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(54) **HYPER-SPECTRAL ASSESSMENT OF MULTIPLE VARIANTS OF CANNABIS**

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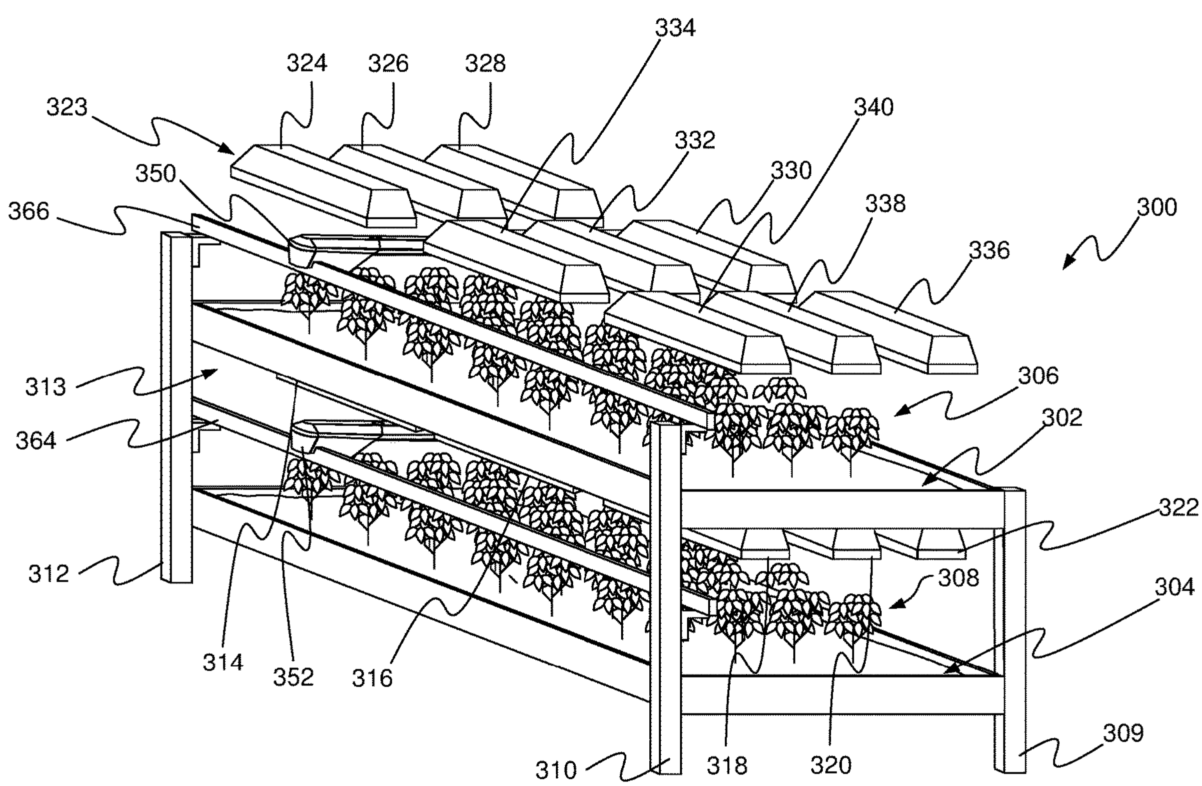
(57) **ABSTRACT**

A method of identifying NPK-deficiency includes measuring intensities of light reflected from a cannabis plant to produce intensities at a set of spectral bands, wherein the cannabis plant is one variety of a plurality of varieties of cannabis. The intensities are applied to a classifier so that the classifier provides one of an indication that the cannabis plant is NPK-deficient or an indication that the cannabis plant is NPK-sufficient, wherein the classifier has been trained using plants that include each of the plurality of varieties of cannabis.



