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(71) Applicant: NORTHESTERN UNIVERSITY [US/US];
360 Huntington Avenue, Boston, MA 02115 (US).

(72) Inventor: EDSON, Ethan, C.; 32 Pontiac Street, Boston,
MA 02120 (US).

(74) Agent: BONHAM, David; Kasvinsky Daisak Bluni PLLC,
50 Doaks Lane, Marblehead, MA 01945 (US).

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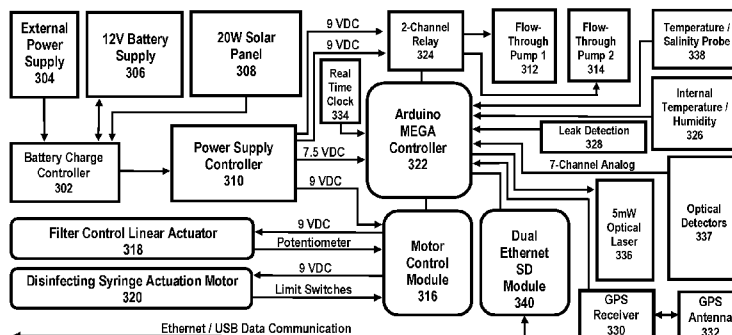


FIG. 3

(57) Abstract: The present disclosure pertains to devices, systems and methods useful for sampling and capturing particles in fluids.

PARTICLE CAPTURE AND SAMPLING

BACKGROUND OF THE INVENTION

[0001] The growing amount of marine plastic debris in the oceans is a result of exponentially rising rates of industrial plastic production and the slow degradation rate of plastics in the environment. Unlike many other substances, plastics can take hundreds of years to break down and have only been produced on an industrial scale for about 75 years. Microplastics are currently defined as pieces of plastic that are 5mm or smaller in diameter and are distinguished by their original use and their size. Primary microplastics begin their life cycle as small plastic particles and are found in the form of pre-production resin pellets used for plastic injection molding, exfoliants, in cosmetic products, industrial abrasives, and synthetic fibers from textiles to name a few. These small and lightweight plastics are easily spilled, blown away, and transported over great distances in river systems and in the ocean. Secondary microplastics begin their life cycle as larger plastic products (e.g. plastic containers, consumer products, and fishing gear) and are broken down into small fragments from ultraviolet radiation, wave action, collision with coastal landforms, and various other ways. Although many plastics sink into aquatic and marine sediments, certain buoyant plastic types (e.g. low-density polyethylene and polypropylene) tend to float on the surface and persist in the environment. These microplastics are carried by ocean currents and tend to accumulate in any of the five major ocean gyres that act as large-scale whirlpools for plastic pollution. However, the exact pathways to these zones and the persistence of microplastics once they reach the ocean are largely unknown.

[0002] The size of these microplastics is of great concern because a wide range of marine organisms can potentially digest them, resulting in physiological problems and/or bioaccumulation of pollutants, among other effects. Other studies have shown that

microplastics are creating a novel unique ecological habitat, called the "Plastisphere", for opportunistic pathogens and distinct bacterial communities in the open ocean.

[0003] Presently, scientists have a difficult time estimating the vast amount of plastic pollution entering the ocean. Without a good understanding of dispersal ability and concentration of microplastics, it is hard to make correlations to other parameters such as fish and marine mammal mortality, transportation of organic pollutants, and general ecosystem and human health in areas impacted by microplastics. Current marine microplastic sampling methods involve towing a net behind a research vessel at sea, analyzing the microplastic particles that are collected, and calculating plastic concentration based on the volume of water that was sieved through the net during the sample time. Additional information regarding microplastic particles and their effects can found in E. Edson and Mark R. Patterson, "MANTARAY: A Novel Autonomous Sampling Instrument for In-situ Measurements of Environmental Microplastic Particle Concentrations," presented at Oceans '15 MTS/IEEE Washington Advance Technical Program, Washington, D.C., October 21, 2015.

SUMMARY

[0004] In the present disclosure, devices, systems and methods useful for sampling and capturing particles in fluids are provided.

[0005] In particular embodiments, methods and systems are provided which pertain to the automation of microplastic particle sampling, with the potential to provide autonomous sampling for days, weeks or even months at sea without the need for human intervention and costly time on research vessels.

[0006] In certain aspects, the present disclosure pertains to automated systems for sampling particles in a water sample from a body of water over a sampling period. These systems may

comprise: (a) a power supply; (b) a fluid intake path configured to receive a stream of sample water from the body of water as a result of an action of one or more pumps; (c) a detection system configured to detect particles in the stream of sample water; (d) a first fluid return path that is configured to receive and return the sample water to the body of water; (e) a second fluid return path comprising a first particle filter that is configured to receive the stream of sample water, pass the stream of sample water through the first particle filter, and return the sample water to the body of water; (f) a controller that is configured to (i) direct the stream of sample water along the first fluid return path until one or more particles are detected, (ii) in the event of detection of one or more particles by the detection system, direct the stream of sample water along the second fluid return path for a predetermined period, (iii) after the predetermined period, redirect the stream of sample water along the first fluid return path.

[0007] In certain embodiments, which can be employed in conjunction with the above aspects, the predetermined period may be a period that sufficient for the particles to reach the first particle filter.

[0008] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the system may comprise (a) a first pump that is configured to be activated by the controller and pump the stream of sample water along the first fluid path and (b) a second pump that is that is configured to be activated by the controller and pump the stream of sample water along the second fluid path.

[0009] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the system may comprise a valve having a first position whereby the stream is directed along the first fluid path and a second position whereby the stream is directed along the second fluid path, and the controller may be configured to switch the valve between the first and second position.

[0010] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the system may comprise: additional particle filters and an actuator that is configured to remove the first particle filter from the second fluid return path and place one of the additional particle filters in the second fluid return path. For example, the first particle filter and the additional particle filters may be organized in a stack and are spaced apart from one another. Moreover, the stack may be positioned in a hollow column that comprises (a) a fluid inlet and (b) a fluid outlet positioned at a different location along a length of the column than that of the fluid inlet, and the actuator may be a linear actuator that is configured move the stack of filters to different discrete positions along the length of the column such that fluid flowing into the column through the fluid inlet is filtered by a different filter at each discrete position.

