CLAIMS

1. A method of measuring a volume of a storage container using a plurality of acoustic devices, the plurality of acoustic devices including a transducer and one or more sensors, the method comprising:

deploying the plurality of acoustic devices into respective positions on an exterior surface of a circumferential wall of the container, wherein the one or more sensors are acoustically coupled to the surface and configured to detect one or more pulses propagating circumferentially along the wall of the container, and wherein the transducer is acoustically coupled to the surface and is configured generate the one or more pulses, wherein the one or more pulses radiate along the wall away from the transducer and toward the one or more sensors in at least a first circumferential path and a second circumferential path;

generating the one or more pulses using the transducer, wherein each pulse is generated at an impulse time;

detecting, using the one or more sensors, the one or more pulses radiating along the first circumferential path and the second circumferential path and recording a respective time that the one or more pulses radiating along a respective circumferential path are detected;

calculating, by a computing device in electronic communication with the one or more sensors based on the impulse time and respective detection times, respective times of flight (TOFs) for the one or more pulses, wherein each respective TOF is an elapsed time for the pulse to travel between two of the acoustic devices along a particular circumferential path;

calculating, with the computing device, respective distances between the acoustic devices in each of the first and second circumferential directions based on the respective TOFs and a speed of sound through the wall; and

determining, with the computing device, the volume of the storage container based on the calculated respective distances.

2. The method of claim 1, wherein deploying the plurality of acoustic devices comprises deploying at least a first acoustic sensor and a second acoustic sensor at respective positions that are separated by a known distance, and further comprising the steps of:

calculating, with the computing device, a TOF for the pulse radiating between the first and second acoustic sensors having the known separation distance; and

calculating, with the computing device, the speed of sound through the wall based on the TOF of the pulse radiating between the first and second acoustic sensors and the known separation distance.

3. The method of claim 1, further comprising:

aligning at least two of the acoustic devices in one or more of a transverse and longitudinal direction relative to the circumferential wall of the container based on the calculated TOFs.

4. The method of claim 3, wherein the step of aligning comprises:

iteratively adjusting the respective position of one or more of the acoustic devices on the surface in one or more of the transverse and longitudinal directions, and

repeating the steps of generating, detecting and calculating TOFs until one or more re-calculated TOFs indicate that the respective positions of at least two of the acoustic devices are aligned in one or more of a transverse and longitudinal direction.

5. The method of claim 4, wherein the deploying step comprises deploying the one or more acoustic devices at respective positions on the surface using one or more robots that are operated under the control of the computing device.

6. The method of claim 4, wherein the step of iteratively adjusting the respective position of one or more of the acoustic devices comprises:

moving the transducer a prescribed amount in the longitudinal direction using the computing device and a robot, wherein the respective position of the transducer and the prescribed amount is measured in near-real time using one or more position sensors on-board the robot.

7. The method of claim 1, wherein deploying the plurality of sensors on the surface of the container at respective positions comprises deploying the plurality of sensors at different respective heights on the surface of the container;

incrementally re-positioning the transducer in the longitudinal direction along the surface of the container using a robot;

repeating the steps of generating, detecting and calculating TOFs for the one or more pulses for each position of the transducer;

determining, based on the calculated TOFs, whether the transducer is aligned with one or more of the sensors in the longitudinal direction; and

calculating, based on the calculated TOFs, the circumference of the container at each position in which the transducer is determined to be in alignment with one or more of the plurality of sensors.

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

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

a plurality of sensors configured to be acoustically coupled to the circumferential wall and to detect one or more pulses radiating circumferentially along the wall of the wall of the container,

a transducer configured to be acoustically coupled to the surface and generate the one or more pulses, wherein the one or more pulses radiate along the wall of the container away from the transducer and toward the plurality of sensors along respective circumferential paths; 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, wherein the one or more software modules are executable by the processor and include:

a signal control module that configures the processor to, using the transducer, generate the one or more pulses using the transducer at respective impulse times, wherein the signal control module further configures the processor to, using the sensors, detect the arrival of the one or more pulses at the sensors, respectively, and record respective detection times,

a signal analysis module that configures the processor to calculate, based on the respective impulse times and respective detection times, respective times of flight (TOFs) for the one or more pulses, wherein respective TOFs are an elapsed

time for the pulse to travel between two of the acoustic devices along a respective circumferential path, and

a geometric analysis module that configures the processor to calculate distances between the acoustic devices based on the respective TOFs and a speed of sound through the wall, and to calculate the volume of the storage container based on the calculated distances.