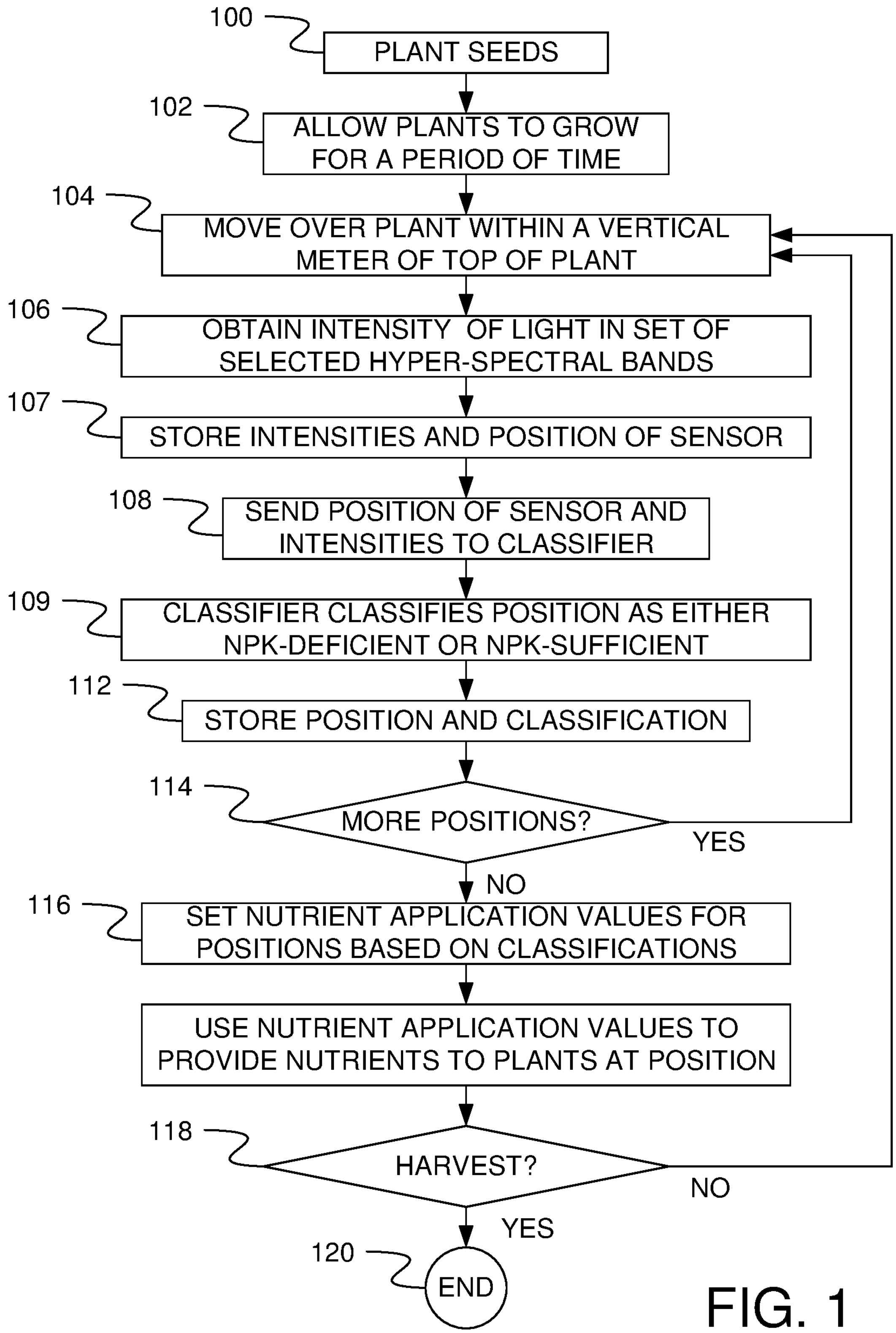

100
PLANT SEEDS
102
ALLOW PLANTS TO GROW FOR A PERIOD OF TIME
104
MOVE OVER PLANT WITHIN A VERTICAL METER OF TOP OF PLANT
106
OBTAIN INTENSITY OF LIGHT IN SET OF SELECTED HYPER-SPECTRAL BANDS
107
STORE INTENSITIES AND POSITION OF SENSOR
108
SEND POSITION OF SENSOR AND INTENSITIES TO CLASSIFIER
109
CLASSIFIER CLASSIFIES POSITION AS EITHER NPK-DEFICIENT OR NPK-SUFFICIENT
112
STORE POSITION AND CLASSIFICATION
114
MORE POSITIONS?
YES
NO
116
SET NUTRIENT APPLICATION VALUES FOR POSITIONS BASED ON CLASSIFICATIONS
USE NUTRIENT APPLICATION VALUES TO PROVIDE NUTRIENTS TO PLANTS AT POSITION
118
HARVEST?
NO
YES
120
END

FIG. 1

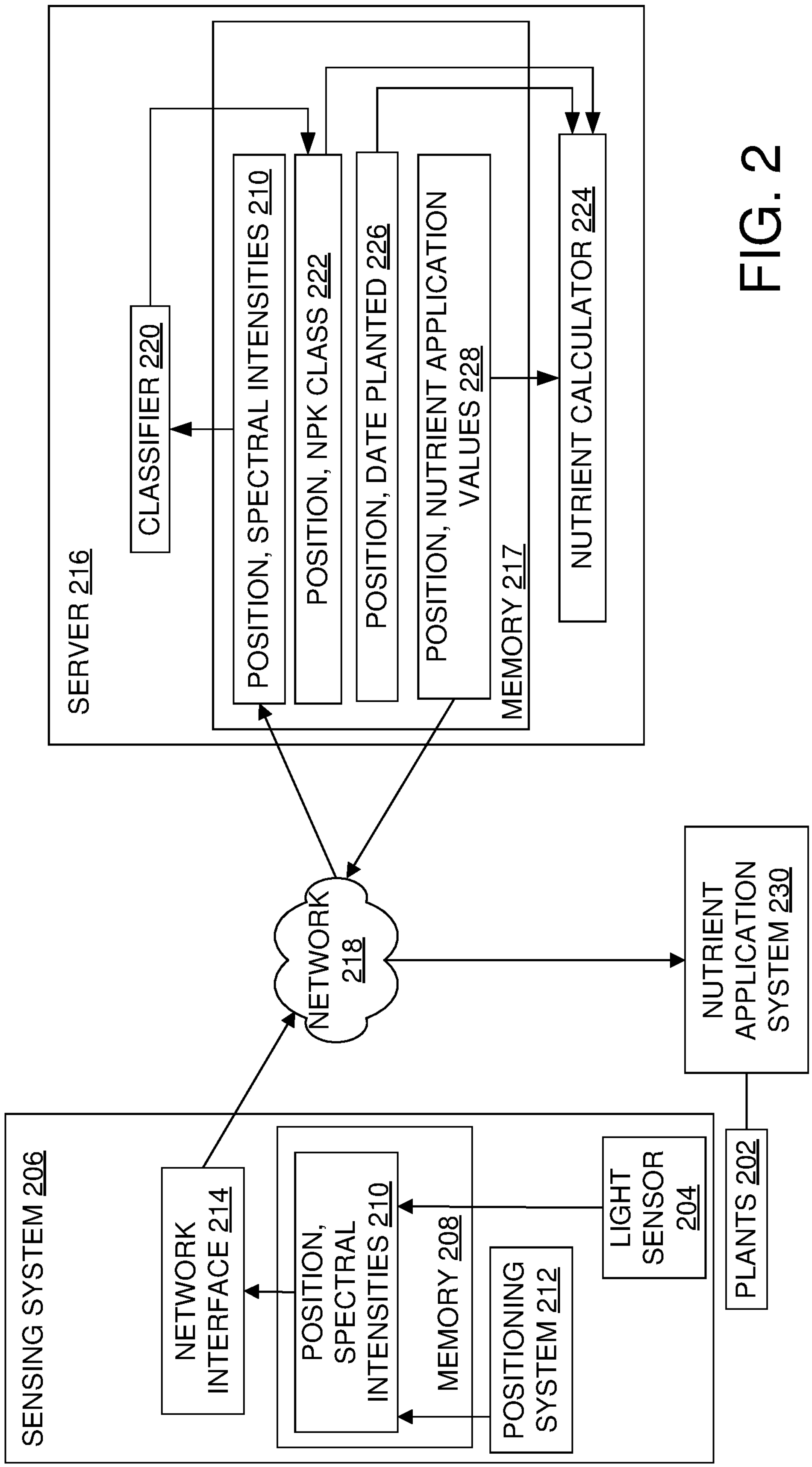

SERVER 216
CLASSIFIER 220
POSITION, SPECTRAL INTENSITIES 210
POSITION, NPK CLASS 222
POSITION, DATE PLANTED 226
POSITION, NUTRIENT APPLICATION VALUES 228
MEMORY 217
NUTRIENT CALCULATOR 224
NETWORK 218
NUTRIENT APPLICATION SYSTEM 230
PLANTS 202
SENSING SYSTEM 206
NETWORK INTERFACE 214
POSITION, SPECTRAL INTENSITIES 210
MEMORY 208
POSITIONING SYSTEM 212
LIGHT SENSOR 204