[0011] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the system for detecting particles may comprise an optical sensor.

[0012] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the system may be configured to detect particles that are larger than 0.5 mm diameter and smaller than 8 mm in diameter.

[0013] In other aspects, the present disclosure pertains to methods for sampling particles in a water sample from a body of water over a sampling period using an automated system. The methods may comprise: (a) drawing a stream of sample water from a body of water and passing the stream of sample water through a particle detector that analyzes the stream of sample water for the presence or absence of particles; (b) directing the stream of sample water along a first fluid return path through which the stream of sample water flows and is returned to the body of water until such time that particles are detected; (c) in the event particles are detected, directing the stream of sample water for a predetermined period along a

second fluid return path comprising a first particle filter through which sample water flows after which it is returned to the body of water; (d) after the predetermined time period has elapsed, redirecting the stream of sample water along the first fluid return path; and (e) performing steps (b)-(d) until such time that the sampling period is complete, at which point the system ceases drawing a stream of sample water from the body of water.

[0014] In certain embodiments, the method may further comprise removing the first particle filter from the second fluid return path and placing a second particle filter in the second fluid return path after the sampling period is complete and repeating steps (a)-(e), thereby sampling additional particles in an additional water sample over an additional sampling period.

[0015] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the first particle filter may be removed from the second fluid return path and the second particle filter may be placed in the second fluid return path using a linear actuator.

[0016] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the additional sampling period may be begun after waiting a period of time.

[0017] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the additional sampling period may be begun after passing a disinfectant through the particle analyzer to prevent biofouling.

[0018] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the method may further comprise obtaining and storing a GPS reading at each sampling period and, optionally obtaining and storing temperature and salinity data.

[0019] In still other aspects, systems for collecting multiple filtrate samples are provided. The systems may comprise: (a) a stack of filters that comprises a first filter, a second filter adjacent the first filter, a first space on a first side of the first filter, a second space between the first and second filters on a second side of the first filter and on a first side of the second filter, and a third space on the second side of the second filter; (b) a hollow column, a fluid inlet and a fluid outlet positioned at a different longitudinal locations along a length of the column, the stack of filters positioned within the column such that the fluid inlet is adjacent the first space and the fluid outlet is positioned downstream of the second side of the first filter and such that fluid flowing into the column through the fluid inlet passes into the first space and through the first filter before exiting the fluid outlet; (c) a linear actuator configured move the stack of filters along the column length such that the fluid inlet is adjacent the second space and such that fluid flowing into the column through the fluid inlet passes into the second space and through the second filter before exiting the fluid outlet.

[0020] In certain embodiments, the stack of filters may further comprises a third filter, wherein the third filter is positioned adjacent the second filter with the third space positioned between the second and third filters on a first side of the third filter, and a fourth space on a second side of the third filter. Moreover, the linear actuator may be configured further move the stack of filters along the column length such that the fluid inlet is adjacent the third space and such that fluid flowing into the column through the fluid inlet passes into the third space and through the third filter before exiting the fluid outlet.

[0021] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the column may be in the form of a hollow cylinder having a cylinder lumen, wherein the first and second filters are in the shape of discs that are parallel to one another and extend across the interior of the hollow cylinder.

[0022] In certain embodiments, which can be employed in conjunction with any of the above aspects and embodiments, the first and second filters may be mounted at spaced apart positions along a length of a rod that is mechanically coupled to linear actuator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 is a schematic perspective view of an instrument, in accordance with an embodiment of the present disclosure.

[0024] FIG. 2 is a fluidics schematic block diagram, in accordance with an embodiment of the present disclosure.

[0025] FIG. 3 is an electrical schematic block diagram, in accordance with an embodiment of the present disclosure.

[0026] FIG. 4 is a general software schematic block diagram, in accordance with an embodiment of the present disclosure.

[0027] FIG. 5 is a cutoff software schematic block diagram, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0028] A more complete understanding of the present disclosure is available by reference to the following detailed description of various specific aspects and embodiments of the disclosure. The detailed description which follows is intended to illustrate but not limit the disclosure.

[0029] The present disclosure includes a detailed description of a fully autonomous sensor, also referred to herein as the "instrument", for capturing and archiving plastic particles. In the

particular embodiment described herein, a fully autonomous sensor is described, which uses a flow-through pump and filtration system to collect and archive multiple discrete samples of customizable volume and can record GPS location, temperature, and salinity data at the point of sampling.

[0030] Plastic particles that may be captured in accordance with the present disclosure may range, for example, from 0.5 mm to 8 mm in diameter, among other values, more typically from 0.5 mm to 4 mm.

[0031] From a mechanical design perspective, and with reference to FIG. 1, a particular embodiment of an instrument 100 in accordance with the present disclosure includes a pressure housing 110 that includes an 8-inch PVC pipe with a bottom cap 110c and a top cleanout adapter 114. The housing 110 floats upright at the surface of the water column, typically with ballast weight at the bottom of the housing and a buoy 112 at the top to allow vertical orientation in the water. Batteries that are used during deployment may be factored in as partial ballast weight to achieve proper orientation. An intake for the instrument rests 30cm below the water line to ensure that the internal pump is not drawing air into the system, while still sampling at a depth where surface particles are actively mixing and residing. A small grate around an intake for the instrument ensures that only small particles, and not larger biotic matter, enter the flow-through system for analysis. Protruding from the top of the pressure housing buoy is a small PVC tube 116 that extends a GPS antenna 118 vertically into the air for increased signal reliability in rougher ocean conditions. In total, the entire drifter housing stands 3 m tall. Canvas wings 120 were attached to the housing 110 side to maximize the dispersal ability of the instrument by catching ocean currents. These canvas wings allow the instrument to move over large spatial distances during a given sample mission. As a drifting instrument, the instrument may be able to better track and follow typical dispersal patterns of microplastics and potentially discover accumulation zones. In order to secure the instrument

inside the pressure housing 110, the instrument may be mounted to the underside of an 8-inch PVC cleanout plug, which securely screws into an 8-inch female cleanout adapter at the top of the pressure housing 110. The internal system components may be built around multiple threaded rods that may be secured to transverse platforms within the housing 110. All components used for sampling and processing may be mounted directly to such threaded rods, or mounted to one of the platforms spanning the length of the instrument.

