



## PNEUMATIC CONVEYING SYSTEM AND METHOD USING OPTICAL FLOW CHARACTERIZATION DATA

### BACKGROUND

5           **[0001]** The exemplary embodiments described herein relate to optical computing devices and methods for measuring characteristics of a dry bulk material or powder. More particularly, embodiments disclosed herein relate to systems and methods for measuring the characteristics of a flowing bulk material or powder and use the measurements to improve flow characteristics.

10           **[0002]** Some industrial applications that use bulk materials and powders include forming set cement compositions for the construction industry. The oil and gas industry also uses set cement compositions for stabilizing and plugging wellbores, among other purposes. The operational parameters relating to cement slurries and the characteristics of the resultant set cement derive, at  
15           least in part, from the dry cement composition and the composition and concentration of the optional cement slurry additives mixed as powders in the dry cement blend composition.

**[0003]** Accordingly, while storing and conveying raw materials used in a blend to form a dry cement, it is desirable to have a correct determination of the  
20           raw materials used and their physical and chemical condition during storage and transfer. It is also desirable to determine flow conditions in a conveying system to optimize energy costs and to avoid damage to the infrastructure for handling the materials. Current techniques include discrete measurements in storage  
25           containers and pipelines at specific locations and times. Other techniques involve imprecise and unreliable methods such as detecting the sound that the raw material makes as it travels through the pipelines. Other approaches include analyzing the discharge of the raw material at the end or at some intermediate point of the pipeline.

**[0004]** These measurement techniques typically involve a complicated,  
30           multi-step process of mixing harsh chemicals with the bulk materials or powders and analyzing the products via expensive, time-consuming methods like x-ray diffraction, gravimetric analysis, slurring and testing viscosity over time in specified temperature and pressure conditions and the like. Moreover, these measurement techniques may be insufficient for taking remedial action when an  
35           error occurs with one or more of the material supplies and an entire batch of dry

cement is lost or deployed on location without satisfying quality standards. In relation to downhole oil and gas operations, improperly deployed cementing operations can increase both costs and liabilities, including costly remedial operations to repair the set cement.

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### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0005] The following figures are included to illustrate certain aspects of the exemplary embodiments described herein, and should not be viewed as exclusive embodiments. The subject matter disclosed is capable of considerable  
10 modifications, alterations, combinations, and equivalents in form and function, as will occur to those skilled in the art and having the benefit of this disclosure.

[0006] FIG. 1 illustrates an exemplary integrated computational element (ICE), according to one or more embodiments.

[0007] FIG. 2 illustrates a block diagram non-mechanistically illustrating  
15 how an optical computing device distinguishes electromagnetic radiation related to a characteristic of interest from other electromagnetic radiation, according to some embodiments.

[0008] FIG. 3 illustrates an exemplary system for monitoring a dry cement present in a container, according to some embodiments.

[0009] FIG. 4 illustrates an exemplary housing that may be used to  
20 house an optical computing device, according to some embodiments.

[0010] FIG. 5 illustrates a system for storing and conveying raw materials from storage containers to transportation units including an optical computing device, according to some embodiments.

[0011] FIG. 6 illustrates a conveyor in a pneumatic conveying system  
25 using optical flow characterization data obtained with an optical computing device, according to some embodiments.

[0012] FIG. 7 illustrates a flowchart including steps in a method for  
30 operating a pneumatic conveying system using optical flow characterization data, according to some embodiments.

### **DETAILED DESCRIPTION**

[0013] The exemplary embodiments described herein relate to optical computing devices and methods for monitoring bulk materials or powders and,  
35 in particular, to systems and methods for determining the flow characteristics

and condition of bulk materials or powders. Methods and systems consistent with the present disclosure are able to characterize the flow by "seeing" the bulk materials or powders as they flow through a conveying system in real time. Accordingly, methods and systems consistent with the present disclosure enable  
5 adjustment of conveying airflow rates based on the instantaneous characterization of material flow through the system.

**[0014]** Many industrial applications commonly use dry bulk materials and powders. For example, the agro-industry, the food industry, and the pharmaceutical industry process large amounts of grains, powders, liquids and  
10 small unit sizes (fruits such as grapes, raisins, and nuts, medications in the form of pills) for storage, packaging, and distribution. Industrial applications of dry bulk materials or powders include storing separated raw materials under dry conditions prior to mixing and preparation for use. Industrial applications of dry  
15 bulk materials typically include systems and methods to store the raw materials in separate containers for each raw material and conveying mechanisms to transport the raw materials from storage containers to a scale tank and from the scale tank to a shipping location, or a deployment location. At each of the storage and conveying stages, it is desirable to have a precise knowledge of the type and physical condition of the material handled. Some of the characteristics  
20 that are relevant in many applications include powder particle size, moisture content, homogeneity of a mixture, and flow conditions in a conveying system.

**[0015]** The oil and gas industry uses bulk materials and powders for making cement blends deployed, for example, to plug boreholes or secure casing strings therein. Some of these cementing projects may be quite challenging, as  
25 it may be desirable to convey a cement composition beyond the ocean floor, several thousand feet underneath the water surface. Accordingly, it is desirable to verify the correct dry cement blend prior to deploying the cement in the field. The oil and gas industry uses many types of cements according to different desirable characteristics for specific applications. In some instances, dry  
30 cements include any one of the raw materials used in Portland cements, gypsum cements, hydraulic cements and Sorel cements. Other dry materials besides dry cement typically used in the oil and gas industry include salt, lime, sand, POZMIX®, and the like. An accurate account of the identity and condition of the raw materials used to prepare the cement mix during storage and conveying of  
35 the raw materials is therefore highly desirable. In some instances, the physical

condition is relevant to reactivity of the raw material in cement slurries. For example, fines (reduced size particles) react differently from coarser particles of the same material. Moreover, coarse materials have a tendency to settle and deposit in storage containers and transfer tubes before arriving to the desired destination, reducing material transfer efficiency. Furthermore, blending conditions may change in time, and thus it is desirable to have a sense of the condition of the bulk material or powder being used in real time, and adapt the blending methodology accordingly.

**[0016]** Current attempts to obtain information about bulk material or powder identity and condition include sample extraction and analysis on a periodical basis at multiple locations. These methods can be time consuming and discrete in nature, providing partial and extemporaneous information that may not be sufficient for a timely remedial action. Thus, when an error occurs in the supply logistics and the wrong material is used, or pipeline corrosion contaminates the sample or the mixture, or an air pump or compressor leaks moisture into the system, an entire batch of the mix may be compromised. This may result in the loss of the batch, or in a worst-case scenario, more serious damage can occur when the wrong batch deploys to the field. Such may be the situation when a compromised cement mix is used in structural engineering, such as plugging or lining a wellbore extending from the sea bed thousands of feet under water.

**[0017]** The exemplary systems and methods described herein employ various configurations of optical computing devices, also commonly referred to as "opticoanalytical devices," for the rapid analysis of dry cements. The disclosed systems and methods may be suitable for use in the oil and gas industry since the described optical computing devices provide a cost-effective, rugged, and accurate means for identifying bulk materials and powders in order to facilitate the effective production of cement slurries and set cements in oil/gas applications. It will be appreciated, however, that the various disclosed systems and methods are equally applicable to other technology fields including, but not limited to, the food and drug industry, industrial applications, mining industries, or any field where it may be advantageous to determine in real-time or near real-time a characteristic of a dry composition, especially to determine the quality of the dry composition and of each of its components.

**[0018]** The optical computing devices disclosed herein, which are described in more detail below, can advantageously provide rapid analysis of at least one characteristic of a dry cement (*e.g.*, the composition of individual components in the dry cement or the particle size distribution in the dry cement). As described above, such a detailed analysis currently requires extensive time, high cost, and harsh chemicals and can give unreliable results. By contrast, the optical computing devices disclosed herein may provide rapid analysis of dry cements with minimal sample prep, if any. Additionally, because the analysis is rapid, multiple measurements may be obtained to reduce error. Further, because of the small size and relatively low cost of the optical computing devices disclosed herein, the methods for analyzing dry cements are suitable not only for laboratory use, but also, in-field analysis (*e.g.*, at a manufacturing or mining site, at a distribution center, or at a well site).

**[0019]** A significant and distinct advantage of the optical computing devices disclosed herein is that they can be configured to specifically detect and/or measure a particular characteristic of interest of a dry cement, thereby allowing qualitative and/or quantitative analyses of the material of interest to occur without having to undertake a time-consuming sample processing procedure. With rapid analyses capabilities on hand, the exemplary systems and methods described herein may be able to determine the identity and flow characteristics of raw materials used to form dry cement compositions.

**[0020]** As used herein, the term "dry cement" refers to a mixture of solid particles including at least some cement particles and is not hydrated beyond ambient conditions (*e.g.*, no additional water has been added). It should be noted that the term "dry cement" does not refer to set cements (*e.g.*, that have been formed from a cement slurry).

**[0021]** Dry cements may comprise a single cement or comprise a blend of two or more cements. Examples of dry cements may include, but are not limited to, hydraulic cements, Portland cement, gypsum cements, pozzolan cements, calcium phosphate cements, high alumina content cements, silica cements, high alkalinity cements, shale cements, acid/base cements, magnesia cements (*e.g.*, Sorel cements), zeolite cement systems, cement kiln dust cement systems, slag cements, micro-fine cements, bentonites, and the like, any derivative thereof, and any combination thereof. Examples of Portland cements may include, but are not limited to, Portland cements classified as Classes A, C,

H, and G according to API and their equivalent, Ordinary Portland cements of Type I, I/II, III, and V according to ASTM, including combinations thereof. Examples of pozzolan cements may include, but are not limited to, fly ash, silica fume, granulated blast furnace slag, calcined shale, opaline shale, pumice, pumicite, diatomaceous earth, volcanic ash, tuft, cement kiln dust, and any combination thereof.

**[0022]** As used herein, the term "characteristic" refers to a chemical, mechanical, or physical property (quantitative or qualitative) of a material of interest (*e.g.*, a dry cement or an analyte thereof). As used herein, the term "analyte" refers to a chemical component. The term analyte encompasses chemical components that are at least one of: present in the material of interest, may be added to the material of interest, involved in a chemical reaction (*e.g.*, reagents and products) transpiring within the material of interest, and not involved in a chemical reaction transpiring within the material of interest. Illustrative characteristics of a material of interest that can be monitored with the optical computing devices disclosed herein can include, for example, chemical composition (*e.g.*, identity and concentration in total or of individual analytes), contaminant content, pH, viscosity, density, ionic strength, salt content, porosity, opacity, bacteria content, particle size distribution, color, temperature, hydration level, oxidation state, and the like. Moreover, the phrase "characteristic of interest" may be used herein to refer to a characteristic of a material of interest.

**[0023]** Examples of analytes within a dry cement may include, but are not limited to,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{FeO}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{SO}_3$ ,  $\text{Mn}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$ ,  $\text{SnO}$ ,  $\text{SrO}$ ,  $(\text{CaO})_3 \cdot \text{SiO}_2$ ,  $(\text{CaO})_2 \cdot \text{SiO}_2$ ,  $(\text{CaO})_3 \cdot \text{Al}_2\text{O}_3$ ,  $(\text{CaO})_3 \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ ,  $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ ,  $\text{SO}_3$ ,  $\text{Ca}(\text{OH})_2$ ,  $\text{Al}(\text{OH})_4^-$ ,  $\text{H}_4\text{SiO}_4$ , free lime, inorganic salts (*e.g.*, sodium, potassium, magnesium, and calcium salts of sulfate, phosphate, and carbonate), metal containing compounds (*e.g.*, bromide, chloride, nitrate, sulfate, and phosphate salts of cadmium, zinc, nickel, copper, lead, and the like, metal oxides of such metals, and the like), hydroxides, water, and any combination thereof.

**[0024]** In some instances, the foregoing analytes may be used in classifying cements (*i.e.*, as a major component) or as grading cements (*i.e.*, as a minor components), which depends on the dry cement. As used herein, the "major component" of a dry cement refers to a component or analyte that

identifies the type of dry cement (*e.g.*, Portland cement versus Sorel cement or Type I Portland cement versus Type V Portland cement). As used herein, the "minor component" of a dry cement refers to a component or analyte that is not a major component. The terms "major component" and "minor component" do not necessarily relate to a concentration. For example, in Ordinary Grade, Class G Portland cement may have about 5%  $\text{CaO}_3 \cdot \text{Al}_2\text{O}_3$  as one of the major components and up to about 6% MgO as one of the minor components.