FIG. 2

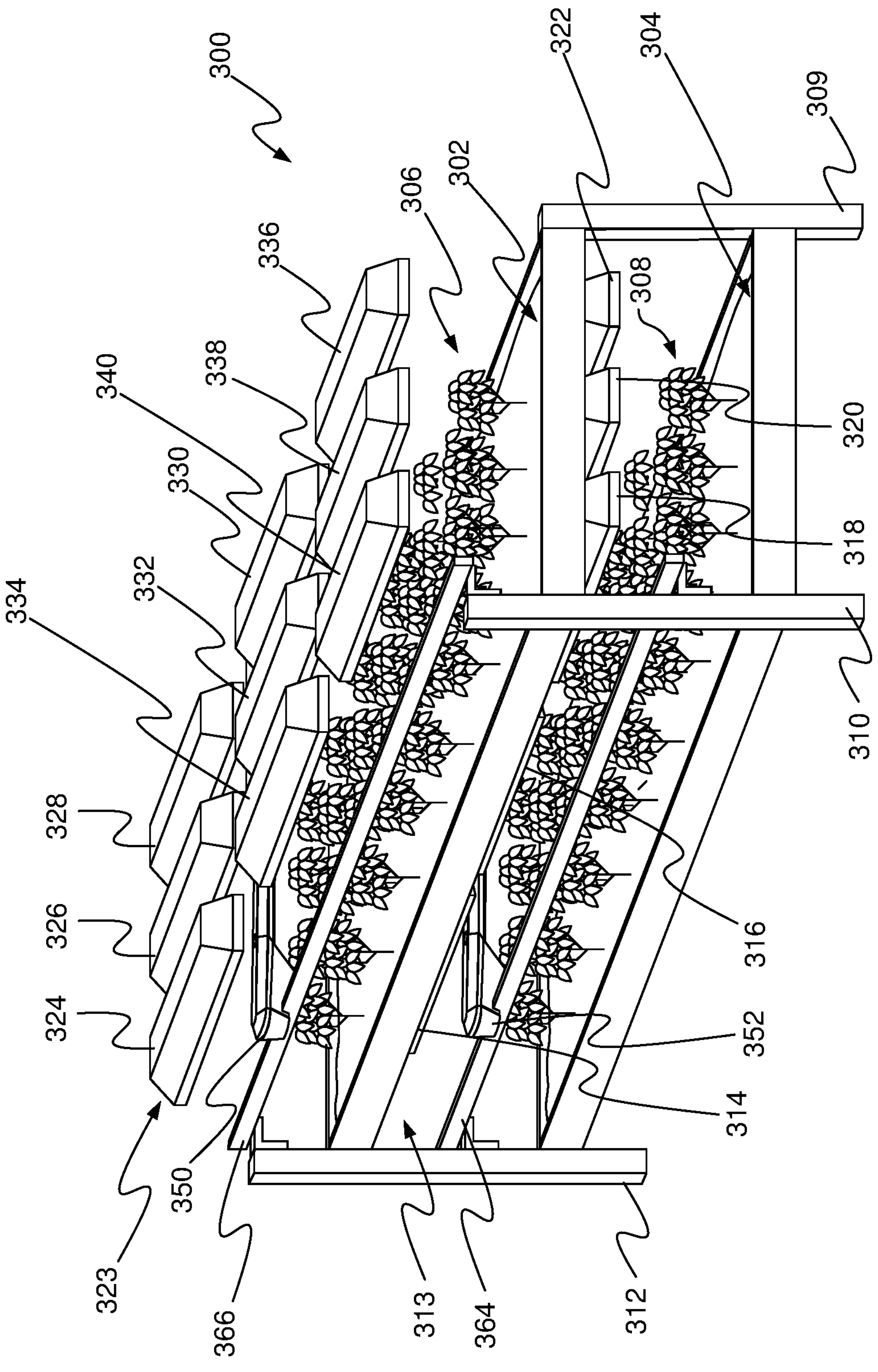

300
336
306
302
322
304
309
340
338
330
308
320
318
334
332
310
328
326
324
316
352
314
323
350
366
313
364
312