[0032] The instrument circulates water through the pressure housing and exhausts it back into the environment while constantly analyzing the flow through water content for particulate. In the particular embodiment describe here, there are two possible channels that water can be circulated through during the analysis process, depending on whether or not a particle is detected by the optical detector.

[0033] With reference now to the fluidics schematic block diagram illustrated in FIG. 2, using a primary 12V circulation pump 202, water is drawn in through intake 204 and into an optical detection module 206. If no particles are present, water continues through a T-flow splitter 208, a backup filter 210, a primary pump 202, a check valve 212 (provided so there is no backflow between systems), and out the exhaust 214. This system may constantly run during a sampling interval until a particle passes through and is detected by the optical detection module 206. If a particle enters the intake 204 and is detected by the optical detection module 206, the primary pump 202 is turned off and a secondary pump 216 is turned on. This diverts the flow of sample water through a second outlet of the T-flow splitter 208 and into a sample filter column 218, where the particle is trapped on one of a number of filters, for example, typically ranging from 2 up to 100 filters or more (28 filters are employed in this particular embodiment). Typical filters have a pore size of about 0.5 mm, among other values. The filtered water then moves its way through the filter column 218, and is pumped out of the exhaust 214 by a secondary pump 216. After a short amount of time, the secondary pump 216 turns off, the

primary pump 202 turns on, and analysis of the flow-through water for particles begins again. The backup filter 210 in the primary system is put in place in the case that the optical detector fails to recognize a particle in the system and the particle makes it through the primary system. Typical backup filters may range from 0.5 mm to 1 mm in pore size, among other values. This prevents particles from clogging and/or damaging the primary pump 202 in the case of a failure by the optical detector 206. Between each sample, a small volume (e.g., 1-2ml) of disinfectant may be pumped by a disinfecting syringe 220 upstream of the optical detection module 206, where it is circulated through the optical detection module 206 to prevent biofouling and clouding of the optical windows in the instrument by algal growth.

[0034] With reference now to the electrical schematic block diagram of FIG. 3, power for the instrument may come from three potential sources and is managed by a battery charge controller 302. An external power supply 304 can be connected for benchtop testing, or for deployments that have access to an external power supply. For deployments without the possibility of solar energy, a battery supply 306, for example, containing one or more primary alkaline battery packs, can be wired in parallel and attached to a port of the external power supply 304. For deployments that offer the opportunity for solar energy harvesting, the battery supply 306 may contain secondary batteries, for example, secondary lead-acid batteries in parallel, which can be attached to the battery input of the battery charge controller 302, and a solar panel 308 (e.g., a 20 W solar panel) can be connected to the top of the instrument. The battery charge controller 302 may ensure that the battery supply 306 is not overcharged, efficiently diverts solar power to the instrument when available, and moderates flow of power to prevent backflow of energy to the solar panels at night. The output of the battery charge controller 302 is connected to a power supply controller 310, which in this instance takes a 10-13VDC input voltage and supplies several 9VDC outputs as well as a 7.5VDC output. The 9V

outputs are used to power both of the onboard pumps 312, 314, as well as a motor driver for a linear actuator 318 for filter changing and a motor driver for a syringe motor 320.

[0035] The 7.5V output provides power for a microcontroller 322 (e.g., a 5V open-source Arduino MEGA 2560 microcontroller, available from Arduino, www.arduino.cc) to control onboard processes. Connected to the microcontroller 322 are two control modules: a motor control module 316, which helps to regulate higher voltage motor control, as well as a dual Ethernet SD module 340 for managing Ethernet communications and data transfer to an SD card for data collection. The motor control module 316 receives a 9V input voltage and uses several h-bridges and Pulse Width Modulation (PWM) to control very precisely the direction and speed of the filter control linear actuator 318 and the disinfecting syringe actuation motor 320. The filter control linear actuator 318 has potentiometer feedback that can be read by the microcontroller 322 to determine a precise position of an actuator arm, which corresponds to the filter that is being exposed to the flow through system, as described in more detail below. The syringe actuation motor 320 has limit switches at extremes of an actuation track that prevent overextension of the syringe and stress on the driving motor. Also connected to the microcontroller 322 is a 2-channel relay assembly 324, which acts as a binary switch for the two onboard circulation pumps 312, 314 to allow the movement of water throughout the instrument. These pumps may both be 12V circulation pumps that produce a flow rate around 300 gallons/hr, among other possibilities.

[0036] The microcontroller 322 also has several input sensors that help to dictate onboard operations and monitor for problems during a deployment. Several watchdog sensors are attached to interrupt pins, so that events like a leak in the pressure housing can result in a proper shutdown and archival of data, as described in more detail below. These sensors include an internal humidity and temperature sensor 326, and a standing water leak sensor 328 located at the bottom of the pressure housing. The microcontroller 322 is also connected to a

GPS receiver 330 with GPS antenna 332, as well as a real time clock (RTC) 334, which provide location and time information so the instrument can make informed decisions about sampling intervals, the amount of water that has been filtered by the instrument, and to calculate particle densities over spatial areas. The instrument also has several data collection modules onboard. During a sampling interval, the microcontroller 322 interrogates an optical detector system, which includes a 5mW optical laser 336 and a plurality (e.g., seven, in the present design) individual photoresistors situated across a flow chamber which act as optical detectors 337. Particles flowing through the system can be detected and grouped into a relative size category using this system. In addition, the microcontroller 322 can interrogate a temperature and salinity probe 338 periodically to gather additional environmental data during a longer deployment. The GPS receiver and antenna 330, 332, RTC 334, optical laser 336, temperature/humidity sensor 326, temperature/salinity probe 338, leak sensor 328, and 2-channel relay assembly 324 are all powered at 5VDC by the microcontroller 322.