**[0025]** As used herein, the term "cement slurry additive" refers to an additive that can be included in a cement slurry with water and a dry cement. Cement slurry additives may be liquids or dry additives (*e.g.*, powders). In some instances, the dry cement and at least one cement slurry additive (typically a dry additive) may be combined to form a mixture that can be used in preparing a cement slurry. The mixture may be prepared at a storage facility, manufacturing facility, laboratory, distribution center, at the well site, or in transit between any of these locations.

**[0026]** Examples of cement slurry additives may include, but are not limited to, set retarders, set accelerators, fillers (*e.g.*, weighting agents, lightweight particles like glass beads, rubber particles, and the like), dispersants, gelling agents, and the like, and any combination thereof.

**[0027]** As used herein, the term "electromagnetic radiation" refers to radio waves, microwave radiation, infrared and near-infrared radiation, visible light, ultraviolet light, X-ray radiation and gamma ray radiation.

**[0028]** As used herein, the term "optical computing device" refers to an optical device that receives an input of electromagnetic radiation from a substance or sample of the substance, and produces an output of electromagnetic radiation from a processing element arranged within the optical computing device. The processing element may be, for example, an integrated computational element (ICE) used in the optical computing device. As discussed in detail below, the ICE optically interacts and changes the electromagnetic radiation incident on a detector such that an output of the detector can be correlated to at least one characteristic of the substance being measured or monitored. The output of electromagnetic radiation from the processing element can be reflected electromagnetic radiation, transmitted electromagnetic radiation, and/or dispersed electromagnetic radiation. Whether the detector analyzes reflected or transmitted electromagnetic radiation may depend on the



structural parameters of the optical computing device as well as other considerations known to those skilled in the art. In addition, emission and/or scattering by the substance, for example via fluorescence, luminescence, Raman scattering, and/or Raleigh scattering, can also be monitored by the optical computing devices.

**[0029]** As used herein, the term "optically interact" or variations thereof refers to the reflection, transmission, scattering, diffraction, or absorption of electromagnetic radiation either on, through, or from one or more processing elements (*i.e.*, integrated computational elements). Accordingly, optically interacted light refers to electromagnetic radiation that has been reflected, transmitted, scattered, diffracted, or absorbed by, emitted, or re-radiated, for example, using the integrated computational elements, but may also apply to interaction with a dry cement.

**[0030]** The exemplary systems and methods described herein will include at least one optical computing device configured to measure at least one characteristic of a dry cement or analyte thereof. In some embodiments, the optical computing devices suitable for use in the exemplary embodiments described herein may be mobile or portable. In some embodiments, the optical computing devices suitable for use in the exemplary embodiments described herein may be a portion of tank, silo, vat, pipeline, tube, or the like that store, mix, transfer or otherwise contain or transport dry cement (*e.g.*, within a wall).

**[0031]** The presently described optical computing devices combine the advantage of the power, precision, and accuracy associated with laboratory spectrometers, while being extremely rugged and suitable for field use. Furthermore, the optical computing devices can perform calculations in real-time or near real-time without the need for time-consuming sample processing. In this regard, in some embodiments the optical computing devices detect and analyze particular characteristics of interest. As a result, interfering signals are discriminated from those of interest by appropriate configuration of the optical computing devices, such that the optical computing devices provide a rapid response regarding the characteristic of interest as based on the detected output. In some embodiments, the detected output is a voltage indicative of the magnitude of the characteristic of interest. The foregoing advantages and others make the optical computing devices particularly well suited for field use.

**[0032]** In some embodiments, the optical computing devices detect not only the composition and concentrations of an analyte in a material of interest, but also determine physical properties and other characteristics of the material of interest as well, based on their analysis of the electromagnetic radiation received from the substance. For example, the optical computing devices can determine the concentration of an analyte and correlate the determined concentration to a characteristic of the material of interest by using suitable processing means. In some embodiments, optical computing devices as disclosed herein provide a measurement of a granularity of a powder sample, or an average particle size in the powder sample. As will be appreciated, the optical computing devices can detect as many characteristics as desired for a given material of interest. All that is required to accomplish the monitoring of multiple characteristics of interest is the incorporation of suitable processing and detection means within the optical computing device for each characteristic of interest (e.g., the concentration of an analyte, the particle size distribution, or the temperature). Another property of a dry cement that can be measured may be the particle size of the different components in the cement.

**[0033]** In some embodiments, the properties of the material of interest can be determined using a combination of characteristics of interest (e.g., a linear, non-linear, logarithmic, and/or exponential combination). Accordingly, the more characteristics detected and analyzed using the optical computing devices, the more accurately the properties of the material of interest will be determined. For example, properties of a dry cement that may be determined using optical computing devices described herein may include, but are not limited to, the absolute concentration of an analyte, the relative ratios of two or more analytes, the presence or absence of an analyte, and the like, and any combination thereof.

**[0034]** Optical computing devices as described herein utilize electromagnetic radiation to perform calculations, as opposed to the hardwired circuits of conventional electronic processors. When electromagnetic radiation interacts with a material of interest, unique physical and chemical information about the material of interest may be encoded in the electromagnetic radiation that is reflected from, transmitted through, or radiated from the material of interest. This information is the spectral "fingerprint" of the material of interest. The optical computing devices described herein are capable of extracting the

information of the spectral fingerprint of multiple characteristics of a material of interest (e.g., a dry cement blend or an analyte thereof), and converting that information into a detectable output regarding the overall properties of the monitored material of interest. That is, through suitable configurations of the optical computing devices, electromagnetic radiation associated with characteristics of interest can be separated from electromagnetic radiation associated with all other components of the material of interest in order to estimate the properties (e.g., reactivity) of the monitored substance (e.g., a dry cement blend or an analyte thereof) in real-time or near real-time.

10       **[0035]** Each of the ICEs used in the exemplary optical computing devices described herein is capable of distinguishing electromagnetic radiation related to the characteristic of interest from electromagnetic radiation related to other components of a dry cement blend.

15       **[0036]** A method according to embodiments disclosed herein includes optically interacting a flow of bulk material or powder in a pneumatic conveyor with an ICE configured to detect a characteristic of the flow. The method also includes generating an output signal corresponding to the characteristic of the flow detected by the ICE and receiving and processing the output signal with a signal processor to yield a value for the characteristic of the flow. Further, in some embodiments the method includes modifying at least one of a flow rate or an air pressure in the pneumatic conveyor in response to the value of the characteristic of the flow.

20       **[0037]** A device according to some embodiments includes a processor circuit and a memory circuit storing commands, which, when executed by the processor circuit, cause the device to perform a method including receiving a first signal from a first optical computing device at a first location in a system for storing and conveying materials. The commands also cause the device to perform the step of receiving a second signal from a second optical computing device at a second location in the system for storing and conveying materials.

25       The first and second signals result from electromagnetic radiation interacted with a bulk material or a powder flowing in a transfer tube, and at least one of the first and second signals results from electromagnetic radiation modified by an ICE according to a characteristic of the flow of bulk material or powder. In some embodiments, the commands also cause the device to perform the step of determining from the first and second signal a characteristic of the flow of the

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bulk material or powder along the transfer tube. Bulk materials or powders as disclosed herein may include not only dry cement, but also may include dry barite powders and blends used for drilling fluids. More generally, bulk materials or powders as disclosed herein include dry powders and blends such as  
5 fertilizers, pharmaceuticals and agro-industrial products.

**[0038]** A method as disclosed herein includes receiving an output signal from each of a plurality of optical computing devices disposed in separate locations in a pneumatic conveyor including a flowing bulk material or powder. In some embodiments, the method includes processing each of the output  
10 signals from the plurality of optical computing devices with a signal processor and determining a characteristic of the flow based on the processing of the output signals. Further, in some embodiments the method includes modifying a characteristic of the pneumatic conveyor in response to the value of characteristic of the flow.

**[0039]** FIG. 1 illustrates an exemplary ICE 100 suitable for use in the optical computing devices used in systems and methods described herein. As illustrated, ICE 100 may include a plurality of alternating layers 102 and 104, such as silicon (Si) and SiO<sub>2</sub> (quartz), respectively. In general, these layers 102, 104 consist of materials whose index of refraction is high and low, respectively.  
20 Other examples might include niobia and niobium, germanium and germania, MgF, SiO<sub>x</sub>, and other high and low index materials known in the art. An optical substrate 106 provides support to layers 102, 104, according to some embodiments. In some embodiments, optical substrate 106 is BK-7 optical glass. In other embodiments, optical substrate 106 may be another type of  
25 optical substrate, such as quartz, sapphire, silicon, germanium, zinc selenide, zinc sulfide, or various plastics such as polycarbonate, polymethylmethacrylate (PMMA), polyvinylchloride (PVC), diamond, ceramics, combinations thereof, and the like.

**[0040]** At the opposite end (*e.g.*, opposite optical substrate 106 in FIG. 1), ICE 100 may include a layer 108 that is generally exposed to the environment of the device or installation. The number of layers 102, 104 and the thickness of each layer 102, 104 are determined from the spectral attributes acquired from a spectroscopic analysis of a characteristic of interest using a conventional spectroscopic instrument. The spectrum of interest of a given  
35 characteristic of interest typically includes any number of different wavelengths.

The exemplary ICE 100 in FIG. 1 does not in fact represent any particular characteristic of interest, but is provided for purposes of illustration only. Consequently, the number of layers 102, 104 and their relative thicknesses, as shown in FIG. 1, bear no correlation to any particular characteristic of interest.

5 Nor are layers 102, 104 and their relative thicknesses necessarily drawn to scale, and therefore should not be considered limiting of the present disclosure. Moreover, those skilled in the art will readily recognize that the materials that make up each layer 102, 104 (*i.e.*, Si and SiO<sub>2</sub>) may vary, depending on the application, cost of materials, and/or applicability of the materials to the  
10 monitored substance.

**[0041]** In some embodiments, the material of each layer 102, 104 can be doped or two or more materials can be combined in a manner to achieve the desired optical characteristic. In addition to solids, ICE 100 may also contain liquids and/or gases, optionally in combination with solids, in order to produce a  
15 desired optical characteristic. In the case of gases and liquids, ICE 100 can contain a corresponding vessel (not shown), which houses gases or liquids. Exemplary variations of ICE 100 may also include holographic optical elements, gratings, piezoelectric, light pipe, digital light pipe (DLP), variable optical attenuators, and/or acousto-optic elements that, for example, can create  
20 transmission, reflection, and/or absorptive properties of interest.

**[0042]** Layers 102, 104 exhibit different refractive indices. By properly selecting the materials of layers 102, 104, their relative thicknesses and spacing ICE 100 may be configured to selectively pass/reflect/refract predetermined fractions of electromagnetic radiation at different wavelengths. Each wavelength  
25 is given a predetermined weighting or loading factor. The thickness and spacing of layers 102, 104 may be determined using a variety of approximation methods from the spectrograph of the characteristic of interest. These methods may include inverse Fourier transform (IFT) of the optical transmission spectrum and structuring ICE 100 as the physical representation of the IFT. The  
30 approximations convert the IFT into a structure based on known materials with constant refractive indices.

**[0043]** The weightings that layers 102, 104 of ICE 100 apply at each wavelength are set to the regression weightings described with respect to a known equation, or data, or spectral signature. Briefly, ICE 100 may be  
35 configured to perform the dot product of the input light beam into ICE 100 and a

desired loaded regression vector represented by each layer 102, 104 for each wavelength. As a result, the output light intensity of ICE 100 is related to the characteristic of interest.

**[0044]** FIG. 2, illustrates a block diagram that non-mechanistically  
5 illustrates how an optical computing device 200 is able to distinguish electromagnetic radiation related to a characteristic of interest from other electromagnetic radiation. As shown in FIG. 2, illumination by incident electromagnetic radiation induces an output of electromagnetic radiation from a bulk material or powder 202 (*e.g.*, sample-interacted light), some of which is  
10 electromagnetic radiation 204 corresponding to the characteristic of interest and some of which is background electromagnetic radiation 206 corresponding to other characteristics of the bulk material or powder 202. In some embodiments, bulk material or powder 202 may include one or more characteristics of interest that may correspond to the one or more analytes of bulk material or powder  
15 202.

**[0045]** Although not specifically shown, one or more processing elements may be employed in the optical computing device 200 in order to restrict the optical wavelengths and/or bandwidths of the system and thereby eliminate unwanted electromagnetic radiation existing in wavelength regions  
20 that have no importance. Such processing elements can be located anywhere along the optical train, such as directly after a light source, which provides the initial electromagnetic radiation.

**[0046]** Beams of electromagnetic radiation 204 and 206 impinge upon the optical computing device 200, which contains an exemplary ICE 208 therein.  
25 In the illustrated embodiment ICE 208 may produce optically interacted light, for example, transmitted optically interacted light 210, and reflected optically interacted light 214. In operation, ICE 208 may be configured to distinguish electromagnetic radiation 204 from background electromagnetic radiation 206.