FIG. 3

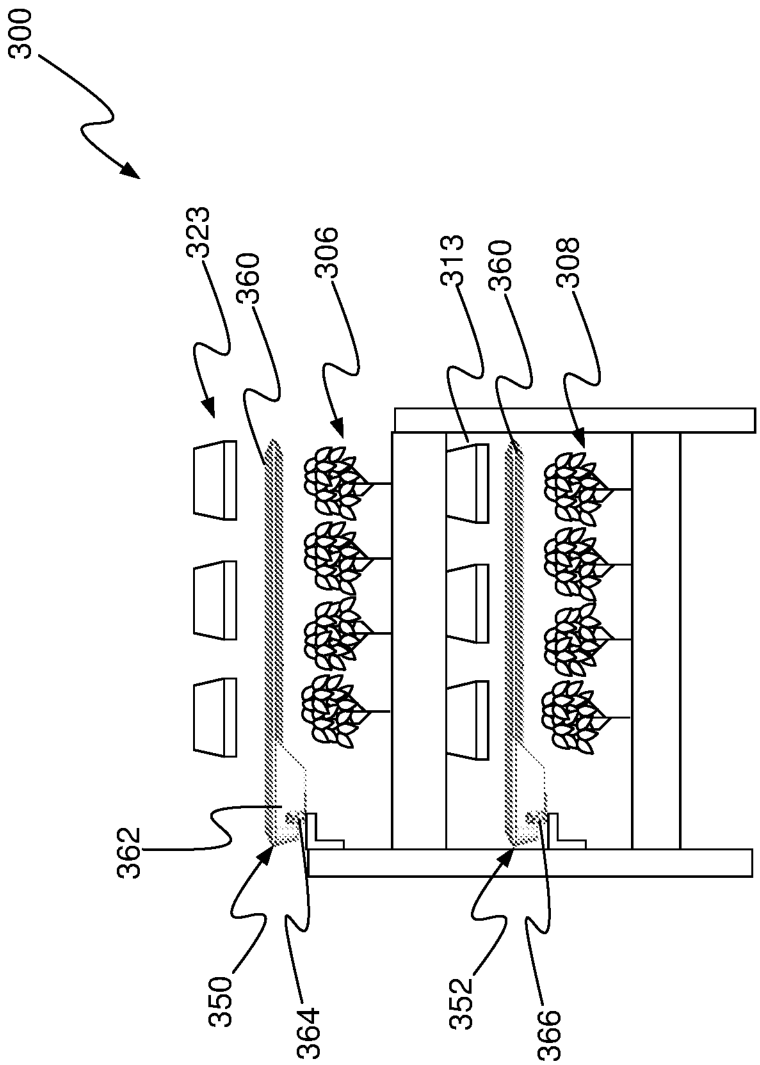


FIG. 4

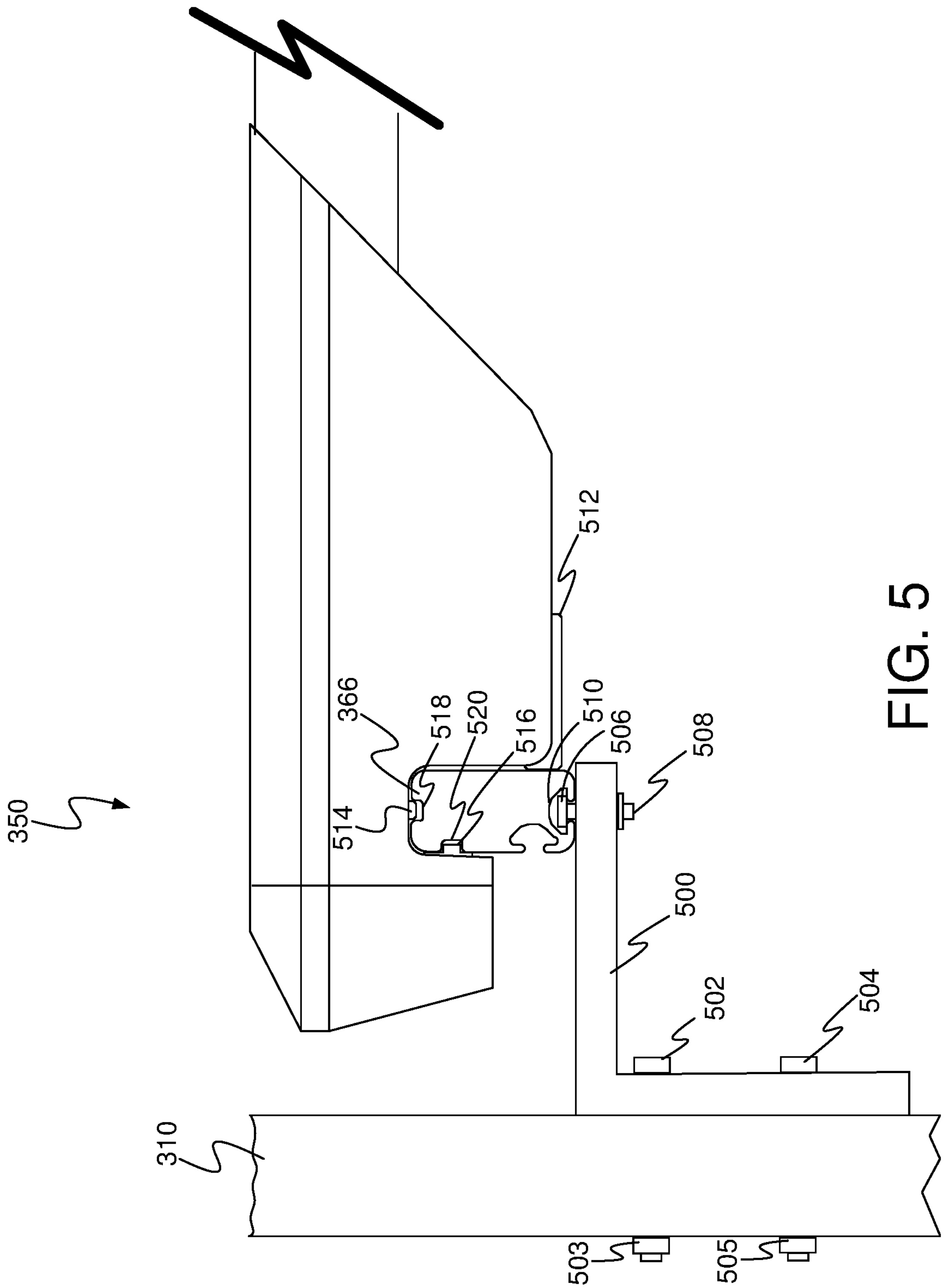


FIG. 5

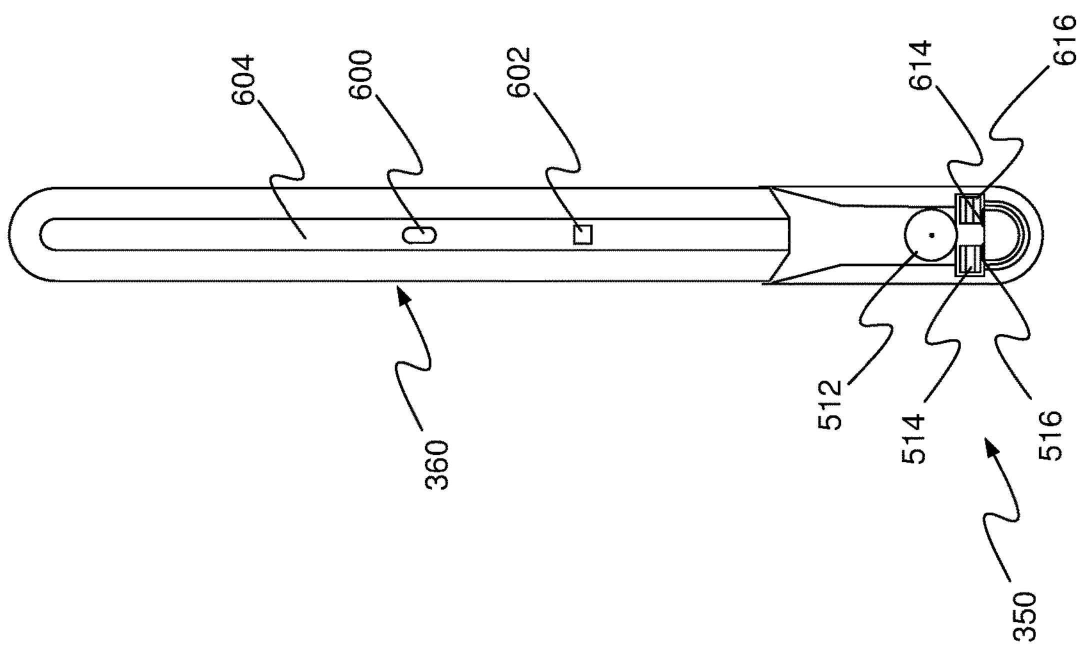


FIG. 6

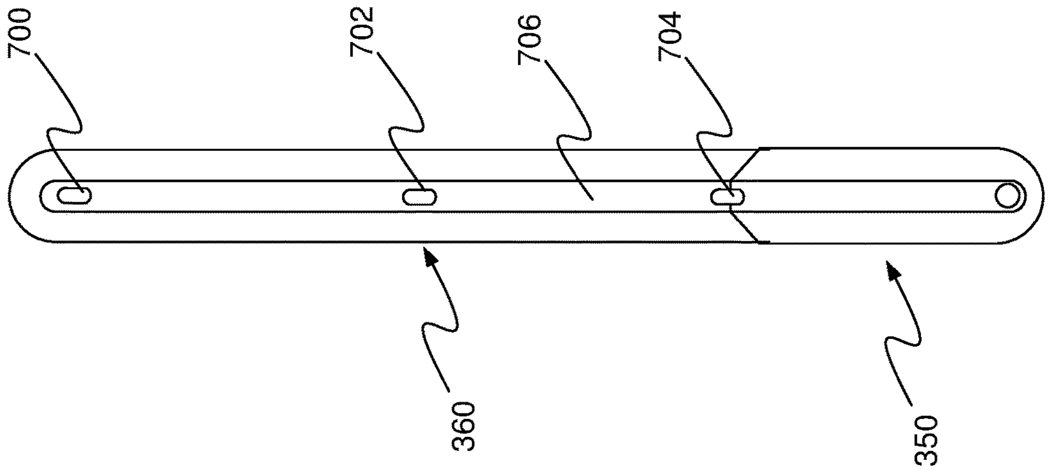


FIG. 7

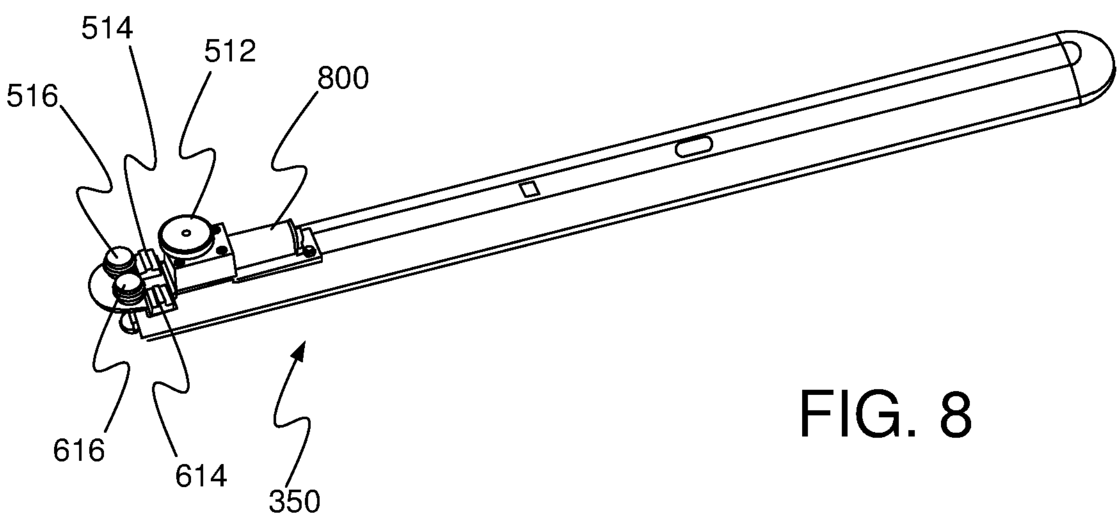