[0037] With reference now to the schematic diagram of FIG. 4, the software behind the instrument was written in a linear manner that allows for manipulation of the number of samples, the volume per sample, and the overall length of a deployment. After this information is determined, the instrument enters a loop that repeats the same sample procedure periodically for the set volume of water sampled. After mission start 402, the GPS location is measured and recorded 406 to mark the beginning boundary of the sample. This can be of use during a free-drifting deployment, where the instrument may move a certain distance over its sample interval. Next, water temperature 408 and water salinity 410 are recorded, which correspond to the starting GPS point. The optical detection module lasers may be powered up 412 and the primary pump activated 414 to allow them to warm up and stabilize. During this time, background water turbidity may be determined to set a baseline for the optical detector, and flow velocity is allowed to stabilize before actual analysis begins. After a stabilization delay

416, a sample timer is switched on and water volume is monitored 418, based on a known flow rate for the pump and elapsed sampling time. Until it is determined 422 that a target volume of water has been reached, the system will analyze the flow through water 420 for particles and also monitor the volume calculation to ensure the correct amount of water is analyzed. If a particle is detected 424, the microcontroller uses a sizing algorithm that is based on the signal drop of individual photodetectors as a particle breaks the laser path. This sizing algorithm computes a maximum width and rough surface area calculation of the particle and stores this data 426 to a sample specific log file. Once a particle is detected, the primary circulation pump is deactivated 428, and the secondary filtration pump is activated 430, which diverts the particle into the filter column. The secondary pump remains active for a predetermined time 432 (e.g., a 10 second delay), to ensure the particle is captured, at which point the secondary pump is deactivated 434 and the primary pump is reactivated 436. The system returns to active monitoring of the sample water for additional particles and performs a check on the water volume calculation to determine when to stop sampling water. If it is determined 422 that the target volume is reached during the sampling interval, the system breaks out of the analysis loop and proceeds to the sample processing and sample changing section. Powering down during this step involves deactivating the flow through pump 438 and shutting down the optical module laser 440. A second GPS point is recorded 442 to determine the secondary boundary of the individual sample. At this point, the microprocessor motor controller is used to position a new filter into place 444 and archive the sample filter from the current run. This is completed by moving the filter column linear actuator a set distance longitudinally to expose a new filter to the flow through system as discussed below. Each filter has a discrete position that can be decoded by the actuator's potentiometer feedback module, such that the motor controller can very precisely move a new filter into exactly the right position for the next sample. After a new sample filter is moved into place, the onboard disinfecting syringe is actuated to release 1-2ml

of disinfectant 446 into the intake of the system. The primary pump is turned on briefly to move the disinfectant into the system, and a short delay allows the disinfectant to interact with the water and surfaces in the internal plumbing. The primary pump is again briefly activated, exhausting the disinfectant. At this point, all data collected during the sampling period can be written to an SD card 448, including GPS points, water temperature and salinity, particle count and sizing information, time information for the sample, and any error messages. The system will then determine, based on preset information, whether or not the mission is over 450. If the mission is not over, the system will sleep until it is time to collect another sample 404. If the mission is over, the system will shut down into sleep mode 450 and wait for retrieval by the user.

[0038] During the deployment, watchdog sensors may be used to monitor internal pressure housing conditions in order to detect a leak or high humidity. Since these processes are written as program interrupts, they can interrupt the program at any point and shut the instrument down in an effort to save any data and minimize electronic short circuits in the pressure housing. Turning now to FIG. 5, after starting the monitoring system 502, it is determined whether or not the interior humidity reaches a predetermined threshold 504 and also whether or not water is present in the bottom of the housing 506 which would indicate a leak. In the event it is determined that the humidity exceeds the threshold 504 or in the event standing water is detected in the bottom of the pressure housing 506, all data are written to the SD card 508 and the electronics perform a hard shutdown 510, which will prevent power from reaching the onboard components and potentially harming the system. This monitoring system may remain active during the entire deployment.

[0039] As noted above, the microprocessor motor controller may be used to position a new filter into place and archive the sample filter from the current run. This may be completed by moving the filter column a set distance longitudinally to expose a new filter to the flow through

system as discussed below. Each filter has a discrete position that can be decoded by the actuator's potentiometer feedback module, so the motor controller can very precisely move a new filter into exactly the right position for the next sample.

[0040] Turning now to FIG. 6, one embodiment of a filter assembly 600 is shown that includes a stack of filters 610 mounted on a rod 612. The stack of filters 610 is placed in a hollow column 620 which comprises a fluid inlet 622 and a fluid outlet 624, positioned at different longitudinal locations along the column 620. The rod 612 is mechanically connected via an arm 632 to an electric linear actuator 630 which is capable of moving the filter stack 610 longitudinally within the column 620. In the embodiment shown, fluid flows into the column 620 via fluid inlet 622 to a space 625a adjacent a first filter 610a. The water then flows through first filter 610a, allowing the **first** filter 610a to capture particles in the sample water, and continues to flow through the filter stack 610 and out the fluid outlet. When it is desired to change filters, the linear actuator 630 is used to raise the filter stack 610 in the column 620 such that the fluid inlet 622 is positioned adjacent a space 625b between the first filter 610a and a second filter 610b. Sample water then flows through the second filter 610b, allowing the second filter 610b to capture particles in the sample water, after which the filtered sample water continues to flow through the remaining filter stack 610 and out the fluid outlet 624. This process is repeated for each sampling period, with the linear actuator 630 raising the filter stack 610, filter by filter, until the fluid inlet 622 is positioned adjacent a space 625y between a next-to-last filter 610y and a last filter 610z. Sample water then flows through the last filter 610z, allowing the last filter 610z to capture particles in the sample water. As noted above, each filter may have a discrete position that can be decoded by a potentiometer feedback module of the actuator, so the motor controller can very precisely move a new filter into precisely the right position for the next sample.

[0041] It should be noted that, while the fluid inlet 622 and fluid outlet 624 are widely spaced in FIG. 6, all that is required is that the fluid inlet 622 and fluid outlet 624 be separated by an amount sufficient such that water flows across a single filter before exiting. For example, the fluid outlet 624 may be positioned adjacent space 625b in FIG. 6.

[0042] Although various embodiments are specifically illustrated and described herein, it will be appreciated that modifications and variations of the present disclosure are covered by the above teachings and are within the purview of the appended claims without departing from the spirit and intended scope of the disclosure.

