[0004] Systems, methods and apparatus of this technical solution provide an autonomous vehicle that can inspect a tank containing a flammable fluid. The autonomous vehicle of this technical solution can perform an in-service tank inspection. An in-service tank inspection can refer to inspecting the tank while the flammable fluid is still contained in the tank. In some cases, an in-service tank inspection can refer to a closed tank inspection, such as inspecting a tank containing a flammable fluid while the lid of the tank is closed or sealed. To perform an in-service tank inspection, the autonomous vehicle of this technical solution can be tetherless and include a propeller, battery, and control unit that can automatically perform a tank inspection process. By automatically performing an in-service tank inspection with the tank lid closed, the autonomous vehicle can save time, reduce resource utilization and increase safety by inspecting the tank without having to empty the tank, which can allow for more frequent tank inspections. The system can more accurately predict the quality, integrity or state of the tank by performing more frequent tank inspection, or collecting inspection data at different intervals.

[0004a] In a first aspect, the present disclosure provides a system to inspect a tank containing a flammable fluid, comprising: a vehicle comprising a battery, a pressure switch, a control unit, a propeller, an inspection device having one or more conductors, and a ranging device; the pressure switch closing an electronic circuit between the control unit and the battery responsive to the pressure switch detecting an ambient pressure greater than a minimum threshold; the battery of the vehicle providing, responsive to closing of the electronic circuit by the pressure switch, power to the control unit, the propeller, the inspection device, and the ranging device; the control unit generating, based on data received from the ranging device, a map of the tank, and determining a first position of the vehicle on the map of the tank; the inspection device receiving, from the control unit responsive to identifying the first position of the vehicle on the map of the tank based on data from the ranging device, a command to initiate inspection at the first position on the map; the inspection device changing, responsive to the command to initiate inspection, a magnetic field in the one or more conductors to induce loops of electric current that extend towards a portion of the tank corresponding to the first position on the map; the inspection device detecting values corresponding to the induced loops of electric current at the portion of the tank corresponding to the first position on the map; the inspection device providing, to the control unit, data comprising the detected values; the control unit determining a quality metric at the portion of the tank corresponding to the first position of the vehicle on the map, and storing, in a memory of the vehicle, the quality metric; and the

propeller of the vehicle moving, responsive to a second command from the control unit, the vehicle through the flammable fluid in the tank towards a second position on the map.

[0004b] In a second aspect, the present disclosure provides a method of inspecting a tank containing a flammable fluid, comprising: providing a vehicle comprising a battery, a pressure switch, a control unit, a propeller, an inspection device having one or more conductors, and a ranging device; closing, by the pressure switch, an electronic circuit between the control unit and the battery responsive to the pressure switch detecting an ambient pressure greater than a minimum threshold; providing, by the battery of the vehicle responsive to closing of the electronic circuit by the pressure switch, power to the control unit, the propeller, the inspection device, and the ranging device; generating, by the control unit based on data received from the ranging device, a map of the tank, and determining a first position of the vehicle on the map of the tank; receiving, by the inspection device from the control unit responsive to identifying the first position of the vehicle on the map of the tank based on data from the ranging device, a command to initiate inspection at the first position on the map; changing, by the inspection device responsive to the command to initiate inspection, a magnetic field in the one or more conductors to induce loops of electric current that extend towards a portion of the tank corresponding to the first position on the map; detecting, by the inspection device, values corresponding to the induced loops of electric current at the portion of the tank corresponding to the first position on the map; providing, by the inspection device to the control unit, data comprising the detected values; determining, by the control unit, a quality metric at the portion of the tank corresponding to the first position of the vehicle on the map, and storing, in a memory of the vehicle, the quality metric; and moving, by the propeller of the vehicle responsive to a second command from the control unit, the vehicle through the flammable fluid in the tank towards a second position on the map.