FIG. 8

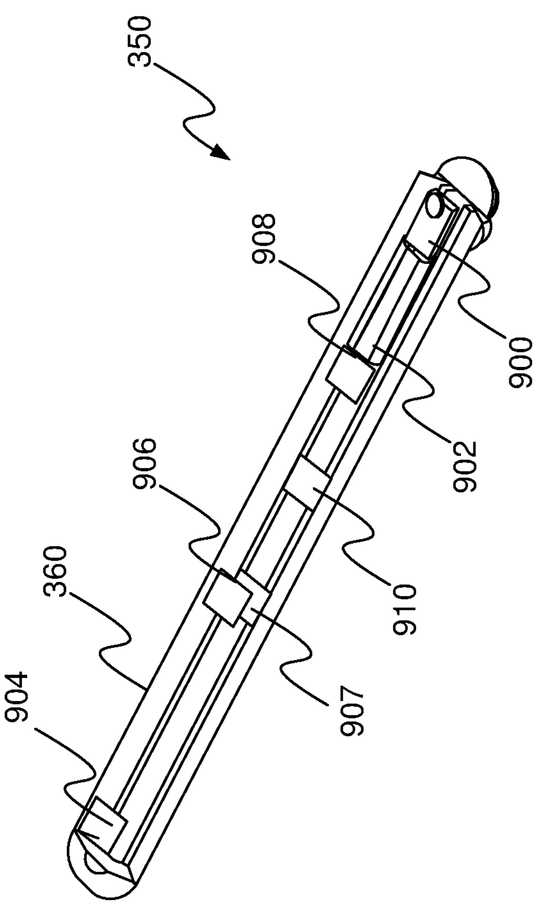


FIG. 9

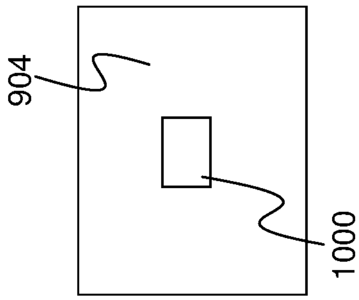


FIG. 10

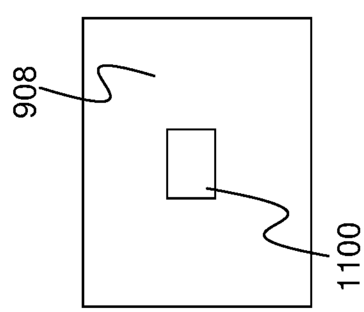


FIG. 11

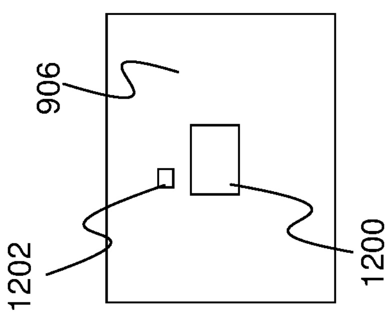


FIG. 12