CLAIMS:

1. An automated system for sampling particles in a water sample from a body of water over a sampling period, the system comprising:
 - a power supply;
 - a fluid intake path configured to receive a stream of sample water from the body of water as a result of the action of one or more pumps;
 - a detection system configured to detect particles in the said stream of sample water;
 - a first fluid return path that is configured to receive and return the sample water to the body of water;
 - a second fluid return path comprising a first particle filter that is configured to receive the stream of sample water, pass the stream of sample water through the first particle filter, and return the sample water to the body of water; and
 - a controller that is configured to (a) direct the stream of sample water along the first fluid return path until one or more particles are detected, (b) in the event of detection of one or more particles by the detection system, direct the stream of sample water along the second fluid return path for a predetermined period, (c) after said predetermined period, redirect the stream of sample water along the first fluid return path.
2. The automated system of claim 1, wherein the predetermined period is a period that sufficient for the particles to reach the first particle filter.
3. The automated system of claim 1, wherein the system comprises (a) a first pump that is configured to be activated by the controller and pump the stream of sample water along the

first fluid path and (b) a second pump that is that is configured to be activated by the controller and pump the stream of sample water along the second fluid path.

4. The automated system of claim 1, wherein the system comprises a valve having a first position whereby the stream is directed along the first fluid path and a second position whereby the stream is directed along the second fluid path; and wherein the controller is configured to switch the valve between the first and second position.
5. The automated system of claim 1, wherein the system further comprises: additional particle filters; and an actuator that is configured to remove the first particle filter from the second fluid return path and place one of the additional particle filters in the second fluid return path.
6. The automated system of claim 5, wherein the first particle filter and the additional particle filters are organized in a stack and are spaced apart from one another.
7. The automated system of claim 6, wherein the stack is positioned in a hollow column that comprises (a) a fluid inlet and (b) a fluid outlet positioned at a different location along a length of the column than that of the fluid inlet; and wherein the actuator is a linear actuator that is configured move the stack to different discrete positions along the length of the column such that fluid flowing into the column through the fluid inlet is filtered by a different filter at each discrete position.
8. The automated system of claim 1, wherein the system for detecting particles comprises an optical sensor.
9. The automated system of claim 1, wherein the system is configured to detect particles that are larger than 0.5 mm diameter and smaller than 8 mm in diameter.

10. A method for sampling particles in a water sample from a body of water over a sampling period using an automated system, the method comprising:

(a) drawing a stream of sample water from a body of water and passing the stream of sample water through a particle detector that analyzes the stream of sample water for the presence or absence of particles;

(b) directing the stream of sample water along a first fluid return path through which the stream of sample water flows and is returned to the body of water until such time that particles are detected;

(c) in the event particles are detected, directing the stream of sample water for a predetermined period along a second fluid return path comprising a first particle filter through which sample water flows after which it is returned to the body of water;

(d) after the predetermined period has elapsed, redirecting the stream of sample water along the first fluid return path; and

(e) performing steps (b)-(d) until such time that the sampling period is complete, at which point the system ceases drawing a stream of sample water from the body of water.

11. The method of claim 10, further comprising removing the first particle filter from the second fluid return path and placing a second particle filter in the second fluid return path after the sampling period is complete and repeating steps (a)-(e), thereby sampling additional particles in an additional water sample over an additional sampling period.

12. The method of claim 11, wherein the first particle filter is removed from the second fluid return path and the second particle filter is placed in the second fluid return path using a linear actuator.

13. The method of claim 11, wherein the additional sampling period is begun after waiting a period of time.
14. The method of claim 11, wherein the additional sampling period is begun after passing a disinfectant through the particle analyzer to prevent biofouling.
15. The method of claim 11, further comprising obtaining and storing a GPS reading at each sampling period and, optionally obtaining and storing temperature and salinity data.
16. A system for collecting multiple filtrate samples comprising: (a) a stack of filters that comprises a first filter, a second filter adjacent the first filter, a first space on a first side of the first filter, a second space between the first and second filters on a second side of the first filter and on a first side of the second filter, and a third space on the second side of the second filter; (b) a hollow column, a fluid inlet and a fluid outlet positioned at a different longitudinally locations along a length of the column, said stack of filters positioned within said column such that the fluid inlet is adjacent the first space and the fluid outlet is positioned downstream of the second side of the first filter, such that fluid flowing into the column through the fluid inlet passes into the first space and through the first filter before exiting the fluid outlet; and (c) a linear actuator configured move the stack of filters along the column length such that the fluid inlet is adjacent the second space and such that fluid flowing into the column through the fluid inlet passes into the second space and through the second filter before exiting the fluid outlet.
17. The system of claim 16, wherein the stack of filters further comprises a third filter, wherein the third filter is positioned adjacent the second filter with the third space positioned between the second and third filters on a first side of the third filter, and a fourth space on a second side of the third filter; and wherein the linear actuator is configured further move the stack of filters

along the column length such that the fluid inlet is adjacent the third space and such that fluid flowing into the column through the fluid inlet passes into the third space and through the third filter before exiting the fluid outlet.

18. The system of claim 16, wherein the column is in a form of a hollow cylinder having a cylinder lumen, wherein the first and second filters are in the shape of discs that are parallel to one another and extend across the interior of the hollow cylinder.
19. The system of claim 16, wherein the first and second filters are mounted at spaced apart positions along a length of a rod that is mechanically coupled to linear actuator.

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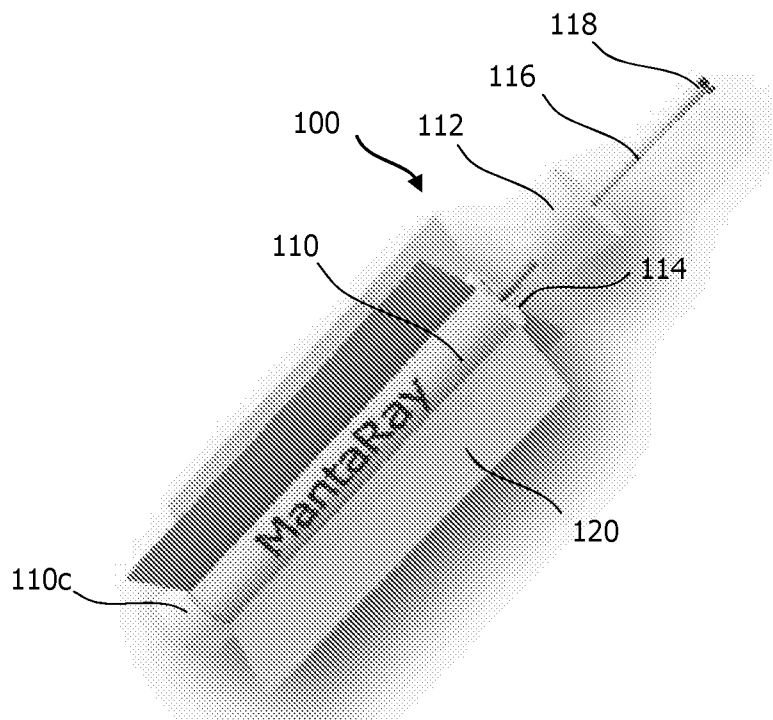