[0005] At least one embodiment is directed to a vehicle to inspect a tank containing a flammable fluid. The vehicle can include a propeller, a battery, a control unit, an inspection device, and a ranging device. The battery can provide power to the propeller, the control unit, the inspection device, and the ranging device. The control unit can generate a map of the tank based on data received from the ranging device. The ranging device can include an acoustic sensor or electromagnetic radiation sensor capable of providing a measurement of the distance between the robot and the environment (e.g., tank shell and obstacles such as pipes or roof

support columns). The control unit can determine a first position of the vehicle on the map of the tank. The propeller, which can be electrically connected to the battery, can move the vehicle through the flammable fluid in the tank. The inspection device, which can be electrically connected to the battery, can determine a quality metric of a portion of the tank. The control unit can be electrically connected to the battery, the ranging device, the propeller and the inspection device. The control unit can cause the propeller to move the vehicle from the first position to a second position within the tank. The control unit can determine, via the inspection device, the quality metric for the portion of the tank at the second position within the tank. The control unit can store, in a data structure in memory of the vehicle, the quality metric corresponding to the second position within the tank.

[0006] The control unit of the vehicle can execute a diagnostic program prior to causing the propeller to move the vehicle. The control unit of the vehicle can be configured to determine, based on results of a diagnostic program, to initiate a tank inspection process, and provide, based on the tank inspection process, a command to cause the propeller to move the vehicle from the first position to the second position within the tank. The control unit of the vehicle can be configured to disable, based on a diagnostic program, the propeller to prevent the propeller from moving the vehicle from the second position. The control unit of the vehicle can be further configured to execute a diagnostic program prior to causing the propeller to move the vehicle, and set a speed of the propeller based on a result of the diagnostic program.

[0007] The control unit of the vehicle can further be configured to cause the propeller to move the vehicle to a plurality of portions of the tank, generate a map of the tank based on traversing a plurality of portions of the tank, and detect an exit condition based on the generated map. The control unit of the vehicle can be further configured to adjust a speed of the propeller based on a current location of the vehicle on the map and detect the exit condition based on an amount of power available in the battery. A plurality of propellers of the vehicle can be configured to move the vehicle in one or more directions. The propeller of the vehicle can be one of a controllable-pitch propeller, skewback propeller, modular propeller, or Voith Schneider propeller. The quality metric of the vehicle can indicate a thickness of the portion of the tank at the second position within the tank.

[0008] At least one embodiment is directed to a method of inspecting a tank containing a flammable fluid. The method can be performed by a vehicle having one or more processors and memory. The method can include lowering, via a cable, the vehicle into the tank containing the flammable fluid, wherein the vehicle can comprise a propeller, a battery, a control unit, an inspection device, and a ranging device. The method can include removing, subsequent to deploying the vehicle, the cable from the tank. The method can include moving, by the propeller, the vehicle through the flammable fluid in the tank. The method can include generating, by the control unit based on data received from the ranging device, a map of the tank. The method can include determining, by the control unit, a first position of the vehicle on the map of the tank. The method can include causing, by the control unit of the vehicle, the propeller to move from the first position to a second position within the tank. The method can include determining, via the inspection device, a quality metric for a portion of the tank corresponding to the second position on the map. The method can include storing, in a data

structure in memory of the vehicle, the quality metric corresponding to the second position within the tank.

[0009] The method can include executing, by the control unit, a diagnostic program prior to causing the propeller to move the vehicle. The method can include determining, by the control unit based on results of a diagnostic program, to initiate a tank inspection process, and providing, by the control unit based on the tank inspection process, a command to cause the propeller to move the vehicle from the first position to the second position within the tank. The method can include disabling, by the control unit based on a diagnostic program, the propeller to prevent the propeller from moving the vehicle from the second position. The method can include executing, by the control unit, a diagnostic program prior to causing the propeller to move the vehicle, and setting, by the control unit, a speed of the propeller based on a result of the diagnostic program.

[0010] The method can include causing, by the control unit, the propeller to move the vehicle to a plurality of portions of the tank, generating, by the control unit, a map of the tank based on traversing a plurality of portions of the tank, and detecting, by the control unit, an exit condition based on the generated map. The method can include adjusting, by the control unit, a speed of the propeller based on a current location of the vehicle on the map. The method can include detecting, by the control unit, the exit condition based on an amount of power available in the battery. The method can include moving, by a plurality of propellers, the vehicle in one or more directions. The propeller of the method can be one of a controllable-pitch propeller, skewback propeller, modular propeller, or Voith Schneider propeller. The quality metric of the method can indicate a thickness of the portion of the tank at the second position within the tank.