**[0047]** Transmitted optically interacted light 210, which may be related  
30 to the characteristic of interest of the bulk material or powder 202, may be conveyed to a detector 212 for analysis and quantification. In some embodiments, detector 212 produces an output signal in the form of a voltage that corresponds to the particular characteristic of bulk material or powder 202. In at least one embodiment, the signal produced by detector 212 and the  
35 characteristic of bulk material or powder 202 (*e.g.*, concentration of an analyte,

or flow speed) may be directly proportional. In other embodiments, the relationship may be a polynomial function, an exponential function, and/or a logarithmic function. The reflected optically interacted light 214 may be related to other characteristics of the bulk material or powder 202, and can be directed away from detector 212. In alternative configurations, ICE 208 is such that reflected optically interacted light 214 relates to the characteristic of interest, and the transmitted optically interacted light 210 relates to other characteristics in the bulk material or powder 202.

**[0048]** In some embodiments, a second detector 216 can be present and arranged to detect the reflected optically interacted light 214. In other embodiments, second detector 216 may be arranged to detect electromagnetic radiation 204 and 206 derived from the bulk material or powder 202 or electromagnetic radiation directed toward or before the bulk material or powder 202. Without limitation, second detector 216 may be used to detect radiating deviations stemming from an electromagnetic radiation source (not shown), which provides the electromagnetic radiation (*i.e.*, light) to the device 200. For example, radiating deviations can include such things as, but not limited to, intensity fluctuations in the electromagnetic radiation, interference fluctuations (*e.g.*, dust or other interferences passing in front of the electromagnetic radiation source), coatings on windows included with optical computing device 200, combinations thereof, or the like. In some embodiments, a beam splitter (not shown) splits electromagnetic radiation 204 and 206, and the transmitted or reflected electromagnetic radiation can then be directed to two or more ICES 208. That is, in such embodiments, the transmitted or reflected electromagnetic radiation passes through ICE 208, which performs the computation before it travels to detector 212.

**[0049]** The characteristic(s) of interest being analyzed using optical computing device 200 can be further processed and/or analyzed computationally to provide additional characterization information about bulk material or powder 202, or an analyte thereof. In some embodiments, the identification and concentration of each analyte of interest in bulk material or powder 202 can be used to predict certain physical characteristics of a resulting dry cement combination. For example, the bulk characteristics of the dry cement (*e.g.*, reactivity, set time, and the like) can be estimated by using a combination of the properties conferred to the dry cement by each of the bulk material or powder

202 used in a cement blend. For example, the relative ratios of some of the analytes can indicate a concentration or range of concentration of cement slurry additives that should be used in preparing a cement slurry from bulk material or powder 202.

5           **[0050]** In some embodiments, knowledge of the composition and concentration of raw materials prevents a reduction in the quality of the dry cement. In some instances, mixing the stored dry cement with one or more other dry cements may achieve a desired classification or grade of dry cement. By way of non-limiting example, lime can degrade over time with exposure to  
10 carbon dioxide. Accordingly, lime is an analyte of interest that may be monitored or measured in bulk material or powder 202, according to some embodiments.

**[0051]** Some embodiments use a computer algorithm to estimate the impact of a certain material quality or a certain flow characteristic in bulk  
15 material or powder 202 on the final cement composition. The algorithm may be part of an artificial neural network configured to use the concentration of each characteristic of interest in order to evaluate the overall characteristic(s) of the dry cement composition and predict the composition and/or concentration of the cement slurry additives included to provide for desired properties in resultant  
20 cement slurries. An artificial neural network can be trained using samples of predetermined characteristics of interest, and thereby generating a virtual library. As the virtual library available to the artificial neural network becomes larger, the neural network can become more capable of accurately predicting the characteristic of interest corresponding to a bulk material or powder or analyte  
25 thereof. Furthermore, with sufficient training, the artificial neural network can more accurately predict the characteristics of the dry cement combination, even in the presence of unknown analytes.

**[0052]** In some embodiments, data collected using the optical computing device can be archived along with data associated with operational  
30 parameters being logged at a job site. Evaluation of job performance allows improvement of future operations and the planning of remedial action, if desired. In addition, the data and information can be communicated (wired or wirelessly) to a remote location by a communication system (*e.g.*, satellite communication or wide area network communication) for further analysis. Automated control  
35 with a long-range communication system can further facilitate the performance



of remote job operations. In particular, an artificial neural network facilitates the performance of remote job operations. In other embodiments, however, remote job operations can occur under direct operator control, where the operator is not at the job site (e.g., via wireless technology).

5           **[0053]** FIG. 3 illustrates an exemplary system 300 for monitoring a bulk material or powder 302, according to one or more embodiments. In the illustrated embodiment, bulk material or powder 302 may be contained within a container 304. In at least one embodiment, container 304 may be a scale tank that actively mixes bulk material or powder 302 present therein into a cement  
10 composition while system 300 collects measurements. In at least one embodiment, container 304 may be a cup or the like of a transport unit, such as a truck or a boat. In other embodiments container 304 may be any other type of container, as generally described or otherwise defined herein. For example, container 304 may be a storage vessel or silo, or a pipeline such as a transfer  
15 tube used in the oil and gas industry, e.g., in a pneumatic conveying system.

**[0054]** System 300 may include at least one optical computing device 306, which may be similar in some respects to optical computing device 200 of FIG. 2. While not shown, device 306 may be housed within a casing or housing configured to substantially protect the internal components of device 306 from  
20 damage or contamination from the external environment. The housing may couple device 306 to container 304 mechanically with mechanical fasteners, threads, brazing or welding techniques, adhesives, magnets, combinations thereof or the like.

**[0055]** As described in detail below, optical computing device 306 may  
25 be useful in determining a particular characteristic of bulk material or powder 302 within container 304, such as determining a concentration of an analyte present within bulk material or powder 302.

**[0056]** Knowing at least some of the characteristics of bulk material or powder 302 may help determine the overall composition of the bulk material or  
30 powder 302. Knowing the composition of bulk material or powder 302 allows for a more accurate determination of the composition and/or concentration of cement slurry additives to use in subsequent cement slurries. In turn, the cementing operation that utilized the cement slurry mitigates premature setting or delayed setting. Further, the resultant set cement may be of higher quality

because the type of and concentration of additives was tailored to the original dry cement.

**[0057]** In some embodiments, device 306 may include an electromagnetic radiation source 308 configured to emit or otherwise generate electromagnetic radiation 310. Electromagnetic radiation source 308 may be any device capable of emitting or generating electromagnetic radiation, as defined herein. For example, electromagnetic radiation source 308 may be a light bulb, a light emitting diode (LED), a laser, a blackbody, a photonic crystal, an X-Ray source, combinations thereof, or the like. In some embodiments, a lens 312 collects or otherwise receives electromagnetic radiation 310 and directs a beam 314 of electromagnetic radiation 310 toward bulk material or powder 302. Lens 312 may be any type of optical device configured to transmit or otherwise convey electromagnetic radiation 310 as desired. For example, lens 312 may be a normal lens, a Fresnel lens, a diffractive optical element, a holographic graphical element, a mirror (*e.g.*, a focusing mirror), a type of collimator, or any other electromagnetic radiation-transmitting device known to those skilled in the art. Some embodiments omit lens 312 from device 306 and electromagnetic radiation source 308 conveys electromagnetic radiation 310 toward bulk material or powder 302 directly from the electromagnetic radiation source 308. In some embodiments, lens 312 includes a plurality of optical elements such as lenses and mirrors configured to direct light from electromagnetic radiation source 308 into bulk material or powder 302.

**[0058]** In one or more embodiments, device 306 may also include a sampling window 316 arranged adjacent to or otherwise in contact with bulk material or powder 302 for detection purposes. In some embodiments, sampling window 316 includes any one of a variety of transparent, rigid or semi-rigid materials that allow transmission of electromagnetic radiation 310 therethrough. For example, sampling window 316 may include materials such as, but not limited to, glasses, plastics, semi-conductors, crystalline materials, sapphire, polycrystalline materials, hot or cold-pressed powders, combinations thereof, or the like.

**[0059]** After passing through sampling window 316, electromagnetic radiation 310 impinges upon and optically interacts with bulk material or powder 302, including any analytes present within bulk material or powder 302. As a result, bulk material 302 generates and reflects optically interacted radiation

318. Those skilled in the art, however, will readily recognize that alternative variations of device 306 allow optically interacted radiation 318 to be transmitted, scattered, diffracted, absorbed, emitted, or re-radiated by and/or from the bulk material or powder 302, or one or more analytes present within the bulk material or powder 302, without departing from the scope of the disclosure.

**[0060]** ICEs 320a, 320b and 320c (hereinafter collectively referred to as ICEs 320) may be included in device 306. ICE 320a directs or otherwise receives optically interacted radiation 318, generated by the interaction with bulk material or powder 302. ICE devices 320 may include spectral components substantially similar to ICE 100 described above with reference to FIG. 1. Accordingly, in operation ICE 320a receives the optically interacted radiation 318 and produces modified electromagnetic radiation 322 corresponding to a particular characteristic of interest of the bulk material or powder 302. In particular, the modified electromagnetic radiation 322 is electromagnetic radiation that has optically interacted with ICE 320a and obtains an approximate mimicking of the regression vector corresponding to the characteristic of interest. In some embodiments, the characteristic of interest corresponds to bulk material or powder 302. In other embodiments, the characteristic of interest corresponds to a particular analyte found in the bulk material or powder 302. In some embodiments, the characteristic of interest may be air contained in a flow of bulk material or powder 302.

**[0061]** It should be noted that, while FIG. 3 depicts ICE 320a as receiving optically interacted radiation 318 from bulk material or powder 302, an ICE component may be arranged at any point along the optical train of the device 306, without departing from the scope of the disclosure. For example, in one or more embodiments, ICE 320b (as shown in dashed lines) may alternatively be arranged within the optical train prior to the sampling window 316 and equally obtain substantially the same results. In other embodiments, sampling window 316 may serve a dual purpose as both a transmission window and a substrate for one of ICEs 320 (*i.e.*, a spectral component). In yet other embodiments, the ICE components 320 may generate modified electromagnetic radiation 322 through reflection, instead of transmission therethrough.

**[0062]** Moreover, while only one ICE 320a is shown in device 306, embodiments are contemplated herein which include the use of at least two ICEs

320 in device 306 configured to cooperatively determine the characteristic of interest in bulk material or powder 302. For example, two or more ICE 320 arranged in series or parallel within device 306 receive optically interacted radiation 318 thereby enhancing sensitivities and detector limits of device 306.

5 In some embodiments, two or more ICEs 320 may be arranged on a movable assembly, such as a rotating disc or an oscillating linear array, which moves such that individual ICEs 320 are able to be exposed to or otherwise optically interact with electromagnetic radiation 310 for a distinct brief period. The two or more ICEs 320 in any of these embodiments may be associated or disassociated  
10 with the characteristic of interest in bulk material or powder 302. In other embodiments, the two or more ICEs 320 have a positive or a negative correlation with the characteristic of interest. Further, according to some embodiments, the two or more ICEs 320 may have opposite correlation with the characteristic of interest. In such embodiments, while a signal in detector 324  
15 increases with an increase in the characteristic of interest for a first ICE 320, the signal in detector 324 decreases for a second ICE 320.

**[0063]** In some embodiments, it may be desirable to monitor more than one characteristic of interest at a time using device 306. In such embodiments, various configurations for multiple ICEs 320 can be used, where each ICE 320 is  
20 configured to detect a particular and/or distinct characteristic of interest corresponding, for example, to bulk material or powder 302 or to an analyte in the bulk material or powder 302. Some embodiments analyze the characteristic of interest sequentially using multiple ICEs 320 interacting with a single beam of optically interacted radiation 318 reflected from or transmitted through bulk  
25 material or powder 302. For example, some embodiments include multiple ICEs 320 arranged on a rotating disc. In such embodiments, the beam of optically interacted radiation 318 interacts with individual ICEs 320 for a reduced time. Advantages of this approach can include the ability to analyze multiple characteristics of interest within bulk material or powder 302 using device 306  
30 and the opportunity to assay additional characteristics simply by adding additional ICEs 320 to the rotating disc corresponding to those additional characteristics.

**[0064]** Other embodiments place multiple devices 306 at a single location along container 304, where each device 306 contains a unique ICE 320  
35 that is configured to detect a particular characteristic of interest. In such

embodiments, a beam splitter can divert a portion of the optically interacted radiation 318 reflected by, emitted from, or transmitted through the bulk material or powder 302 and into each one of devices 306. Each one of devices 306, in turn, can be coupled to a corresponding detector (e.g., detector 324) or  
5 detector array that is configured to detect and analyze an output of electromagnetic radiation from the respective optical computing device. Parallel configurations of optical computing devices can be particularly beneficial for applications that require low power inputs and/or no moving parts.