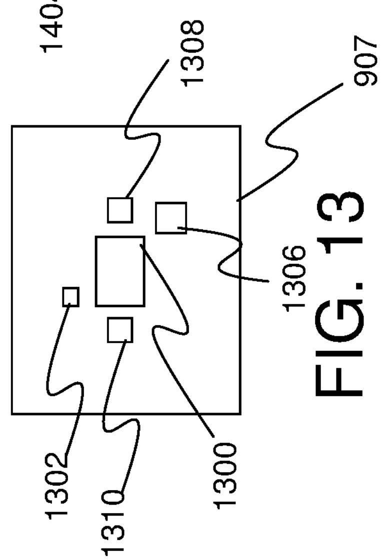


FIG. 13

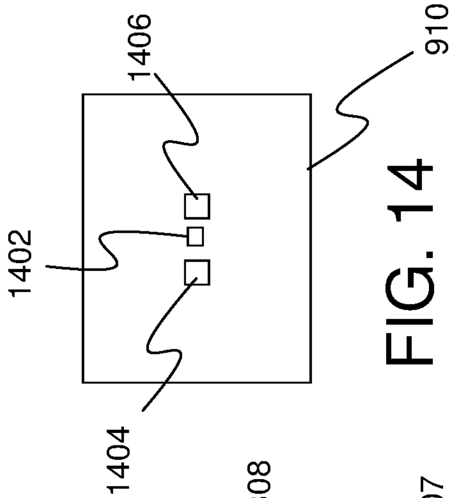


FIG. 14

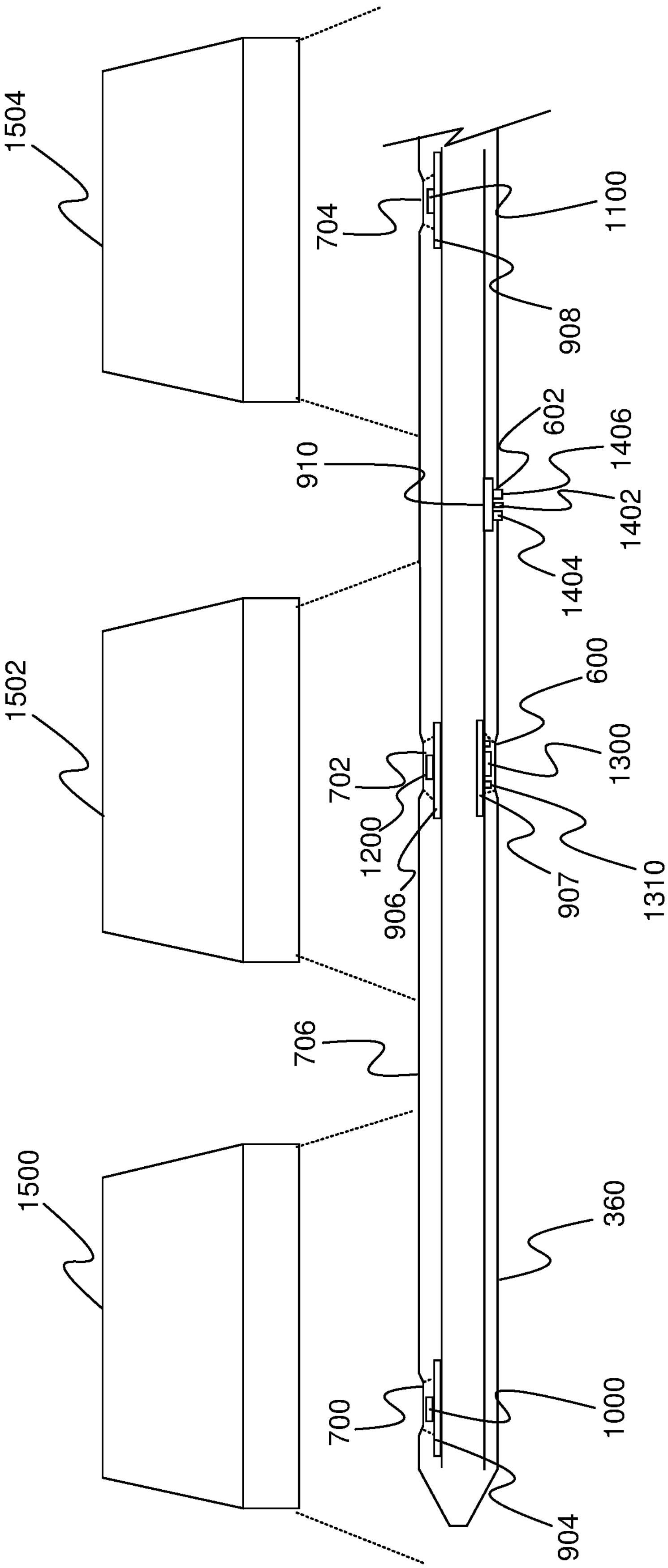

1504
704
1100
908
602
1406
910
1402
1404
1502
600
702
1300
1200
906
907
1310
706
1500
360
700
1000
904

