflow assembly including:
 - a first end configured to connect to the housing;
 - a second end opposite the first end;
 - an air inlet in a top surface of the airflow assembly at the first end;
 - an air outlet at the second end;
 - an air flow chamber including an inlet portion, a constriction portion, and an outlet portion, the constriction portion having a constriction diameter smaller than a diameter of the inlet portion and the outlet portion, the constriction portion having a lateral opening;
 - a pressure sensor connected to the lateral opening of the constriction portion; and
 - a mouthpiece configured to connect to the second end of the airflow assembly, the mouthpiece including a one-way valve that permits air flow from a mouthpiece

inlet connected to the second end of the airflow assembly to a mouthpiece outlet opposite the mouthpiece inlet;

wherein the one or more storage devices store instructions that are operable, when executed by the one or more processors, to cause the one or more processors to perform operations comprising:

obtaining sensor data from the pressure sensor, the sensor data including data obtained from a plurality of inspiration repetitions;

generating one or more inspiration signatures using the sensor data, the one or more inspiration signatures including an air flow rate and air volume for each of a plurality of inspiration repetitions.

19. The incentive spirometer device of claim 18, wherein air flow is prevented from entering the housing.

20. The incentive spirometer device of claim 18, wherein the airflow assembly and the mouthpiece are disposable.