**[0065]** Those skilled in the art will appreciate that any of the foregoing  
10 configurations can include a series configuration in any of the present embodiments. For example, a movable housing may arrange two devices 306 in series to perform an analysis at a single location in container 304. Likewise, multiple detection stations, each containing devices 306 in parallel, can perform a similar analysis in series.

**[0066]** Modified electromagnetic radiation 322 generated by ICE 320a  
15 may subsequently be conveyed to the detector 324 for quantification of the signal. Detector 324 may be any device capable of detecting electromagnetic radiation, such as an optical transducer. In some embodiments detector 324 is a thermal detector such as a thermopile or photo-acoustic detector, a  
20 semiconductor detector, a piezo-electric detector, a charge coupled device (CCD) detector, a video or array detector, a split detector, a photon detector (such as a photomultiplier tube), photodiodes, combinations thereof, or the like, or other detectors known to those skilled in the art.

**[0067]** In some embodiments, detector 324 may be configured to  
25 produce an output signal 326 in real-time or near real-time in the form of a voltage (or current) that corresponds to the particular characteristic of interest in bulk material or powder 302. The voltage returned by detector 324 is essentially the dot product of the optical interaction of optically interacted radiation 318 with ICE 320a as a function of the concentration of the  
30 characteristic of interest. As such, output signal 326 produced by detector 324 and the characteristic of interest are related to one another. For example, output signal 326 may be directly proportional to the characteristic of interest. In other embodiments, however, the relationship may correspond to a polynomial function, an exponential function, a logarithmic function, and/or a  
35 combination thereof. In some embodiments, output signal 326 associated with

ICE 320a may be negatively correlated with the characteristic of interest. Accordingly, output signal 326 decreases when the characteristic of interest increases.

**[0068]** In some embodiments, device 306 may include a second  
5 detector 328, which may be similar to first detector 324 in that it may be any device capable of detecting electromagnetic radiation. Similar to second detector 216 of FIG. 2, second detector 328 of FIG. 3 detects radiating deviations stemming from the electromagnetic radiation source 308. Accordingly, a beam splitter 311 (in dashes) may direct a portion of  
10 electromagnetic radiation 310 to detector 328, which may be configured to monitor radiating deviations in electromagnetic radiation source 308. In some embodiments, another ICE device 320c (shown in dashes) before detector 328 modifies the electromagnetic radiation impinging on detector 328. Undesirable radiating deviations can occur in the intensity of the electromagnetic radiation  
15 310 due to a wide variety of reasons and potentially causing various negative effects on the output of the device 306. These negative effects can be particularly detrimental for measurements taken over a period. In some embodiments, radiating deviations can occur due to a build-up of a layer of residual material on sampling window 316. This reduces the amount and quality  
20 of light ultimately reaching first detector 324. Without proper compensation, such radiating deviations could result in false readings and output signal 326 may inaccurately relate the characteristic of interest.

**[0069]** To compensate for these undesirable effects, second detector 328 generates a compensating signal 330 generally indicative of the radiating  
25 deviations of the electromagnetic radiation source 308, thereby normalizing output signal 326 generated by first detector 324. As illustrated, second detector 328 may receive a portion of optically interacted radiation 318 via a beam splitter 332 in order to detect the radiating deviations. In some embodiments, second detector 328 receives electromagnetic radiation from any  
30 portion of the optical train in device 306 to detect radiating deviations, without departing from the scope of the disclosure.

**[0070]** In some applications, output signal 326 and compensating signal 330 may be conveyed to or otherwise received by a signal processor 334  
communicably coupled to both detectors 324, 328. Signal processor 334 may be  
35 a computer including a non-transitory machine-readable medium, configured to

normalize output signal 326 using compensating signal 330, in view of any radiating deviations detected by second detector 328. In some embodiments, computing output and compensating signals 326, 330 may entail computing a ratio of the two signals 326, 330. For example, the concentration or magnitude  
5 of each characteristic of interest determined using optical computing device 306 can be fed into an algorithm run by signal processor 334. The algorithm may be configured to make predictions on how the bulk material or powder 302 in combination with cement slurry additives, optionally at varying concentrations, will behave in a cement slurry.

10 **[0071]** Systems similar to that illustrated in FIG. 3 may be useful in analyzing bulk material or powders. For example, a system may include a probe that can be inserted into a dry cement for analysis of a characteristic thereof. As such, the dry cement may be contained within a container not having a device 306 connected thereto (*e.g.*, a bag of dry cement as shipped from a distributor).  
15 Further, the dry cement may be a pile or mound of dry cement in open air.

**[0072]** Those skilled in the art will readily recognize that, in one or more embodiments, electromagnetic radiation derives from the bulk material or powder 302 itself. For example, various substances naturally radiate electromagnetic radiation that is able to interact with at least one of ICE  
20 components 320. In some embodiments, for example, bulk material or powder 302 or a substance within the bulk material or powder 302 may be a blackbody radiating substance configured to radiate heat that may optically interact with at least one of ICE components 320. In other embodiments, the bulk material or powder 302 or the substance within the bulk material or powder 302 may be  
25 radioactive or chemo-luminescent and emit electromagnetic radiation that is able to interact with ICE 320. In yet other embodiments, mechanical, magnetic, electric, actuation induces electromagnetic radiation from bulk material or powder 302 or from a substance within the bulk material or powder 302. For instance, in at least one embodiment, a voltage across bulk material or powder  
30 302 or the substance within bulk material or powder 302 induces the electromagnetic radiation. As a result, in embodiments contemplated herein the electromagnetic radiation source 308 may be omitted from the particular optical computing device.

**[0073]** FIG. 4 illustrates an exemplary housing 400 that may be used to  
35 house an optical computing device, according to one or more embodiments. In

some embodiments, housing 400 may be mechanically coupled to container 304 using, for example, mechanical fasteners, brazing or welding techniques, adhesives, magnets, combinations thereof or the like. Housing 400 substantially protects the internal components of device 306 from damage or contamination  
5 from the external environment. Those skilled in the art, however, will readily recognize that several alternative designs and configurations of housings used to house the optical computing devices are suitable for the presently disclosed systems and methods. Indeed, housing embodiments described and disclosed herein are by way of example only, and should not limit the scope to the  
10 exemplary systems and methods disclosed herein.

**[0074]** As illustrated, the housing 400 may be in the general form of a bolt 450, which encloses the various components of an optical computing device, such as device 306 of FIG. 3. In one embodiment, components of the device 306 housed within housing 400 may be generally housed within a stem 452 of a  
15 bolt 450, and bolt 450 may have a hex head 454 for manual manipulation of housing 400 using, for example, a wrench or other suitable torque-generating hand tool.

**[0075]** In at least one embodiment, housing 400 defines external threads 456 that are compatible with corresponding mating pipe threads provided in, for example, an opening defined in container 304 (FIG. 3) that is  
20 configured to receive housing 400. A thread sealant between threads 456 and the mating pipe threads may prevent leakage of moisture or any undesirable substance through the juncture between housing 400 and the pipe. Sampling window 316 is configured to be in optical communication with bulk material or  
25 powder 302 (FIG. 3) and allows optical interaction between bulk material or powder 302 and other internal components of internally housed device 306.

**[0076]** FIG. 5 illustrates a system 500 for storing and conveying raw materials from storage containers 505 to transport units 550 including an optical computing device 506, according to some embodiments. System 500 includes a  
30 storage container 505 including at least one of a hopper 502 or a storage bin 504 to store a bulk material or powder 501. Hopper 502 may be a storage container with an open top, while storage bin 504 may include a top enclosure (e.g., a tank). Bulk material or powder 501 may include any one of fly ash, silica flour, salts, or any of the materials mentioned above in a dry cement  
35 combination, including cement additives in powder form. Other dry materials



501 besides dry cement that may be transferred in hopper 502 include salt, lime, sand, POZMIX®, and the like. In some embodiments of system 500, hopper 502 conveys different materials through transfer tube 507a into scale tank 510, sequentially. Transfer tube 507a conveys bulk material or powder 501 from any one of storage containers 505 (including storage bin 504) to a scale tank 510. In some embodiments, a pump 530 creates a negative air pressure in the scale tank to generate a flow of bulk material or powder 501, thus 'pulling' bulk material or powder 501 through transfer tube 507a. In other embodiments, the bulk material may gravity flow from 505 through 507a into 510. Scale tank 510 receives raw materials from different storage containers 505 such as hopper 502 and storage bin 504 and forms a mix, such as dry cement. The mixture may be developed by ribbon blending, jets, multiple transfers and such, with optical computing device 506d determining when the mixture is satisfactorily homogeneous. Transfer tube 507b conveys the mixed materials to a truck 550a or a ship 550b for shipping the blended materials (e.g., dry cement) to a deployment location. Transfer tubes 507a and 507b will be referred hereinafter to as transfer tubes 507. In some embodiments transfer tube 507b includes a flow of the bulk material or powder mixed with air, the air provided by an air pump 540 creating a positive air pressure in the scale tank, thus 'pushing' bulk material or powder 501 through transfer tube 507b. In some embodiments, the role of pump 530 and air compressor 540 may be reversed, so that an air compressor 540 'pushes' raw material from storage containers 505 into scale tank 510. Or in some embodiments pump 530 may be used to 'pull' a material mix from scale tank 510 to transport units 550a (e.g., a truck) and 550b (e.g., a ship). Transport units 550a and 550b will be referred hereinafter to as transport units 550.

**[0077]** In some embodiments, it may be desirable to know in real time that the correct material is in any one of storage containers 505, or in any one of transfer tubes 507, scale tank 510, or even within transport units 550. Accordingly, system 500 includes a plurality of optical computing devices disposed in different locations. Optical computing device 506a is located within hopper 502. Optical computing device 506b is located within storage bin 504. Optical computing device 506c is located within transfer tube 507a. Optical computing device 506d is located within scale tank 510. Optical computing device 506e is located within transfer tube 507b. Optical computing device 506f

is located within truck 550a, and optical computing device 506g is located within ship 550b. Optical computing devices 506a-g will be collectively referred to hereinafter as optical computing devices 506. In some embodiments, at least one of optical computing devices 506 may be as optical computing device 306 in  
5 FIG. 3.

**[0078]** System 500 also includes a signal processor 534 having a processor circuit 536 and a memory circuit 537 storing commands. Signal processor 534 may be similar to signal processor 334 of FIG. 3. When executed by processor circuit 536 the commands cause signal processor 534 to perform a  
10 method including receiving a first signal from a first optical computing device 506a at a first location in system 500. The commands may also cause signal processor 534 to perform the step of receiving a second signal from a second optical computing device 506b at a second location in system 500. The first and second location in system 500 may be any one of storage containers 505,  
15 transfer tubes 507, scale tank 510, or even transport units 550. In that regard, optical computing devices 506 and signal processor 534 may exchange data and signals via a wire connection, or a wireless connection. The first and second signal may result from a light interacted with a bulk material or powder 501, and at least one of the first and second signals results from an electromagnetic  
20 radiation modified by an ICE. In some embodiments, the commands further cause signal processor 534 to perform the step of determining from the first and second signal a characteristic of the bulk material or powder, or of the flow of the bulk material or powder. More generally, processor circuit 536 may execute commands stored in memory circuit 537 that cause signal processor 534 to  
25 perform at least one of the steps in any method consistent with the present disclosure. A Human Machine Interface (HMI) 560 may be coupled to signal processor 534, and be configured to monitor the operation of system 500 by a human operator. Accordingly, HMI 560 may issue warnings, alert messages, or alarms, based on the data provided by signal processor 534 upon collecting  
30 signals from each of optical computing devices 506.

**[0079]** Optical computing devices 506 enable real time monitoring and detection of various compounds in most any phase, including powders, liquids and slurries. For example, an ICE in any one of optical computing devices 506 (e.g., ICE 100 in FIG. 1) may identify cement powder ingredients used in dry  
35 cement compositions. Monitoring and detecting the chemical composition (or at

least key ingredients) through optical computing devices 506 enables identification and verification of bulk material or powder 501 in hopper 502, in storage bin 504 or in one of the transfer tubes 507a and 507b. Optical computing devices 506 also enable detection of the condition of bulk material or powder 501. For example, optical computing devices 506 may determine when excessive moisture or decomposition occurs in storage or while conveyed in and out of scale tank 510. A window or a probe provides optical communication between optical computing devices 506 and storage containers 505, transfer tubes 507, or transport units 550. The window may be similar to window 316 of FIG. 3, and the probe may include a waveguide device to transmit electromagnetic radiation, such as an optical fiber.