FIG. 15

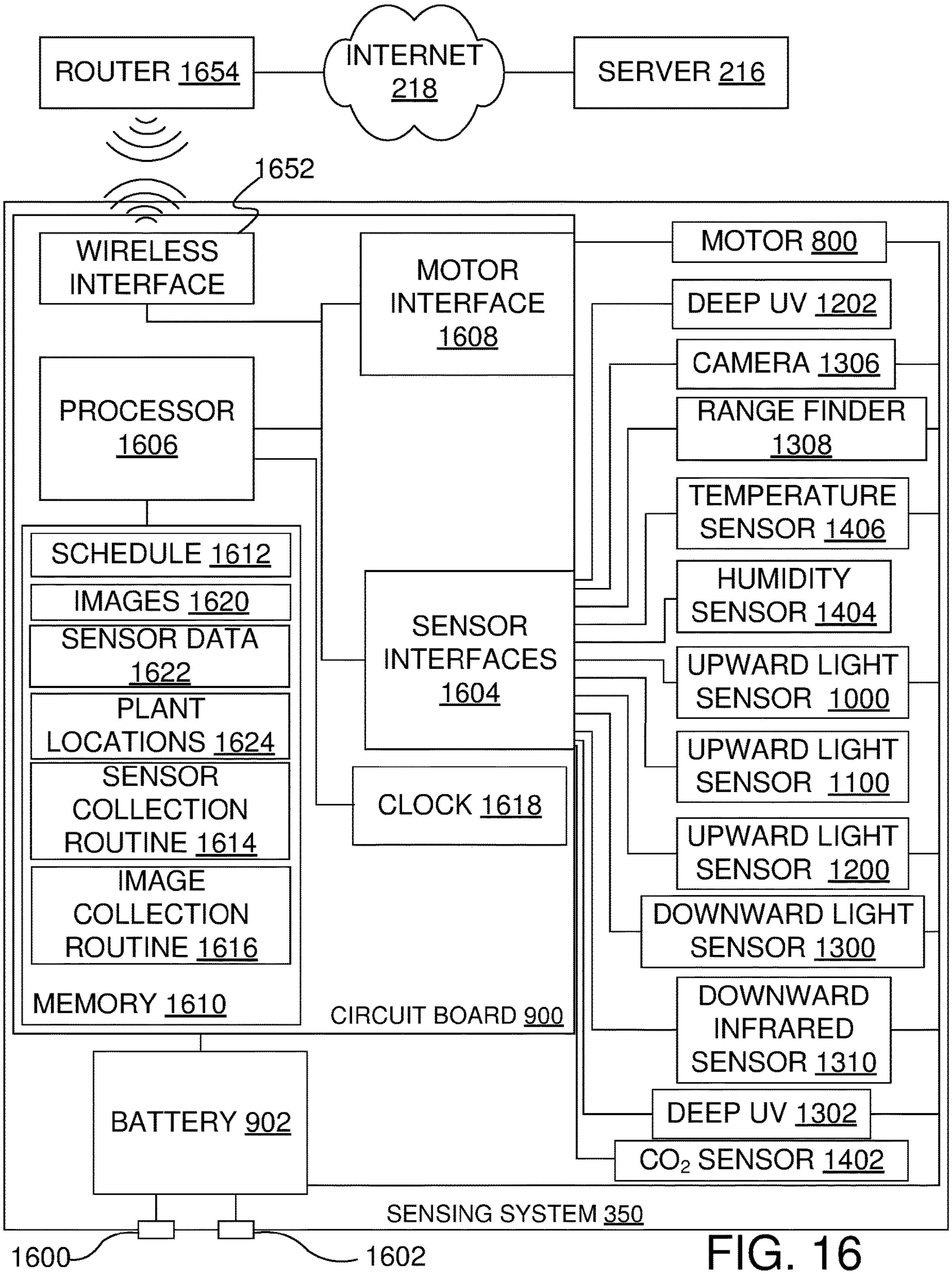

ROUTER 1654
INTERNET 218
SERVER 216
1652
WIRELESS INTERFACE
MOTOR INTERFACE 1608
PROCESSOR 1606
SCHEDULE 1612
IMAGES 1620
SENSOR DATA 1622
PLANT LOCATIONS 1624
SENSOR COLLECTION ROUTINE 1614
IMAGE COLLECTION ROUTINE 1616
MEMORY 1610
SENSOR INTERFACES 1604
CLOCK 1618
CIRCUIT BOARD 900
MOTOR 800
DEEP UV 1202
CAMERA 1306
RANGE FINDER 1308
TEMPERATURE SENSOR 1406
HUMIDITY SENSOR 1404
UPWARD LIGHT SENSOR 1000
UPWARD LIGHT SENSOR 1100
UPWARD LIGHT SENSOR 1200
DOWNWARD LIGHT SENSOR 1300
DOWNWARD INFRARED SENSOR 1310
DEEP UV 1302
CO_2 SENSOR 1402
BATTERY 902
SENSING SYSTEM 350
1600
1602

FIG. 16

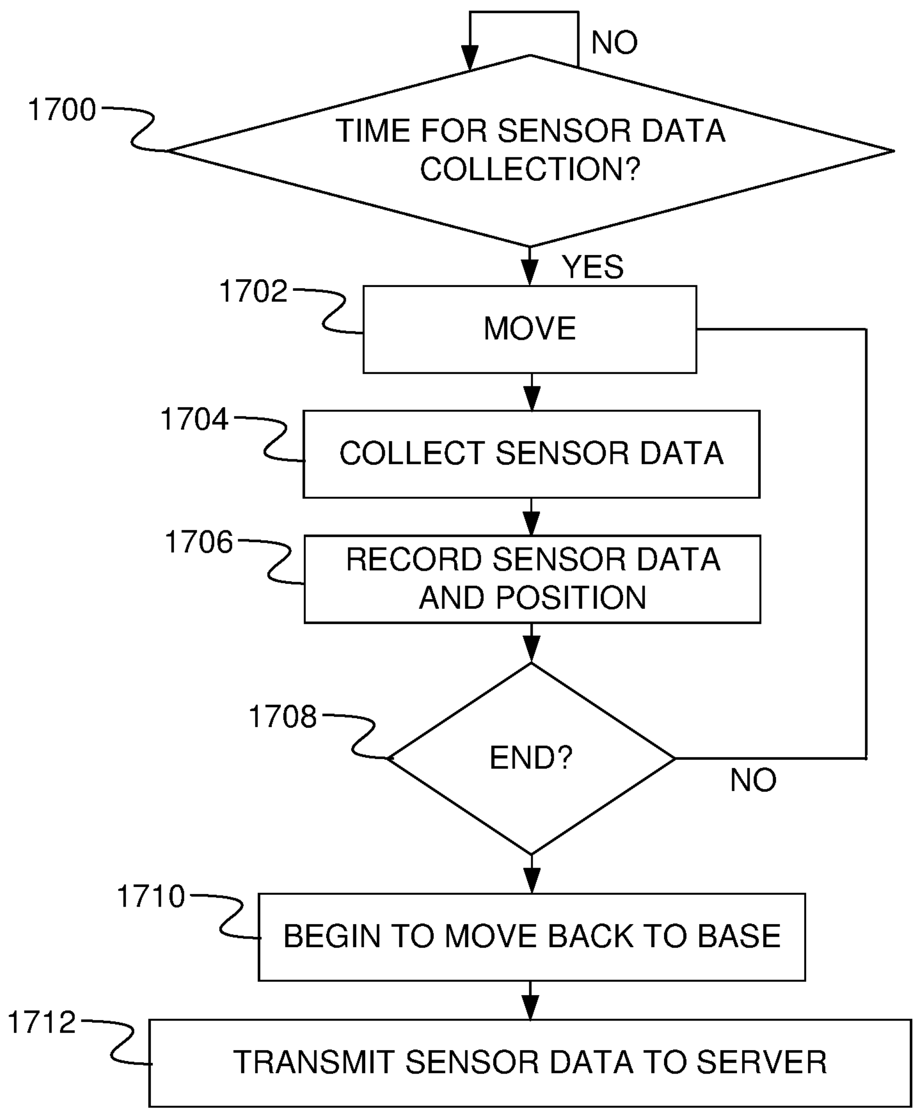

NO
1700
TIME FOR SENSOR DATA COLLECTION?
YES
1702
MOVE
1704
COLLECT SENSOR DATA
1706
RECORD SENSOR DATA AND POSITION
1708
END?
NO
1710
BEGIN TO MOVE BACK TO BASE
1712
TRANSMIT SENSOR DATA TO SERVER