[0011] At least one embodiment is directed to a system to inspect a tank containing a flammable fluid. The system can include a battery, a pressure switch, a control unit, a propeller, an inspection device having one or more conductors, and a ranging device. The inspection device can be electrically connected to the control unit and the battery. The inspection device can receive, from the control unit responsive to identifying a first position of the vehicle on a map of the tank based on data from the ranging device, a command to initiate inspection at the first position on the map. The inspection device can change, responsive to the command to initiate inspection, a magnetic field in the one or more conductors to induce loops of electric

current that extend towards a portion of the tank corresponding to the first position on the map. The inspection device can detect values

corresponding to the induced loops of electric current at the portion of the tank corresponding to the first position on the map. The inspection device can provide, to the control unit, data comprising the detected values to cause the control unit to determine a quality metric at the portion of the tank corresponding to the first position of the vehicle on the map, and store, in memory of the vehicle, the quality metric.

[0012] The inspection device can generate pulsed eddy currents to determine the quality metric. The inspection device can include a plurality of conductors arranged in an array to generate array eddy currents to determine the quality metric at a portion of the tank corresponding to a second position of the vehicle on the map. The inspection device can include an ultrasonic array or ultrasonic phased array system to determine a second quality metric at the portion of the tank corresponding to the first position of the vehicle on the map.

[0013] The inspection device can include at least two different types of sensors. The inspection device can obtain measurements from the at least two different types of sensors to generate the quality metric at the portion of the tank corresponding to the first position of the vehicle on the map. The quality metric can indicate a thickness of the portion of the tank corresponding to the first position of the vehicle on the map. The quality metric can indicate a predictive corrosion metric based on a plurality of tank inspection performed by the vehicle during a time interval. The inspection device can selects, based on a condition associated with the portion of the tank corresponding to the first position of the vehicle on the map, one of the at least two different types of sensors to inspect the portion of the tank.

[0014] The system can include a model generator that generates a risk-based inspection model based on a time-series of quality metrics determined based on the loops of electric current provided by the inspection device that extend towards the portion of the tank. The model generator can aggregate historical quality metrics obtained from a plurality of tank inspections to forecast a level of thickness of the tank based on the quality metric.

[0015] The ranging device can detect acoustic waves reflected off one or more portions of the tank, and the control unit generates the map of the tank based on the detected acoustic waves.

[0016] At least one embodiment is directed to a method of inspecting a tank containing a flammable fluid. The method can include lowering, via a cable, a vehicle into the tank containing the flammable fluid. The vehicle can include a battery, a control unit, an inspection

method can include aggregating historical quality metrics obtained from a plurality of tank inspections. The method can include forecasting, using the aggregated historical quality metrics, a level of thickness of the tank based on the quality metric.

[0022] The method can include receiving acoustic waves reflected off one or more portions of the tank. The method can include generating the map of the tank based on the acoustic waves.

[0023] At least one embodiment is directed to a vehicle to inspect a tank containing a flammable fluid. The vehicle can include a propeller, a latch mechanism, a pressure switch, and an inspection device. The vehicle can include a control unit in communication with the propeller, the latch mechanism, the pressure switch, and the inspection device. The control unit can receive an indication from the pressure switch to power on. The control unit can receive the indication responsive to the pressure switch detecting an ambient pressure greater than a minimum threshold. The control unit can receive, from the latch mechanism, an indication of a state of the latch mechanism. The control unit can determine, based on the state of the latch mechanism, that the cable used to lower the vehicle into the tank containing the flammable fluid is detached from the vehicle. The control unit can command, responsive to the determination that the cable is detached from the vehicle, the propeller to move the vehicle through the flammable fluid. The control unit can determine, via the inspection device and subsequent to generation of a portion of a map, a quality metric of a portion of the tank.

[0024] The pressure switch can detect that the vehicle is submerged by a threshold depth in the flammable fluid. The pressure switch can provide, responsive to detection of the threshold depth, an indication to power on the control unit of the vehicle. The vehicle can be powered off as it is lowered through a vapor layer in the tank above the flammable fluid.

[0025] The latch mechanism can disengage the cable used to lower the vehicle into the flammable fluid in the tank. The latch mechanism can couple the cable to the vehicle to lower the vehicle into the flammable fluid in the tank. The vehicle can include an actuator that locks or unlocks the latch mechanism. The control unit can cause the actuator to unlock the latch

mechanism to disengage the cable subsequent to the vehicle lowered into the flammable fluid in the tank.