**[0080]** Accordingly, methods and systems consistent with the present disclosure provide fast identification of dry materials contained in a storage bin, a hopper, or a pneumatic conveyor. System 500 also includes a programmed control system with alarms and reporting to prevent contamination of bulk materials or powders from interconnecting piping with different storage bins, or from different materials delivered to the storage bin or hopper. Accordingly, system 500 enhances the confidence level for adding to a blend the correct materials in their suitable condition. Accordingly, embodiments consistent with the present disclosure decrease the likelihood of ruined bulk material or powder batches being disposed of. Thus decreasing waste disposal costs and material costs to the plant. Methods and systems consistent with the present disclosure also decrease the likelihood of compromised bulk material blends: arriving on location, mixing in a blend, and pumped into a borehole. This also decreases the cost of poor quality, and the likelihood of downtime due to test and repair of damaged structures. Furthermore, embodiments consistent with the present disclosure decrease occurrence of equipment damage due to flash setting in the mixing and pumping system and/or poor slurry mixability.

**[0081]** FIG. 6 illustrates a conveyor 600 in a pneumatic conveying system using optical flow characterization data obtained with optical computing devices 506h, 506i, and 506j, according to some embodiments. Consistent with embodiments disclosed herein, conveyor 600 may be located upstream or downstream of a scale tank (e.g., scale tank 510 of FIG. 5) to form a blend with different bulk materials or powders. Optical computing devices 506h-j measure chemical compositions in flowing bulk materials or powders 501 under rapid flow

conditions in a pneumatic tube such as transfer tube 507. More generally, embodiments of the present disclosure may include a transfer tube 507 that is part of other type of conveyor system, such as a screw conveyor (with a helicoid blade rotating along the axis of transfer tube 507), or a gravity-based conveying system, where transfer tube 507 makes an angle with the horizontal to facilitate displacement of bulk material or powder 501 by gravity. Accordingly, optical computing device 506 makes measurements at the speed it takes to collect an electromagnetic signal in an optical detector (e.g., detectors 324 and 328, cf. FIG. 3). As such, rapidly flowing fluids and powders can be measured using optical computing device 506 because bulk material and powder 501 moves slowly relative to the measurement speed of optical computing device 506. In some embodiments, optical computing devices 506h-j measure moisture content of materials in a high velocity pneumatic transfer drying system. Optical computing devices 506h-j may also be used in other material conveying systems with a reduced rate of material transfer, as known in the art. In that regard, real time measurement of the moisture content of the air in the pneumatic transfer tube 507 flow would be valuable to detect potentially negative conditions associated with high moisture levels or high relative humidity.

**[0082]** The optical computing devices 506h-j may each be communicably coupled to a signal processor 634 configured to process data obtained by each optical computing devices 506h-j. Some embodiments include optical computing devices 506 mounted on a wall of transfer tube 507, or inside the transfer tube in a rod, tube, pipe, or other structure exposed to the flow of bulk material or powder 501. In some embodiments, optical computing devices 506 may be located along a direction substantially perpendicular to the direction of flow of the bulk material or powder in transfer tube 506. Optical computing device 506 is able to detect different flow types 601, 602, and 603 of bulk material or powder 501 flowing through transfer tube 507 and in what portion of transfer tube 507. For example, flow type 601 includes material flow aerated at the top of transfer tube 507, flow type 602 may include more dense material flow in the middle portion of transfer tube 507, and flow type 603 may include an even more dense material flow at the bottom portion of transfer tube 507.

**[0083]** In some embodiments, flow types 601, 602, and 603 relate to a segregation of the material flow according to a particle size, with flow type 601 at the top mostly including fines (reduced size particles), and flow type 603 at

the bottom containing coarser particles of the same neat or blended material. Accordingly, embodiments of the present disclosure enable determining a flow profile in conveyor 600 and, more particularly, within transfer tube 507. Flow types 601, 602, and 603 may be apparent when the transfer tube 507 is horizontally positioned. However, there is no limitation to the specific orientation of transfer tube 507 with respect to gravity. More generally, conveyor 600 may be oriented at any angle relative to horizontal or gravity, including vertically oriented or any angular configuration between horizontal and vertical.

**[0084]** Moreover, while FIG. 6 illustrates a straight transfer tube 507, there is no limitation as to the specific shape of transfer tube 507 in conveyor 600. In some embodiments, for instance, conveyor 600 may include an elbow portion having a curve or even a sharp angle (e.g., a 90° angle). There is also no limitation as to the number of flow types that may be present inside conveyor 600. For example, some embodiments may include multiple flow types (e.g., two-phase, dense phase, or dilute phase flow), or a homogeneously aerated flow throughout (e.g., dilute phase flow).

**[0085]** In some embodiments, data obtained with characterization of the flow through transfer tube 507 by optical measurement systems 400 enables improving performance of the transfer system. Accordingly, using data from optical measurement systems 400, the conveying airflow rate (e.g., through pump 530 of FIG. 5) may be adjusted to provide a homogeneous flow moving at a desired speed. Some embodiments use data from optical measurement systems 400 to adjust conveying air pressure (e.g., through compressor 540, cf. FIG. 5), and piping layout (e.g., length, diameter, orientation, and trajectory of transfer tubes 506). In some embodiments, a flow profile provided by optical measurement systems 400 may indicate when blended materials (e.g., downstream from scale tank 510, cf. FIG. 5) are segregating during the pneumatic transfer. Furthermore, some powders may have a tendency to adhere to the inside surface of transfer tube 507, forming a layer or a plaque of residual material that may eventually corrode or damage transfer tube 507. The residual material eventually reduces material flow rate, or some constituents may be lost to the blend, thus affecting the blend's performance and/or contaminating following, possibly different blends. Accordingly, optical measurement systems 400 may determine material deposition in portions of the interior surface of transfer tube 507, and even determine thickness, shape, and

size of the layer of residual material. Accordingly, adjusting airflow rate and pressure in real time produces a desired conveying rate with reduced material segregation and maintained blend quality.

**[0086]** Some embodiments include at least two optical computing devices 506 arranged at selected positions along a direction of flow of the bulk material or powder in transfer tube 507. A time correlation of measurements between two or more optical computing devices 506 along transfer tube 507 enables measurement of flow velocities of bulk material or powder 501. For example, in a "slug" flow type, relatively rarefied portions of flow follow dense portions of material ("slugs"). In such conditions, optical computing device 506 may detect the passage of the slug by a change in the density of the material flow. Accordingly, a first optical computing device 506 may record the passage of a slug at a first time and a first position. Thus, and a second optical computing device records the passage of the slug at a second time and a second position; thus, signal processor 634 may determine the velocity or flow rate of the slug by correlating the measurements of optical computing devices 506h and 506j. In embodiments where little material is transferred the first and second optical computing devices 506 record the passage of discrete portions of material forming a first and a second string of high and low density measurements. Signal processor 634 obtains the speed of material flow by correlating the first and second strings of measurements in time, with knowledge of the distance separating the first and second optical computing devices 506.

**[0087]** FIG. 7 illustrates a flowchart including steps in a method 700 for operating a pneumatic conveying system using optical flow characterization data, according to some embodiments. Embodiments consistent with method 700 include operating a pneumatic conveyor in a system for storing and conveying materials from containers to transport units (e.g., conveyor 600, cf. FIG. 6, and system 500, cf. FIG. 5). A pneumatic conveyor as used in some embodiments of method 700 may include a transfer tube as any one of transfer tubes 507 in FIG. 5. Accordingly, a pneumatic conveyor in methods consistent with method 700 may include at least one optical computing device that has an ICE, a detector, and a signal processor (e.g., detectors 324 and 328, and signal processor 334, cf. FIG. 3, and optical computing device 506, cf. FIG. 4). In some embodiments the optical computing device is mounted on a transfer tube to detect a flow type of a bulk material or powder (e.g., optical computing device

506, transfer tube 507, bulk material or powder 501, and flow types 601, 602, 603, cf. FIG. 6). In some instances, at least one of the steps in method 700 includes using computers and optionally artificial neural networks. For example, in some embodiments at least one or more of the steps in method 700 is performed by a signal processing circuit including a memory circuit storing commands executed by a processor circuit (e.g., signal processor 534, processing circuit 536, and memory circuit 537, cf. FIG. 5). Steps in methods consistent with the present disclosure may include at least any of the steps in method 700, performed in any order. Furthermore, embodiments consistent with the present disclosure may include one or more of the steps in method 700 performed overlapping in time, or simultaneous in time.

**[0088]** Step 710 includes optically interacting a flow of bulk material or powder in a pneumatic conveyor with an ICE. In some embodiments, step 710 includes providing an electromagnetic radiation source, and in some embodiments step 710 may include using an electromagnetic radiation generated internally in the pneumatic conveyor (e.g., by a flare sparked inside a transfer tube). Further, in some embodiments step 710 includes using a natural electromagnetic radiation from the sun or any other natural source of electromagnetic radiation. Step 720 includes detecting the modified electromagnetic radiation resulting from optically interacting the flow of bulk material or powder with the ICE, in the detector. In some embodiments, step 720 includes processing a detector signal with the signal processor. Accordingly, processing a detector signal may include finding a time correlation between signals provided by at least two optical measurement systems disposed at selected locations.

**[0089]** Step 730 includes producing an output signal correlated with the characteristic of the flow of bulk material or powder. In some embodiments, step 730 includes determining the characteristic of the flowing bulk material or powder. The characteristic of the bulk material or powder may be an identification of the bulk material or powder, a purity value (e.g., 98%, 99% concentration or higher), a contaminant concentration value, a moisture concentration value, a particle size value, a homogeneity, an air content, and a flow speed, among others. In some embodiments, determining a particle size is useful in determining a quality of the bulk material or powder stored in the container within the system for storing and conveying raw materials. For

example, larger particle sizes that can lead to a reduced strength set cement may benefit from a strengthening cement slurry additive (e.g., fibers or other resilient particles). In the other hand, bulk materials or powders with a smaller particle size typically use more water to hydrate completely because of the increased surface area relative to weight.

**[0090]** Step 740 includes modifying flow parameters to maintain the quality of a blend according to the characteristic of the flow of bulk material or powder. In some embodiments, step 740 includes adjusting flow parameters to improve or maintain the quality of a blend according to the value of the characteristic of the flowing bulk material or powder. For example, step 740 may include storing the collected data and correlating the data with a success or failure measure. In some embodiments step 740 includes correlating a measurement from the at least one optical computing device with a determination that a cement mix was satisfactory, or not. Step 740 may also include reducing blend segregation and degradation, thus increasing blend homogeneity and maintaining blend quality.

**[0091]** Step 750 includes modifying flow parameters to reduce maintenance and equipment cost according to the characteristic of the flow of bulk material or powder. Further, in some embodiments step 750 includes providing data for material conveying tests, and incorporating the data in models including economic factors. Some of the economic factors may include the cost of equipment in the conveying system (e.g., pumps, air compressors, pipes of given length and diameter), and the structures in which the system will be deployed (i.e., pipeline layout). Accordingly, step 750 may include optimizing the piping layout design in the material conveying system, thus reducing installation costs due to a reduced number of components such as pipes, pumps and compressors. Step 750 may include reducing piping material cost due to a reduced number of components, and reducing maintenance cost from a better and more detailed knowledge of component erosion (e.g., on the inside face of the transfer tubes) provided by step 730.

**[0092]** Step 750 may include optimizing, with the data provided in step 730, the conveying airflow through the system, and reducing equipment cost due to smaller size equipment being purchased. In some embodiments, step 750 includes reducing energy consumption, cost, and environmental impact of the material conveying system throughout the life of the system. And reducing



the amount of time to complete a batch and deliver a material blend to the well site on or ahead of time. This reduces for example the number of failed cement jobs, which can save costs in terms of liability and repair.

**[0093]** When the system detects a discrepancy in the material  
5 contained in the transfer tube versus the criteria stored in the system, some embodiments shut down the transfer process in the transfer system. For example, a valve in a transfer tube between a storage container and the scale tank may be closed. Or a valve in a transfer tube between the scale tank and a transportation unit may be closed. Some embodiments issue a warning (pop-  
10 up) on the screen of the HMI, stating what the discrepancy is, and that the operator may address before allowing continued operation of the material transfer from the storage container to the scale tank. In some embodiments, the HMI is configured to record the alert event and the operator's response to the warning in the system for later reporting.