9. The system of claim 8, further comprising:

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

a position control module, among the software modules, wherein the position control module configures the processor to, using the robot, iteratively adjust the respective position of the transducer on the surface in the longitudinal direction and re-calculate respective TOFs until the transducer is aligned in the longitudinal direction with at least one of the acoustic sensors, wherein alignment achieved when a minimum re-calculated TOF of a pulse traveling between the transducer and the at least one sensor is identified by the processor.

10. The system of claim 8, wherein the plurality of sensors include at least a first acoustic sensor and a second acoustic sensor deployed at respective positions that are separated by a known distance in one or more of the longitudinal direction and transverse direction.

11. The system of claim 10, wherein the signal analysis module further configures the processor to calculate a TOF for the pulse radiating between the first and second acoustic sensors having the known separation distance and further configures the processor to calculate the speed

of sound through the wall based on the TOF of the pulse radiating between the first and second acoustic sensors and the known separation distance.

12. The system of claim 10, further comprising:

an array of acoustic sensors, the array including at least two parallel longitudinal rows of acoustic sensors, and the wherein acoustic sensors in a longitudinal row are spaced apart a known longitudinal spacing, and wherein the two rows are spaced apart in the transverse direction a known transverse spacing.

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

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

a plurality of sensors configured to be acoustically coupled to the circumferential wall and to detect one or more pulses radiating circumferentially along the wall of the container,

a transducer configured to be acoustically coupled to the surface and generate the one or more pulses, wherein the one or more pulses radiate along the the wall of the container away from the transducer and toward the plurality of sensors along respective circumferential paths;

a robot configured to deploy one or more of the acoustic devices on the surface of the circumferential wall, wherein the robot includes a drive system and one or more position sensors for monitoring a position of the robot, wherein the robot is configured to controllably deploy the one or more acoustic devices on the surface; 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, wherein the one or more software modules are executable by the processor and include:

a signal control module that configures the processor to, using the transducer, generate one or more pulses using the transducer at respective impulse times, wherein the signal control module further configures the processor to, using the sensors, detect the arrival of the one or more pulses at the sensors, respectively, and record respective detection times,

a signal analysis module that configures the processor to calculate, based on the respective impulse times and respective detection times, respective times of flight (TOFs) for the one or more pulses, wherein respective TOFs are an elapsed time for the pulse to travel between two of the acoustic devices along a respective circumferential path,

a geometric analysis module that configures the processor to calculate distances between the acoustic devices based on the respective TOFs and a speed of sound through the wall, and to calculate the volume of the storage container based on the calculated distances, and

a position control module that configures the processor to, using the robot, iteratively adjust the respective position of one or more of the acoustic devices on the surface and re-calculate respective TOFs until at least two of the acoustic devices are aligned in one of a transverse direction and a longitudinal direction,

wherein alignment of the at least two devices is achieved when the re-calculated TOF of a pulse radiating between the at least two acoustic devices is minimized.

14. The system of claim 13, wherein the plurality of sensors include at least a first acoustic sensor and a second acoustic sensor deployed at respective positions that are separated by a known distance in one or more of the transverse direction and the longitudinal direction.

15. The system of claim 14, wherein the signal analysis module further configures the processor to calculate a TOF for the pulse radiating between the first and second acoustic sensors having the known separation distance and further configures the processor to calculate the speed of sound through the wall based on the TOF of the pulse radiating between the first and second acoustic sensors and the known separation distance.

16. The system of claim 13, wherein the processor is configured to control alignment of at least two of the acoustic devices in one or more of a transverse and longitudinal direction relative to the circumferential wall of the container based on the calculated TOFs.

17. The system of claim 16, wherein the position control module configures the processor to adjust the position of the transducer a prescribed amount in the longitudinal direction until the transducer is aligned with one or more of the plurality of sensors.

18. The system of claim 17, wherein the processor is configured to calculate the circumference of the container for each position in which the transducer is aligned with the one or more of the plurality of sensors.