FIG. 1

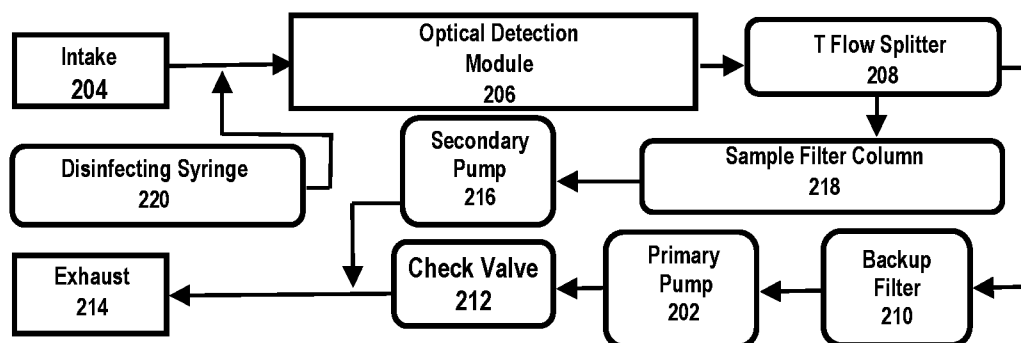


FIG. 2

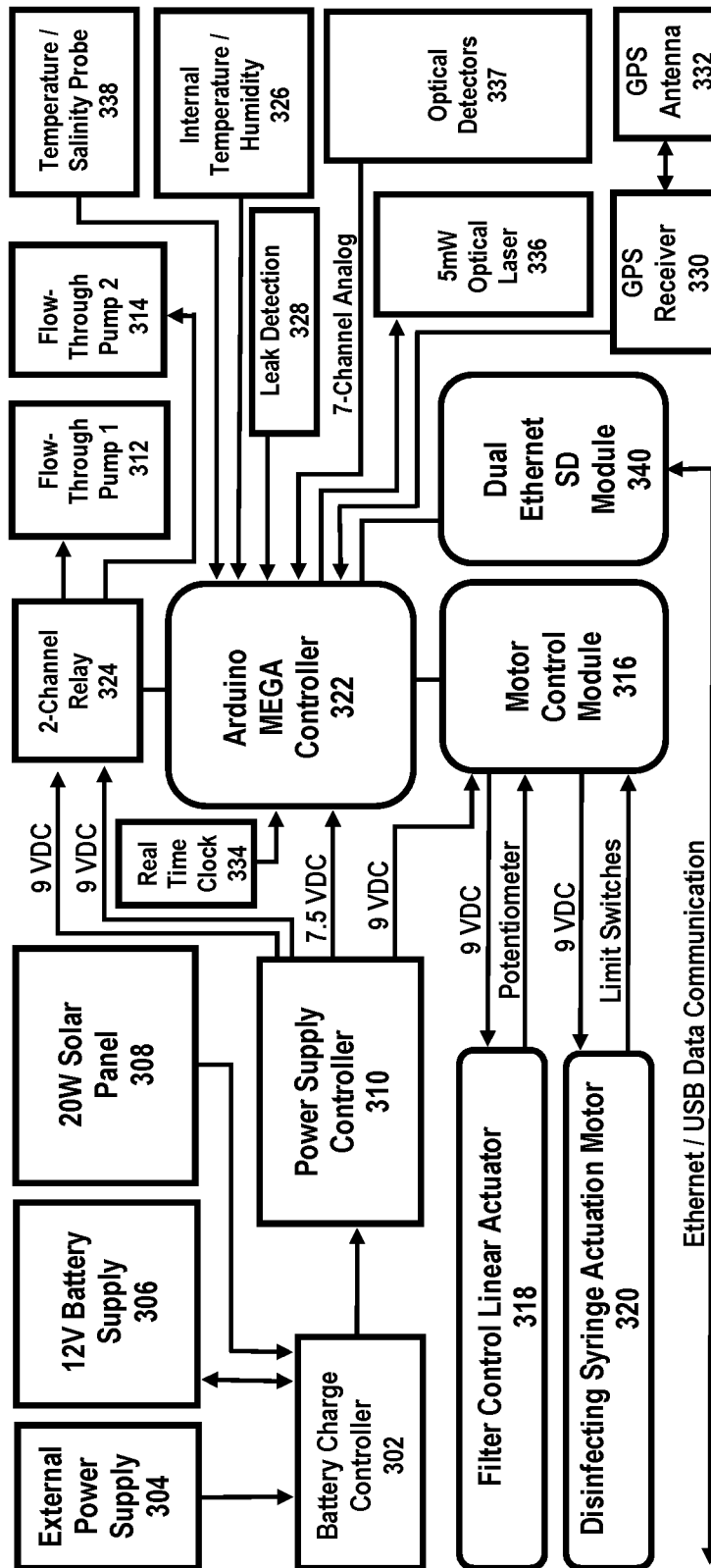


FIG. 3

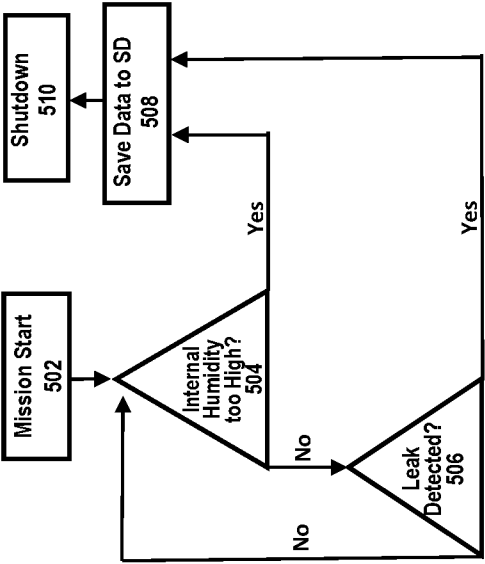