[0026] The control unit can detect an exit condition in a tank inspection process. The control unit can cause the latch mechanism to re-engage the cable to couple to the cable to the vehicle. The cable can be a passive rope, such as a passive metal rope.

[0027] The control unit can execute a diagnostic program to detect a state of the cable. The control unit can generate, based on the state of the cable, a command to control at least one of the propeller or the latch mechanism coupling the cable to the vehicle.

[0028] The sensor can determine that the vehicle is in contact with the floor of the tank. The control unit can detect, via the sensor, that the vehicle is in contact with the tank floor. The control unit can command the latch mechanism to decouple the cable from the vehicle in the flammable fluid. The control unit can command the propeller to move the vehicle responsive to the second state of the latch mechanism.

[0029] The control unit can receive, from a remote computing device, an indication that the cable is decoupled from the vehicle in the flammable fluid. The control unit can receive, from a remote computing device, an indication to perform a tank inspection process comprising causing the propeller to move the vehicle to one or more positions in the tank, and determine one or more quality metrics.

[0030] At least one embodiment is directed to a method of inspecting a tank containing a flammable fluid. The method can include lowering, via a cable, a vehicle into the tank containing the flammable fluid. The vehicle can include a control unit, a propeller, a pressure switch, a latch mechanism, and an inspection device. The method can include the control unit receiving, from the pressure switch, an indication to power on. The method can include removing, subsequent to deploying the vehicle, the cable from the tank. The method can include the control unit receiving, from the latch mechanism, an indication of a state of the latch mechanism. The method can include the control unit determining, based on the state of the latch mechanism, that the cable used to lower the vehicle into the tank containing the flammable fluid is detached from the vehicle. The method can include the control unit commanding, responsive to the determination that the cable is detached from the vehicle, the propeller to move the vehicle through the flammable fluid. The method can include the control

indication to perform a tank inspection process comprising causing the propeller to move the vehicle to one or more positions in the tank, and determine one or more quality metrics.

[0037] At least one embodiment is directed to a method of inspecting a tank containing a flammable fluid. The method can include opening a lid of a tank containing the flammable fluid. The method can include connecting a cable to a vehicle. The vehicle can include a battery and a control unit. The method can include lowering, via the cable and through an opening of the tank, the vehicle through a vapor barrier within the tank and on top of the flammable fluid. The method can include disengaging the cable from the vehicle subsequent to the vehicle contacting the floor of the tank. The method can include removing the cable from the tank. The method can include closing the lid of the tank to seal the vehicle in the tank. The method can include performing, via the control unit of the vehicle, a tank inspection process under battery power. The tank inspection process can include generating a map of the tank and determining a quality metric for a portion of the tank corresponding to a location on the generated map.

[0038] The method can include initializing, in memory of the vehicle, a map data structure for the tank. The method can include storing, in the map data structure, the map.

[0039] The method can include determining, by the control unit upon being lowered in the tank, to generate the map for the tank. The method can include instructing, by the control unit, a ranging device of the vehicle to generate the map for the tank.

[0040] The method can include establishing a predetermined duration for the tank inspection process. The method can include storing the predetermined duration in a configuration file in memory of the vehicle. The method can include initiating, by the vehicle responsive to being sealed in the tank and beginning the tank inspection process, a timer based on the predetermined duration. The method can include terminating the tank inspection process responsive to expiration of the timer.

[0041] The method can include identifying, by the control unit, an uninspected portion of the tank based on the generated map. The method can include causing, by the control unit, a propeller of the vehicle to move the vehicle towards the identified uninspected portion of the tank.

[0042] The method can include identifying, by the control unit, an absence of any uninspected portions of the floor of the tank based on the generated map. The method can

include providing, responsive to identifying the absence, an indication that the tank inspection process is complete. The indication that the tank inspection process is complete can include a wireless signal or acoustic signal.

[0043] The method can include unreeling, by a winch located external to the tank, the cable to lower the vehicle into the tank. The method can include reeling, by the winch, the cable subsequent to disengaging the cable from the vehicle to remove the cable from within the tank. The method can include unreeling, upon completion of the tank inspection process comprising generating the map of the tank and storing a plurality of indications of the quality metric for the at least one portion of the tank, the cable into the tank. The method can include re-engaging the cable with the vehicle. The method can include reeling the cable re-engaged with the vehicle to remove the vehicle from within the tank.

