CLAIMS

1. A method of measuring an interior volume of a storage container containing a medium therein using a plurality of acoustic devices, the method comprising:

deploying the plurality of acoustic devices into respective positions on an exterior surface of a circumferential wall of the container, the acoustic devices including an ultrasonic transducer and an ultrasonic sensor, in which the ultrasonic transducer is acoustically coupled to the surface and is configured to transmit one or more ultrasonic signals through the wall of the container and across the interior volume of the container, and in which the ultrasonic sensor is acoustically coupled to the surface and configured to detect the one or more ultrasonic signals;

transmitting one or more ultrasonic signals using the ultrasonic transducer, in which each signal is transmitted at a respective impulse time;

detecting, using the ultrasonic sensor, the one or more signals and recording a respective detection time;

calculating, by a computing device in electronic communication with the ultrasonic transducer and the ultrasonic sensor, respective times of flight (TOFs) for the one or more signals based on the respective impulse times and respective detection times, in which a respective TOF is an elapsed time for a signal to travel along a path between the respective positions of the ultrasonic transducer and the ultrasonic sensor;

aligning, with the computing device based on the respective TOFs, the ultrasonic transducer and the ultrasonic sensor in a circumferential direction and/or a longitudinal direction relative to the circumferential wall of the container;

calculating, with the computing device, a distance between the respective positions of the aligned ultrasonic transducer and ultrasonic sensor based on the calculated respective TOF and a speed of sound through the medium; and

determining, with the computing device, the volume of the storage container based on the calculated distance and the respective positions of the aligned ultrasonic transducer and ultrasonic sensor.

2. A method according to Claim 1, in which the step of aligning comprises:

adjusting the respective position of one or more of the ultrasonic transducer and the ultrasonic sensor on the surface in one or more of the circumferential direction and the longitudinal direction, and

performing the steps of transmitting, detecting and calculating respective TOFs for one or more acoustic signals transmitted between the adjusted respective positions of the ultrasonic transducer and ultrasonic sensor.

3. A method according to Claim 2, repeating the adjusting, transmitting, detecting and calculating steps until determining, with the computing device based on the calculated TOFs, that the ultrasonic transducer and the ultrasonic sensor are aligned.

4. A method according to Claim 3, in which the step of adjusting the respective position of one or more of the ultrasonic transducer and the ultrasonic sensor on the surface comprises:

moving one or more of the ultrasonic transducer and the ultrasonic sensor a prescribed amount in one or more of the longitudinal and the circumferential direction using a robot operating under the control of the computing device, in which the prescribed amount is measured in near-real time using one or more position sensors on-board the robot and in which the robot is configured to move according to a feedback control loop.

5. A method according to Claim 1, further comprising:

deploying a plurality of ultrasonic sensors at different respective positions on the surface;

iteratively aligning, using a robot under the control of the computing device, the ultrasonic transducer with each one of the plurality of ultrasonic sensors;

performing the steps of generating, detecting and calculating respective TOFs for each respective position of the ultrasonic transducer that is aligned with one of the plurality of ultrasonic sensors; and

calculating, based on the calculated TOFs, a diameter of the container for each respective position of the ultrasonic transducer that is aligned with one of the plurality of ultrasonic sensors.

6. A method according to Claim 1, further comprising:

adjusting the respective position of one or more of the ultrasonic transducer and the ultrasonic sensor on the surface in one or more of the circumferential direction and the longitudinal direction using one or more robots under the control of the computing device, and

performing the steps of transmitting, detecting and calculating respective TOFs for one or more acoustic signals transmitted between the adjusted respective positions of the ultrasonic transducer and ultrasonic sensor.

7. A method according to Claim 1, further comprising:

prior to the step of calculating the distance, measuring the speed of sound in the medium.