FIG. 5

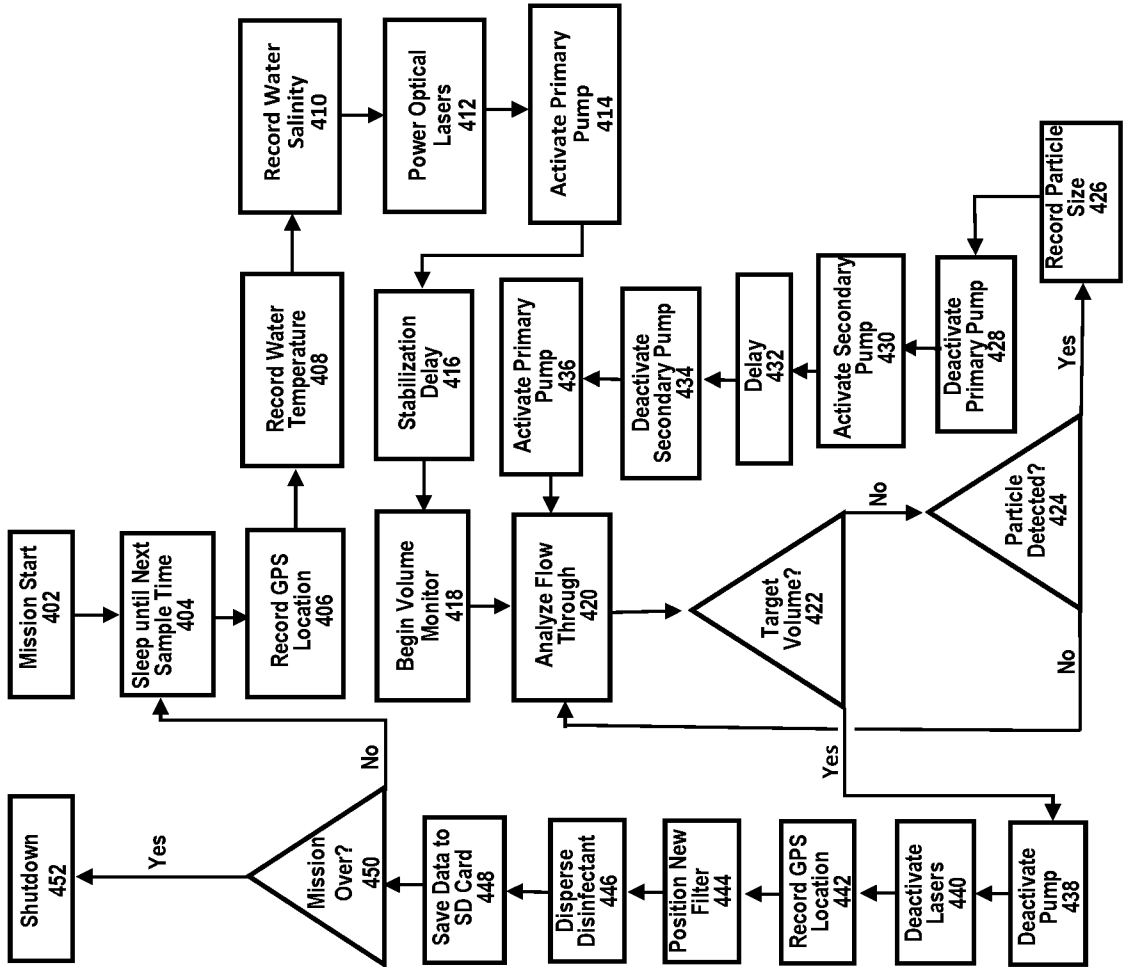


FIG. 4

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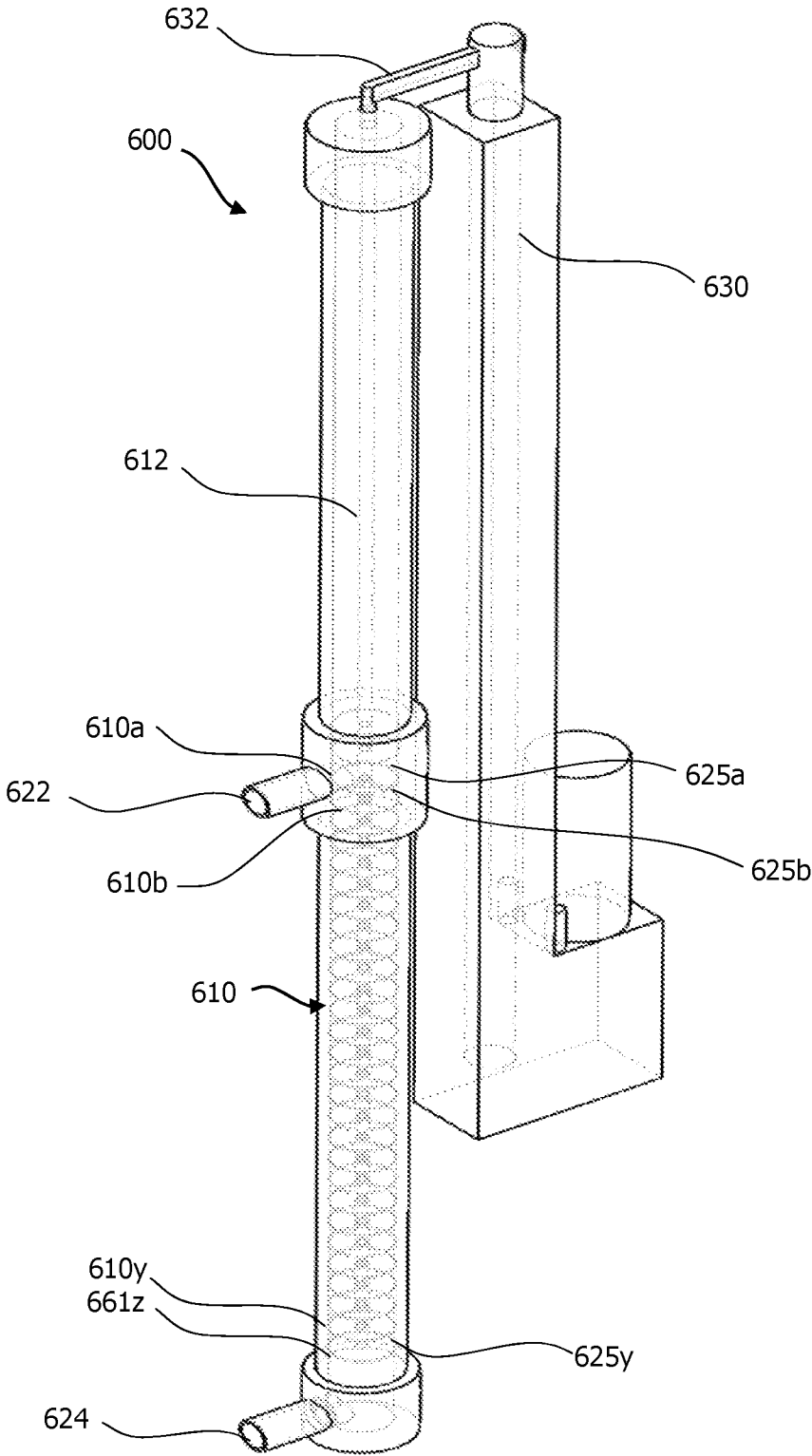