[0044] At least one embodiment is directed to a system of inspecting a tank containing a flammable fluid. The system can include a vehicle comprising a battery and a control unit. The system can include a cable connected to the vehicle. The system can include a winch located external to a tank lowering, through an opening of the tank, the vehicle through a vapor barrier within the tank and on top of a flammable fluid contained in the tank. The vehicle can disengage from the cable subsequent to the vehicle contacting the floor of the tank. The winch can remove the cable from the tank. The lid of the tank is closed to seal the vehicle in the tank subsequent to removal of the cable from the tank. The control unit of the vehicle can perform a tank inspection process under battery power, the tank inspection process comprising generating a map of the tank and determining a quality metric for a portion of the tank corresponding to a location on the generated map.

[0045] The control unit can initialize, in memory of the vehicle, a map data structure for the tank, and store the map in the map data structure. The control unit can determine, upon the vehicle contacting the floor of the tank, to generate the map for the tank. The control unit can instruct a ranging device of the vehicle to collect data used to generate the map for the tank.

[0046] The control unit can retrieve, from a configuration file stored in memory of the vehicle, a predetermined duration for the tank inspection process. The control unit can initiate, subsequent to being sealed in the tank and beginning the tank inspection process, a timer based on the predetermined duration.

[0047] The control unit can terminate the tank inspection process responsive to expiration

What is claimed is:

1. A system to inspect a tank containing a flammable fluid, comprising:

a vehicle comprising a battery, a pressure switch, a control unit, a propeller, an inspection device having one or more conductors, and a ranging device;

the pressure switch closing an electronic circuit between the control unit and the battery responsive to the pressure switch detecting an ambient pressure greater than a minimum threshold;

the battery of the vehicle providing, responsive to closing of the electronic circuit by the pressure switch, power to the control unit, the propeller, the inspection device, and the ranging device;

the control unit generating, based on data received from the ranging device, a map of the tank, and determining a first position of the vehicle on the map of the tank;

the inspection device receiving, from the control unit responsive to identifying the first position of the vehicle on the map of the tank based on data from the ranging device, a command to initiate inspection at the first position on the map;

the inspection device changing, responsive to the command to initiate inspection, a magnetic field in the one or more conductors to induce loops of electric current that extend towards a portion of the tank corresponding to the first position on the map;

the inspection device detecting values corresponding to the induced loops of electric current at the portion of the tank corresponding to the first position on the map;

the inspection device providing, to the control unit, data comprising the detected values;

the control unit determining a quality metric at the portion of the tank corresponding to the first position of the vehicle on the map, and storing, in a memory of the vehicle, the quality metric; and

the propeller of the vehicle moving, responsive to a second command from the control unit, the vehicle through the flammable fluid in the tank towards a second position on the map.

2. The system of claim 1, comprising:

a latch mechanism of the vehicle configured to couple the vehicle to a passive metal rope used to lower the vehicle into the flammable fluid in the tank;

a sensor of the vehicle configured to determine that the vehicle is in contact with the floor of the tank; and

the latch mechanism decoupling the passive metal rope from the vehicle responsive to

the sensor indicating that the vehicle is in contact with the floor of the tank.

3. The system of claim 1, wherein the control unit is further configured to:

determine, based on results of a diagnostic program, to initiate a tank inspection process; and

provide, based on the tank inspection process, the second command to cause the propeller to move the vehicle from the first position to the second position within the tank.

4. The system of claim 1, wherein the ranging device detects acoustic waves reflected off one or more portions of the tank, and the control unit generates the map of the tank based on the detected acoustic waves.

5. The system of claim 1, wherein the inspection device comprises an ultrasonic phased array system.

6. The system of claim 1, wherein the inspection device comprises at least two different types of sensors, and selects, based on a condition associated with the portion of the tank corresponding to the first position of the vehicle on the map, one of the at least two different types of sensors to inspect the portion of the tank.

7. The system of claim 1, wherein the inspection device comprises at least two different types of sensors, and is configured to:

select, based on a condition associated with the portion of the tank corresponding to the first position of the vehicle on the map, one of the at least two different types of sensors to inspect the portion of the tank; and

select, based on a condition associated with a portion of the tank corresponding to the second position of the vehicle on the map, the other of the at least two different types of sensors to inspect the portion of the tank corresponding to the second position.