**[0094]** It is recognized that the various embodiments herein directed to  
15 computer control and artificial neural networks, including various blocks, modules, elements, components, methods, and algorithms, can be implemented using computer hardware, software, combinations thereof, and the like. To illustrate this interchangeability of hardware and software, various illustrative  
20 blocks, modules, elements, components, methods and algorithms have been described generally in terms of their functionality. Whether such functionality is implemented as hardware or software will depend upon the particular application and any imposed design constraints. For at least this reason, it is to be recognized that one of ordinary skill in the art can implement the described  
25 functionality in a variety of ways for a particular application. Further, various components and blocks can be arranged in a different order or partitioned differently, for example, without departing from the scope of the embodiments expressly described.

**[0095]** Computer hardware used to implement the various illustrative  
30 blocks, modules, elements, components, methods, and algorithms described herein can include a processor configured to execute one or more sequences of instructions, programming stances, or code stored on a non-transitory, computer-readable medium. The processor can be, for example, a general purpose microprocessor, a microcontroller, a digital signal processor, an  
35 application specific integrated circuit, a field programmable gate array, a

programmable logic device, a controller, a state machine, a gated logic, discrete hardware components, an artificial neural network, or any like suitable entity that can perform calculations or other manipulations of data. In some embodiments, computer hardware can further include elements such as, for example, a memory (e.g., random access memory (RAM), flash memory, read only memory (ROM), programmable read only memory (PROM), erasable read only memory (EPROM)), registers, hard disks, removable disks, CD-ROMs, DVDs, or any other like suitable storage device or medium.

**[0096]** Executable sequences described herein can be implemented with one or more sequences of code contained in a memory. In some embodiments, such code can be read into the memory from another machine-readable medium. Execution of the sequences of instructions contained in the memory can cause a processor to perform the process steps described herein. One or more processors in a multi-processing arrangement can also be employed to execute instruction sequences in the memory. In addition, hard-wired circuitry can be used in place of or in combination with software instructions to implement various embodiments described herein. Thus, the present embodiments are not limited to any specific combination of hardware and/or software.

**[0097]** As used herein, a machine-readable medium will refer to any medium that directly or indirectly provides instructions to a processor for execution. A machine-readable medium can take on many forms including, for example, non-volatile media, volatile media, and transmission media. Non-volatile media can include, for example, optical and magnetic disks. Volatile media can include, for example, dynamic memory. Transmission media can include, for example, coaxial cables, wire, fiber optics, and wires that form a bus. Common forms of machine-readable media can include, for example, floppy disks, flexible disks, hard disks, magnetic tapes, other like magnetic media, CD-ROMs, DVDs, other like optical media, punch cards, paper tapes and like physical media with patterned holes, RAM, ROM, PROM, EPROM, and flash EPROM.

**[0098]** Embodiments disclosed herein include:

**[0099]** A. A method that includes optically interacting a flow of bulk material or powder in a pneumatic conveyor with an integrated computational element ("ICE") configured to modify an electromagnetic radiation according to a

characteristic of the flow of bulk material or powder, detecting the modified electromagnetic radiation with a detector, producing an output signal with a signal processor, the output signal being correlated to the characteristic of the flow of bulk material or powder, and modifying at least one of a feed rate or a differential air pressure in the pneumatic conveyor in response to the characteristic of the flow of bulk material or powder, wherein the bulk material or powder comprises at least one of a dry cement or a dry cement component.

**[00100]** B. A device that includes a processor circuit, and a memory circuit storing commands, which, when executed by the processor circuit, causes the device to perform a method comprising receiving a first signal from a first optical computing device at a first location in a system for storing and conveying materials, receiving a second signal from a second optical computing device at a second location in the system for storing and conveying materials, wherein the first and second signal result from a light interacted with a bulk material or a powder flowing in a transfer tube, and at least one of the first and second signals results from modifying the interacted light with an Integrated Computational Element (ICE) according to a characteristic of the flow of bulk material or powder, and determining, from the first and second signal, the characteristic of the flow of bulk material or powder along the transfer tube.

**[00101]** C. A method that includes receiving an output signal from each of a plurality of optical computing devices disposed in separate locations in a pneumatic conveyor flowing a bulk material or powder, processing each of the output signals from the plurality of optical computing devices with a signal processor, determining a characteristic of the flow of bulk material or powder based on processing of the output signals, and modifying a physical parameter of the pneumatic conveyor in response to the value of the characteristic of the flow of bulk material or powder.

**[00102]** Each of embodiments A, B, and C may have one or more of the following additional elements in any combination: Element 1: wherein the characteristic of the flow of bulk material or powder is a concentration of air in the bulk material or powder, and wherein modifying at least one of a feed rate or a differential air pressure comprises increasing an air pressure when the concentration of air in the bulk material or powder is below a threshold value. Element 2: wherein the characteristic of the flow of bulk material or powder is a moisture content of the bulk material or powder and further comprising reducing

the moisture content of the bulk material or powder when the moisture content is greater than a threshold value. Element 3: wherein the characteristic of the flow of bulk material or powder is a layer of residual material on an inner wall of the pneumatic conveyor, and modifying at least one of a material feed rate or a differential air pressure comprises increasing the flow velocity when the layer of residual material is detected on the inner wall of the pneumatic conveyor. Element 4: wherein the characteristic of the flow of bulk material or powder is a blend composition of at least two bulk materials or powders, the method further comprising adjusting an amount of one of the at least two bulk materials or powders according to a desired blend composition. Element 5: further comprising determining whether the flow of the bulk material or powder is a dense-phase, multi-phase flow or a dilute phase flow based on the characteristic of the bulk material or powder. Element 6: wherein the characteristic of the flow of bulk material or powder is a particle size of the bulk material or powder flowing in the pneumatic conveyor.

**[00103]** Element 7: wherein the first location is within a pneumatic conveyor in the system for storing and conveying materials. Element 8: wherein the second location is within a pneumatic conveyor located downstream from the first location in the system for storing and conveying materials. Element 9: wherein the first location and the second location are axially offset from each other along a pneumatic conveyor in the system for storing and conveying materials. Element 10: wherein the first location and the second location are offset along a direction substantially perpendicular to a direction of flow of a bulk material or powder in a pneumatic conveyor of the system for storing and conveying materials.

**[00104]** Element 11: wherein at least two of the plurality of optical computing devices are disposed in different locations along the direction of the flow of bulk material or powder, the method further comprising correlating in time the output signals from the at least two of the plurality of optical computing devices in the signal processor, and determining a flow rate of the bulk material or powder. Element 12: wherein determining a characteristic of the flow of bulk material or powder comprises determining a flow profile in the pneumatic conveyor. Element 13: wherein determining a characteristic of the flow of bulk material or powder comprises determining whether a flow of the bulk material or powder is a segregated flow or a homogenous flow. Element 14: wherein

modifying a characteristic of the pneumatic conveyor comprises modifying at least one of a material feed rate or a differential air pressure in the pneumatic conveyor. Element 15: wherein modifying a characteristic of the pneumatic conveyor comprises modifying at least one of a pipe length, a pipe diameter, or  
5 a pipe trajectory in the pneumatic conveyor. Element 16: wherein determining a characteristic of the bulk material or powder comprises determining at least partially a shape and a size of a layer of residual material deposited inside the pneumatic conveyor. Element 17: further comprising determining a difference in the characteristic of the flow of bulk material or powder at the different locations  
10 in the pneumatic conveyor.

**[00105]** The exemplary embodiments described herein are well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the exemplary embodiments described herein may be modified and practiced in  
15 different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered, combined, or modified and all such variations  
20 are considered within the scope and spirit of the present invention. The invention illustratively disclosed herein suitably may be practiced in the absence of any element that is not specifically disclosed herein and/or any optional element disclosed herein. While compositions and methods are described in terms of "comprising," "containing," or "including" various components or steps,  
25 the compositions and methods can also "consist essentially of" or "consist of" the various components and steps. All numbers and ranges disclosed above may vary by some amount. Whenever a numerical range with a lower limit and an upper limit is disclosed, any number and any included range falling within the range is specifically disclosed. In particular, every range of values (of the form,  
30 "from about a to about b," or, equivalently, "from approximately a to b," or, equivalently, "from approximately a-b") disclosed herein is to be understood to set forth every number and range encompassed within the broader range of values. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee. Moreover, the indefinite articles "a" or "an," as used in the claims, are defined herein to mean one or  
35

more than one of the element that it introduces. If there is any conflict in the usages of a word or term in this specification and one or more patent or other documents that may be incorporated herein by reference, the definitions that are consistent with this specification should be adopted.

5           **[00106]** As used herein, the phrase "at least one of" preceding a series of items, with the terms "and" or "or" to separate any of the items, modifies the list as a whole, rather than each member of the list (i.e., each item). The phrase "at least one of" does not require selection of at least one item; rather, the phrase allows a meaning that includes at least one of any one of the items,  
10 and/or at least one of any combination of the items, and/or at least one of each of the items. By way of example, the phrases "at least one of A, B, and C" or "at least one of A, B, or C" each refer to only A, only B, or only C; any combination of A, B, and C; and/or at least one of each of A, B, and C.

## CLAIMS

The invention claimed is:

1. A method comprising:
  - optically interacting a flow of bulk material or powder in a pneumatic conveyor with an integrated computational element ("ICE") configured to modify an electromagnetic radiation according to a characteristic of the flow of bulk material or powder;
  - detecting the modified electromagnetic radiation with a detector;
  - producing an output signal with a signal processor, the output signal being correlated to the characteristic of the flow of bulk material or powder; and
  - modifying at least one of a feed rate or a differential air pressure in the pneumatic conveyor in response to the characteristic of the flow of bulk material or powder, wherein the bulk material or powder comprises at least one of a dry cement or a dry cement component.
  
2. The method of claim 1, wherein the characteristic of the flow of bulk material or powder is a concentration of air in the bulk material or powder, and wherein modifying at least one of a feed rate or a differential air pressure comprises increasing an air pressure when the concentration of air in the bulk material or powder is below a threshold value.
  
3. The method of claim 1, wherein the characteristic of the flow of bulk material or powder is a moisture content of the bulk material or powder and further comprising reducing the moisture content of the bulk material or powder when the moisture content is greater than a threshold value.
  
4. The method of claim 1, wherein the characteristic of the flow of bulk material or powder is a layer of residual material on an inner wall of the pneumatic conveyor, and modifying at least one of a material feed rate or a differential air pressure comprises increasing the flow velocity when the layer of residual material is detected on the inner wall of the pneumatic conveyor.
  
5. The method of claim 1, wherein the characteristic of the flow of bulk material or powder is a blend composition of at least two bulk materials or

powders, the method further comprising adjusting an amount of one of the at least two bulk materials or powders according to a desired blend composition.

6. The method of claim 1, further comprising determining whether the flow of the bulk material or powder is a dense-phase, multi-phase flow or a dilute phase flow based on the characteristic of the bulk material or powder.

7. The method of claim 1, wherein the characteristic of the flow of bulk material or powder is a particle size of the bulk material or powder flowing in the pneumatic conveyor.

8. A device comprising:

a processor circuit; and

a memory circuit storing commands, which, when executed by the processor circuit, causes the device to perform a method comprising:

receiving a first signal from a first optical computing device at a first location in a system for storing and conveying materials;

receiving a second signal from a second optical computing device at a second location in the system for storing and conveying materials, wherein the first and second signal result from a light interacted with a bulk material or a powder flowing in a transfer tube, and at least one of the first and second signals results from modifying the interacted light with an Integrated Computational Element (ICE) according to a characteristic of the flow of bulk material or powder; and

determining, from the first and second signal, the characteristic of the flow of bulk material or powder along the transfer tube.

9. The device of claim 8, wherein the first location is within a pneumatic conveyor in the system for storing and conveying materials.

10. The device of claim 8, wherein the second location is within a pneumatic conveyor located downstream from the first location in the system for storing and conveying materials.



11. The device of claim 8, wherein the first location and the second location are axially offset from each other along a pneumatic conveyor in the system for storing and conveying materials.

12. The device of claim 8, wherein the first location and the second location are offset along a direction substantially perpendicular to a direction of flow of a bulk material or powder in a pneumatic conveyor of the system for storing and conveying materials.

13. A method comprising:

receiving an output signal from each of a plurality of optical computing devices disposed in separate locations in a pneumatic conveyor flowing a bulk material or powder;

processing each of the output signals from the plurality of optical computing devices with a signal processor;

determining a characteristic of the flow of bulk material or powder based on processing of the output signals; and

modifying a physical parameter of the pneumatic conveyor in response to the value of the characteristic of the flow of bulk material or powder.

14. The method of claim 13, wherein at least two of the plurality of optical computing devices are disposed in different locations along the direction of the flow of bulk material or powder, the method further comprising correlating in time the output signals from the at least two of the plurality of optical computing devices in the signal processor, and determining a flow rate of the bulk material or powder.