8. A method according to Claim 7, in which the step of measuring the speed of sound in the medium comprises:

deploying a particular ultrasonic transducer and a particular ultrasonic sensor at respective positions on the surface having a known distance therebetween;

measuring, with the computing device using the particular ultrasonic transducer and ultrasonic sensor, TOF for at least one acoustic signal transmitted between the particular ultrasonic transducer and the particular ultrasonic sensor; and

calculating, with the computing device, the speed of sound through the medium based on the TOF of the signal traveling between the ultrasonic transducer and the particular ultrasonic sensor and the known distance.

9. A method according to Claim 1, further comprising:

identifying, with the computing device based on the calculated respective TOFs, one or more of: a type of a medium contained within the storage container, a volume of the medium contained within the storage container.

10. A method according to Claim 1, in which the ultrasonic transducer and the ultrasonic sensor are combined into an acoustic transceiver unit that is configured to both transmit and receive the one or more ultrasonic signals, and in which the step of aligning comprises:

controllably positioning the transceiver relative to the circumferential wall of the container such that the one or more acoustic signals travel along a path extending across the internal volume of the container along a diameter of the container.

11. A system for measuring a volume of a storage container, the system comprising:

a plurality of acoustic devices configured to be acoustically coupled to an exterior surface of a circumferential wall of the container at respective positions, the acoustic devices including:

an ultrasonic transducer configured to transmit one or more ultrasonic signals across an interior volume of the container that is bounded by the wall, and

an ultrasonic sensor configured to detect the one or more ultrasonic signals;

a robot configured to controllably deploy one or more of the acoustic devices on the surface, in which the robot includes a drive system and one or more position sensors for monitoring a position of the robot; and

a control computing system comprising:

a non-transitory computer readable storage medium,

one or more processors in electronic communication with the plurality of acoustic devices, the robot and the computer readable storage medium,

one or more software modules comprising executable instructions stored in the storage medium, in which the one or more software modules are executable by the processor and include:

an acoustic control module that configures the processor to, using the ultrasonic transducer, transmit one or more acoustic signals at respective impulse times, in which the acoustic control module further configures the processor to, using the ultrasonic sensor, detect the arrival of the one or more signals and record respective detection times,

an acoustic analysis module that configures the processor to calculate a respective time of flight (TOF) for the one or more acoustic signals traveling between the respective positions of the ultrasonic transducer and the ultrasonic sensor, and calculate a respective distance therebetween based on the respective TOF,

a position control module that configures the processor to, using the robot, adjust the respective position of one or both of the ultrasonic transducer and the ultrasonic sensor on the surface and, for each adjusted respective position, re-calculate a respective distance between the ultrasonic transducer and the ultrasonic sensor based on one or more acoustic signals traveling therebetween, in which the position control module configures the processor to determine based on the calculated TOFs, whether the ultrasonic transducer and the ultrasonic sensor are aligned in a circumferential direction and/or a longitudinal direction, relative to the surface of the container, and

a geometric analysis module that configures the processor to calculate a volume of the storage container based on the calculated respective distances and corresponding respective positions of the ultrasonic transducer and the ultrasonic sensor.

12. A system according to Claim 11, in which the position control module configures the processor to determine based on the calculated TOFs, whether the ultrasonic transducer and ultrasonic sensor are aligned in both the circumferential direction and the longitudinal direction relative to the surface of the container.

13. A system according to Claim 12, in which the position control module configures the processor to iteratively adjust the respective position of one or more of the ultrasonic transducer and the ultrasonic sensor on the surface and re-calculate TOF until determining that the ultrasonic transducer and sensor are aligned.

14. A system according to Claim 11, further comprising: a plurality of ultrasonic sensors including at least a first ultrasonic sensor and a second ultrasonic sensor, in which the plurality of ultrasonic sensors are separated by a known distance in one or more of the circumferential direction and the longitudinal direction.

15. A system according to Claim 12, in which the position control module configures the processor to, using the robot, align the ultrasonic transducer with each of the plurality of ultrasonic sensors in the longitudinal direction and circumferential direction and, for each respective position in which the ultrasonic transducer is aligned with one of the plurality of ultrasonic sensors, calculate a respective diameter of the container based on the calculated TOFs.