8. The system of claim 1, wherein the quality metric indicates a predictive corrosion metric based on a plurality of tank inspections performed by the vehicle during a time interval.

9. The system of claim 1, wherein the control unit is configured to:

identify an uninspected portion of the tank based on the map; and

cause the propeller of the vehicle to move the vehicle towards the identified uninspected portion of the tank.

10. The system of claim 1, wherein the control unit is configured to:

identify an absence of any uninspected portions of a floor of the tank based on the map; and

provide, responsive to identification of the absence, an indication that a tank inspection process is complete.

11. A method of inspecting a tank containing a flammable fluid, comprising:

providing a vehicle comprising a battery, a pressure switch, a control unit, a propeller, an inspection device having one or more conductors, and a ranging device;

closing, by the pressure switch, an electronic circuit between the control unit and the battery responsive to the pressure switch detecting an ambient pressure greater than a minimum threshold;

providing, by the battery of the vehicle responsive to closing of the electronic circuit by the pressure switch, power to the control unit, the propeller, the inspection device, and the ranging device;

generating, by the control unit based on data received from the ranging device, a map of the tank, and determining a first position of the vehicle on the map of the tank;

receiving, by the inspection device from the control unit responsive to identifying the first position of the vehicle on the map of the tank based on data from the ranging device, a command to initiate inspection at the first position on the map;

changing, by the inspection device responsive to the command to initiate inspection, a magnetic field in the one or more conductors to induce loops of electric current that extend towards a portion of the tank corresponding to the first position on the map;

detecting, by the inspection device, values corresponding to the induced loops of electric current at the portion of the tank corresponding to the first position on the map;

providing, by the inspection device to the control unit, data comprising the detected values;

determining, by the control unit, a quality metric at the portion of the tank corresponding to the first position of the vehicle on the map, and storing, in a memory of the vehicle, the quality metric; and

moving, by the propeller of the vehicle responsive to a second command from the

control unit, the vehicle through the flammable fluid in the tank towards a second position on the map.

12. The method of claim 11, comprising:

coupling, via a latch mechanism of the vehicle, the vehicle to a passive metal rope used to lower the vehicle into the flammable fluid in the tank;

determining, by a sensor of the vehicle, that the vehicle is in contact with the floor of the tank; and

decoupling, via the latch mechanism, the passive metal rope from the vehicle responsive to the sensor indicating that the vehicle is in contact with the floor of the tank.

13. The method of claim 11, comprising:

determining, by the control unit based on results of a diagnostic program, to initiate a tank inspection process; and

providing, by the control unit based on the tank inspection process, the second command to cause the propeller to move the vehicle from the first position to the second position within the tank.

14. The method of claim 11, comprising:

detecting, by the ranging device, acoustic waves reflected off one or more portions of the tank; and

generating, by the control unit, the map of the tank based on the detected acoustic waves.

15. The method of claim 11, wherein the inspection device comprises an ultrasonic phased array system.

16. The method of claim 11, wherein the inspection device comprises at least two different types of sensors, comprising:

selecting, based on a condition associated with the portion of the tank corresponding to the first position of the vehicle on the map, one of the at least two different types of sensors to inspect the portion of the tank.

17. The method of claim 11, wherein the inspection device comprises at least two different

types of sensors, comprising:

selecting, based on a condition associated with the portion of the tank corresponding to the first position of the vehicle on the map, one of the at least two different types of sensors to inspect the portion of the tank; and

selecting, based on a condition associated with a portion of the tank corresponding to the second position of the vehicle on the map, the other of the at least two different types of sensors to inspect the portion of the tank corresponding to the second position.

18. The method of claim 11, wherein the quality metric indicates a predictive corrosion metric based on a plurality of tank inspections performed by the vehicle during a time interval.

19. The method of claim 11, comprising:

identifying, by the control unit, an uninspected portion of the tank based on the map; and

moving, by propeller, the vehicle towards the identified uninspected portion of the tank.

20. The method of claim 11, comprising:

identifying, by the control unit, an absence of any uninspected portions of a floor of the tank based on the map; and

providing, by the control unit responsive to identification of the absence, an indication that a tank inspection process is complete.