15. The method of claim 13, wherein determining a characteristic of the flow of bulk material or powder comprises determining a flow profile in the pneumatic conveyor.

16. The method of claim 13, wherein determining a characteristic of the flow of bulk material or powder comprises determining whether a flow of the bulk material or powder is a segregated flow or a homogenous flow.

17. The method of claim 13, wherein modifying a characteristic of the pneumatic conveyor comprises modifying at least one of a material feed rate or a differential air pressure in the pneumatic conveyor.

18. The method of claim 13, wherein modifying a characteristic of the pneumatic conveyor comprises modifying at least one of a pipe length, a pipe diameter, or a pipe trajectory in the pneumatic conveyor.

19. The method of claim 13, wherein determining a characteristic of the bulk material or powder comprises determining at least partially a shape and a size of a layer of residual material deposited inside the pneumatic conveyor.

20. The method of claim 13, further comprising determining a difference in the characteristic of the flow of bulk material or powder at the different locations in the pneumatic conveyor.

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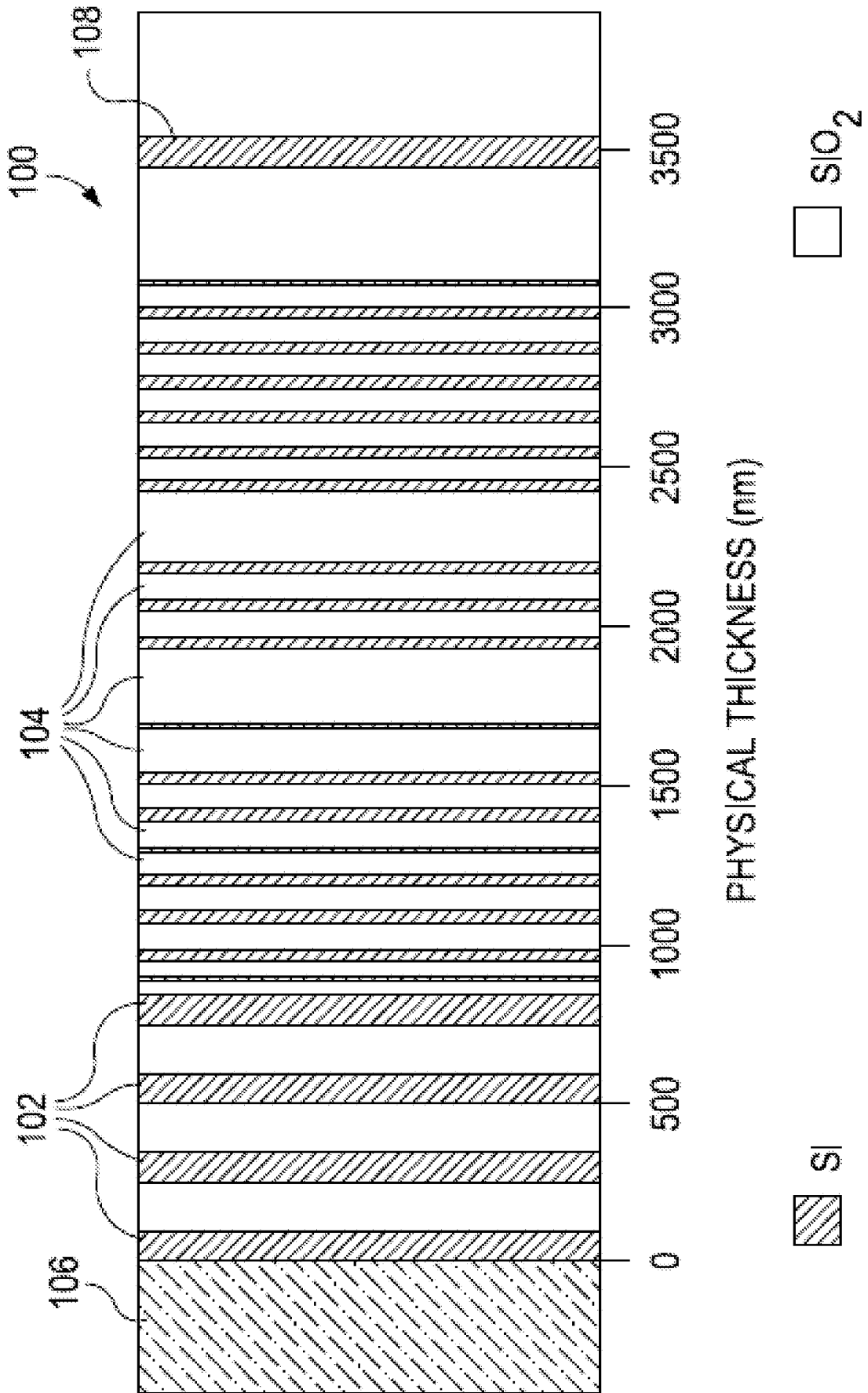


FIG. 1

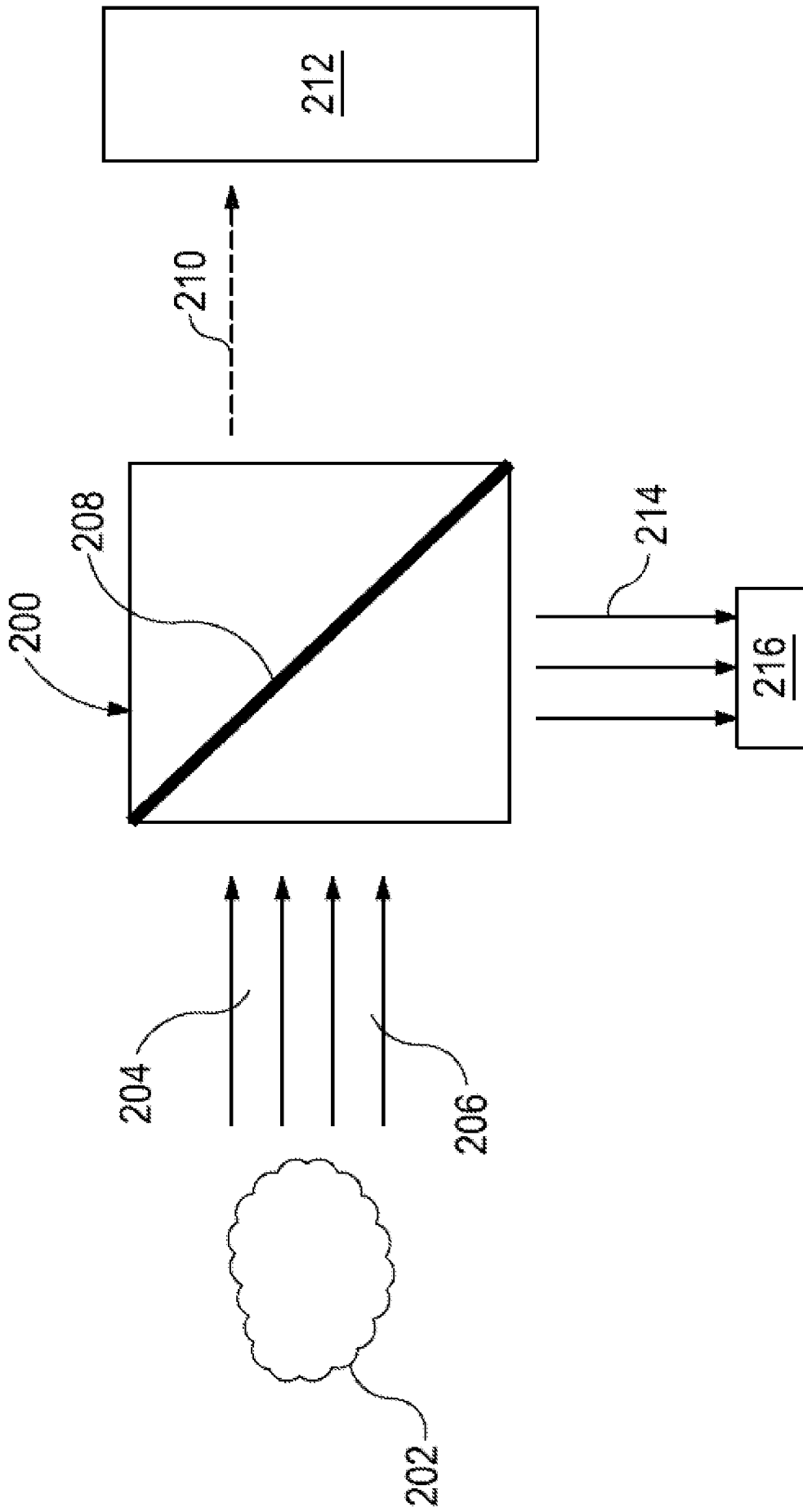


FIG. 2



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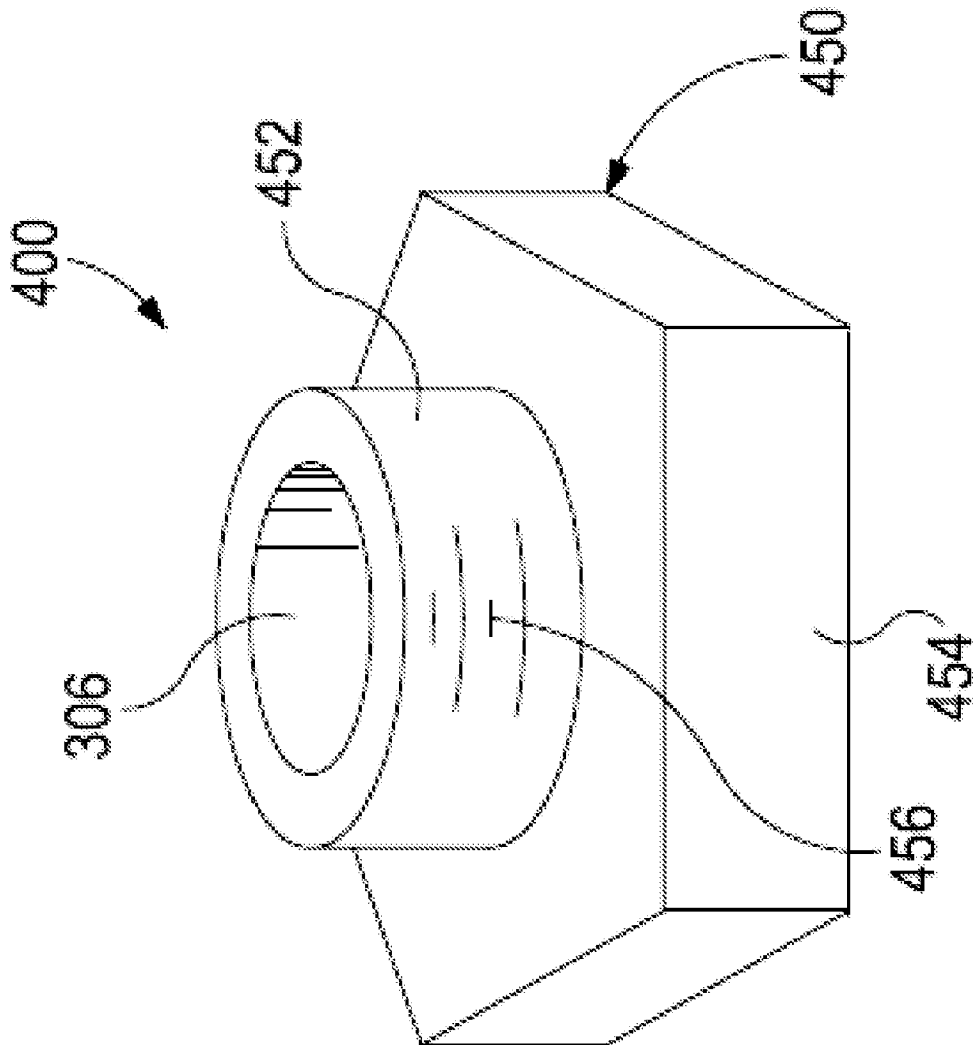