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/25930

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: Claims 1-15, directed to a method and system for sampling particles in a water sample from a body of water over a sampling period using an automated system.

Group II: Claims 16-19, directed to a system for collecting multiple filtrate samples.

The inventions listed as Group I-II do not relate to a single special technical feature under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

****please see the end of this form for continuation****

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-15

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/25930

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01N 15/02 (2016.01)

CPC - G01N 15/0205; G01N 15/0227; G01N 15/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

CPC: G01N15/0205; G01N15/0227; G01N15/02; C02F2209/00; C02F2301/043; C02F1/001; C02F1/00; C02F2209/10; C02F2209/005
IPC(8): G01N 15/02 (2016.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC: 356/335; 700/271; 210/739; 210/420; 210/744; 210/418; 210/143; 210/103; 210/248; 210/340; 210/104; 210/500.1; 422/68.1; 73/28.04; 435/288.7

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Pat Base (AU BE BR CA CH CN DE DK EP ES FI FR GB IN JP KR SE TH TW US WO), Google Patent, Google Scholar; Search terms: particle filter water detector controller automatic bypass power second optical valve switch actuator column stack disinfect biofouling membrane sensor route path particulate solids alternate current electrical change move activate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/0292844 A1 (WOLF) 18 November 2010 (18.11.2010); para [0011]-[0013], [0040], [0055], [0057], [0067], [0068], [0074]; figures 1A and 4A-4B; abstract; claims 1-2	1-4 and 9-10
Y		5-6, 8 and 11-15
A		7
Y	US 6,558,554 B1 (JONES et al.) 06 May 2003 (06.05.2003); col 1, ln 22-34 and ln 64-67; col 2, ln 1-67; col 3, ln 1-4; figure 1; claim 8	5-6 and 11-15
A		7
Y	US 2011/0311996 A1 (FRIEDBERGER et al.) 22 December 2011 (22.12.2011); para [0001], [0002]; abstract	8
Y	US 4,830,750 A (JANDOUREK et al.) 16 May 1989 (16.05.1989); col 4, ln 50-51	12
Y	US 2009/0041621 A1 (KELLY et al.) 12 February 2009 (12.02.2009); para [0006], [0016], [0018]; abstract	13-14
Y	US 2005/0207939 A1 (ROUSSI et al.) 22 September 2005 (22.09.2005); para [0013]-[0032], [0034], [0094]; abstract	15
A	US 3,608,734 A (SCHNEIDER) 28 September 1971 (28.09.1971); col 2, ln 48-67; figure 1; claim 7	7

☒ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 July 2016

Date of mailing of the international search report

19 AUG 2016

Name and mailing address of the ISA/US

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Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/25930

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,651,802 A (CARTER et al.) 29 July 1997 (29.07.1997); col 5, ln 22-38; col 7, ln 27-40; figures 1 and 7	7
A	US 2013/0061659 A1 (AJAY et al.) 14 March 2013 (14.03.2013); the entire document	1 and 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/25930

****continuation of Box III (Lack of Unity)****

Special Technical Feature:

Group I does not require a stack of filters that comprises a first filter, a second filter adjacent the first filter, a first space on a first side of the first filter, a second space between the first and second filters on a second side of the first filter and on a first side of the second filter, and a third space on the second side of the second filter; a hollow column, a fluid inlet and a fluid outlet positioned at a different longitudinally locations along a length of the column, said stack of filters positioned within said column such that the fluid inlet is adjacent the first space and the fluid outlet is positioned downstream of the second side of the first filter, such that fluid flowing into the column through the fluid inlet passes into the first space and through the first filter before exiting the fluid outlet; and a linear actuator configured move the stack of filters along the column length such that the fluid inlet is adjacent the second space and such that fluid flowing into the column through the fluid inlet passes into the second space and through the second filter before exiting the fluid outlet, as required by group II.

Group II does not require a power supply; a fluid intake path configured to receive a stream of sample water from the body of water as a result of the action of one or more pumps; a detection system configured to detect particles in the said stream of sample water; a first fluid return path that is configured to receive and return the sample water to the body of water; a second fluid return path comprising a first particle filter that is configured to receive the stream of sample water, pass the stream of sample water through the first particle filter, and return the sample water to the body of water; and a controller that is configured to direct the stream of sample water along the first fluid return path until one or more particles are detected, in the event of detection of one or more particles by the detection system, direct the stream of sample water along the second fluid return path for a predetermined period, after said predetermined period, redirect the stream of sample water along the first fluid return path, as required by Group I.

Common Technical Features:

Group I and II share the technical feature of filter, sample, and inlet/intake. However, these shared technical features do not represent a contribution over prior art, because the shared technical feature is being anticipated by US 2013/0061659 A1 to Ajay et al. (hereinafter Ajay). Ajay teaches filter, sample, and inlet/intake (para [0096]-[0097]; figure 1; particle detector 12 including a filter arrangement 10, aspirator inlet 50, and sample air).

As the shared technical features were known in the art at the time of the invention, they cannot be considered common technical features that would otherwise unify the groups. Therefore, Groups I-II lack unity under PCT Rule 13.