FIG. 4

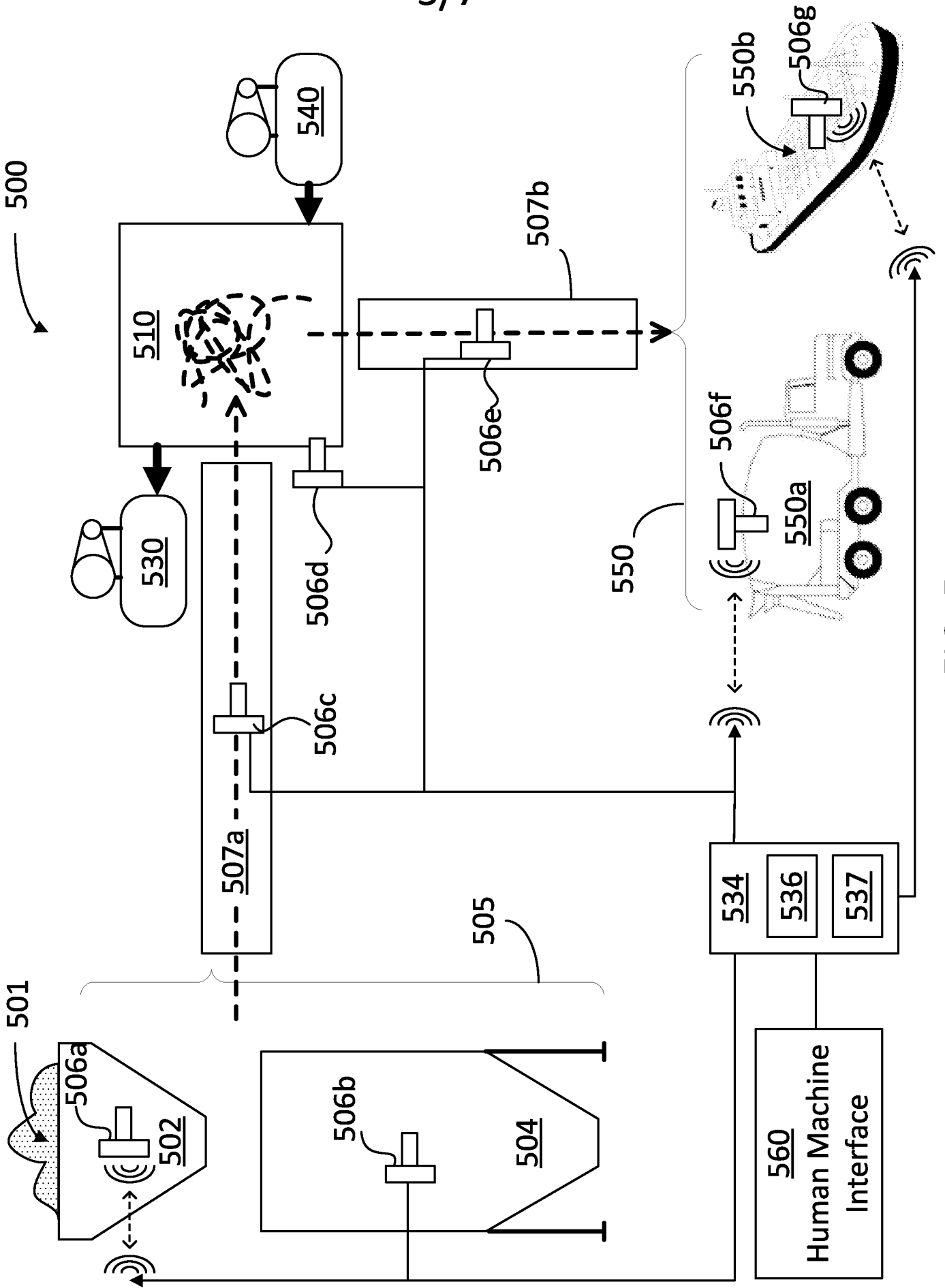


FIG. 5

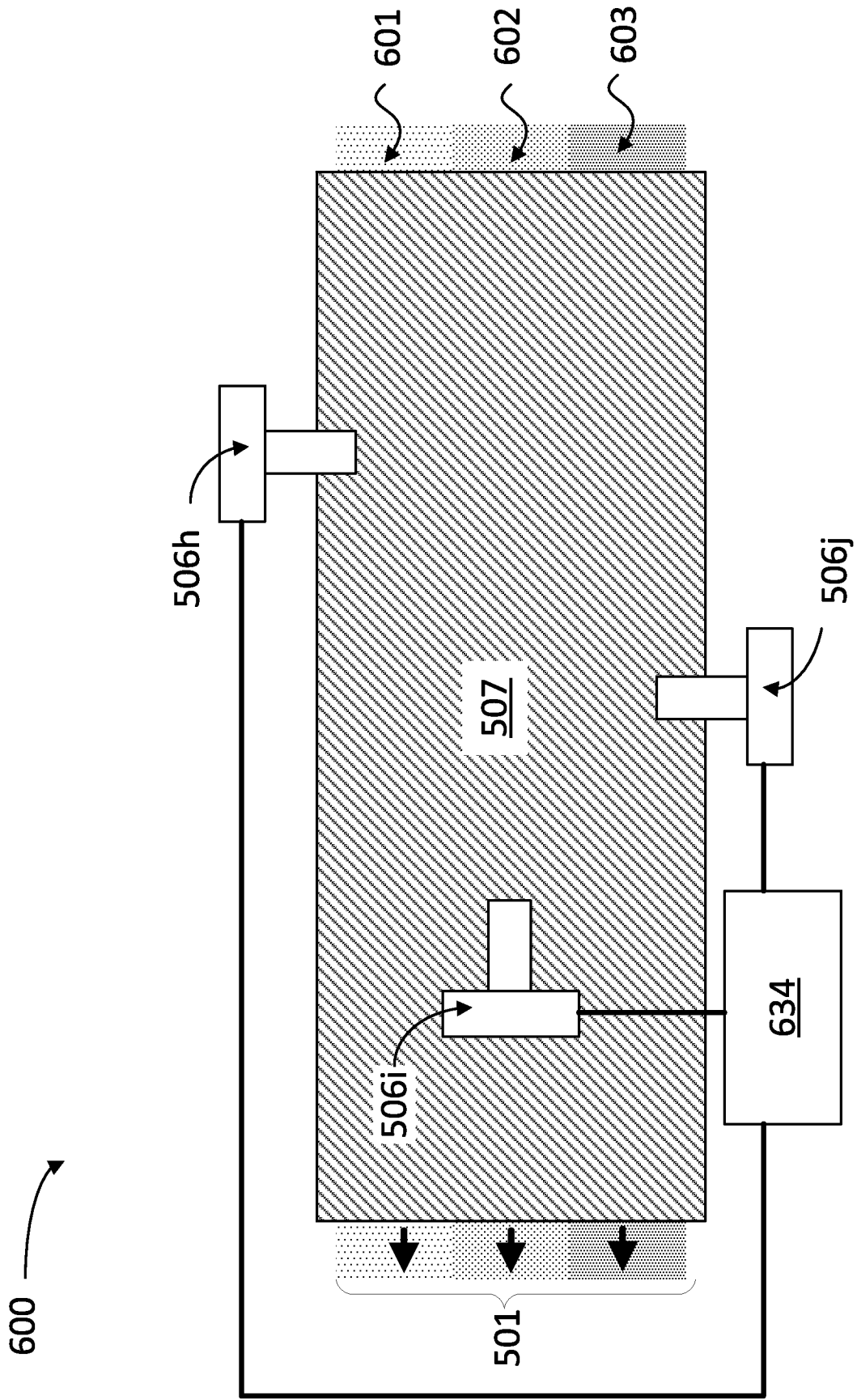


FIG. 6



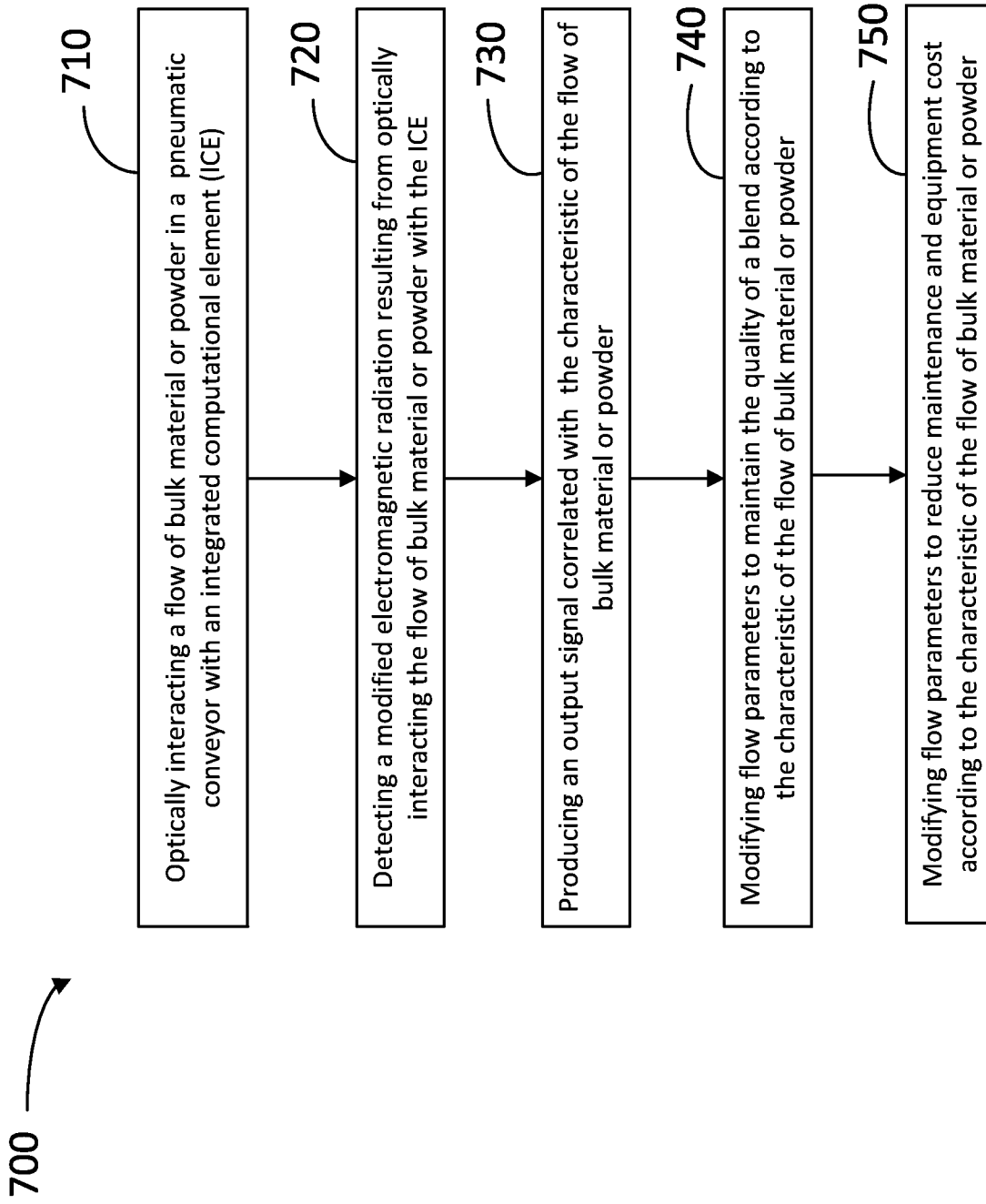


FIG. 7

**A. CLASSIFICATION OF SUBJECT MATTER****B65G 53/66(2006.01)i**

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)  
B65G 53/66; B65G 45/22; B65G 47/19; B65G 47/22; B65G 47/31; G01F 1/76Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
Korean utility models and applications for utility models  
Japanese utility models and applications for utility modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
eKOMPASS(KIPO internal) & Keywords: conveyor, optical, bulk, powder, electromagnetic, flow, radiation, processor, signal, rate, air pressure**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013-0275061 A1 (FOUAD-FAHMI, THARWAT) 17 October 2013 See abstract, paragraphs [0037], [0048], claims 12, 17, and figure 1.	13-20
A		1-12
Y	US 5141097 A (OIRY et al.) 25 August 1992 See abstract, column 4, line 12 - column 5, line 6, and figure.	13-20
A	US 5102281 A (HANDKE, WAYNE A.) 07 April 1992 See abstract, column 2, lines 25-46, and figures 1, 2.	1-20
A	US 5297667 A (HOFFMAN et al.) 29 March 1994 See abstract, column 3, line 26 - column 4, line 57, and figure 1.	1-20
A	US 8141695 B2 (KRAUS et al.) 27 March 2012 See abstract, column 6, lines 11-65, and figures 1-3.	1-20

 Further documents are listed in the continuation of Box C. See patent family annex.

\* 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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

14 July 2015 (14.07.2015)

Date of mailing of the international search report

**15 July 2015 (15.07.2015)**

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2014/062539**

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US 5297667 A	29/03/1994	WO 94-11281 A1	26/05/1994
US 8141695 B2	27/03/2012	EP 2528848 A2 JP 2013-518012 A US 2011-0186406 A1 WO 2011-092629 A2 WO 2011-092629 A3	05/12/2012 20/05/2013 04/08/2011 04/08/2011 17/11/2011