FIG. 17

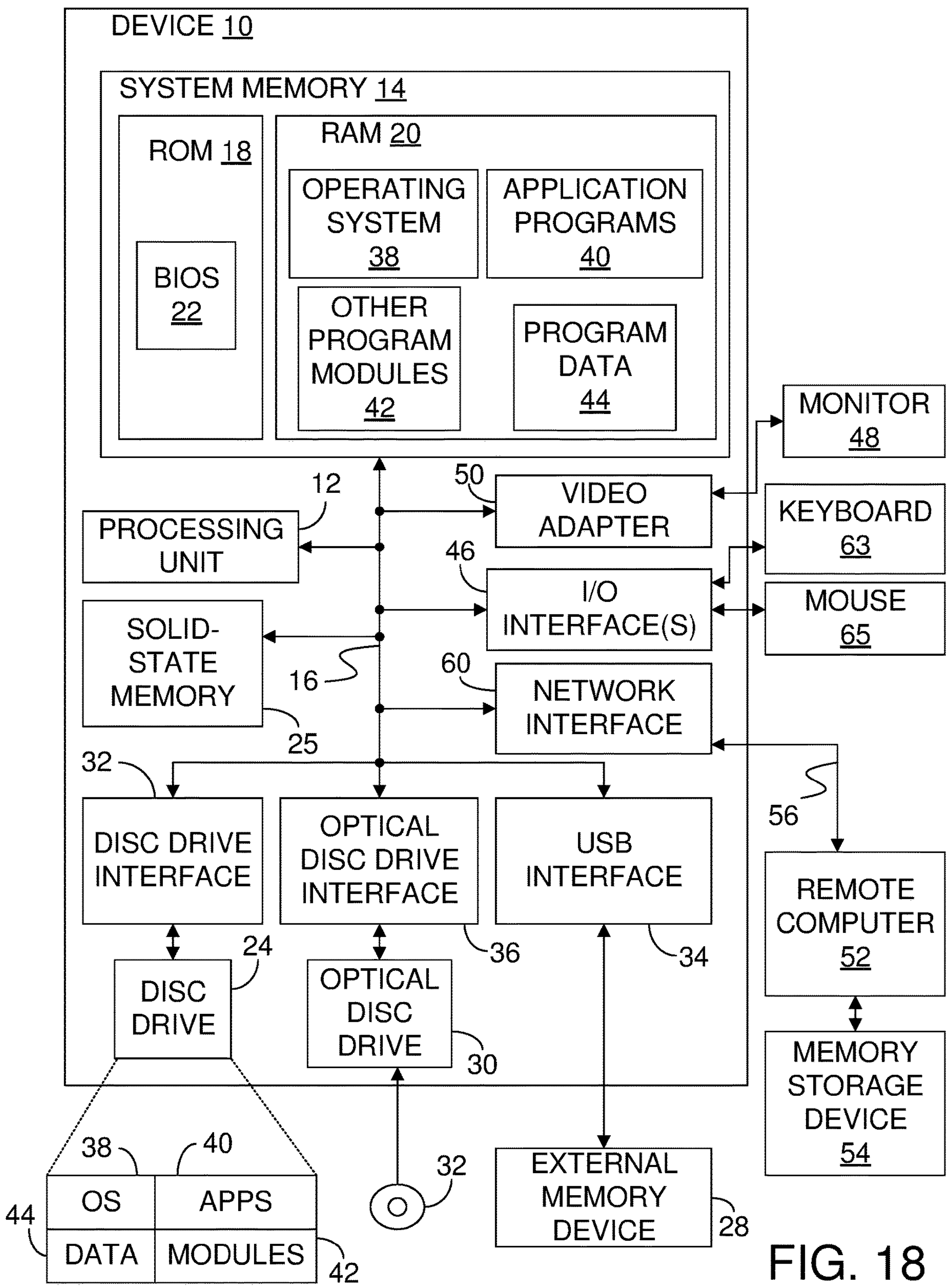

DEVICE 10
SYSTEM MEMORY 14
ROM 18
BIOS 22
RAM 20
OPERATING SYSTEM 38
APPLICATION PROGRAMS 40
OTHER PROGRAM MODULES 42
PROGRAM DATA 44
MONITOR 48
12
50
VIDEO ADAPTER
KEYBOARD 63
PROCESSING UNIT
46
I/O INTERFACE(S)
MOUSE 65
SOLID-STATE MEMORY
16
60
NETWORK INTERFACE
25
32
56
DISC DRIVE INTERFACE
OPTICAL DISC DRIVE INTERFACE
USB INTERFACE
REMOTE COMPUTER 52
24
36
34
DISC DRIVE
OPTICAL DISC DRIVE
30
MEMORY STORAGE DEVICE 54
38
40
32
OS
APPS
44
DATA
MODULES
42
EXTERNAL MEMORY DEVICE
28

FIG. 18

HYPER-SPECTRAL ASSESSMENT OF MULTIPLE VARIANTS OF CANNABIS

BACKGROUND

[0001] Nutritional deficiencies in plants reduce the yield of grow operations by limiting the growth of the plants or in worst cases, killing the plants. In particular, the inability of plants to receive enough nitrogen (N), phosphorus (P) or potassium (K) affects the yield of grow operations. At the same time, in order to be efficient and ecologically sound, grow operations do not want to add excess amounts of Nitrogen, Phosphorous or Potassium to the plant bed.

[0002] The discussion above is merely provided for general background information and is not intended to be used as an aid in determining the scope of the claimed subject matter. The claimed subject matter is not limited to implementations that solve any or all disadvantages noted in the background.

SUMMARY

[0003] A method of identifying NPK-deficiency includes measuring intensities of light reflected from a cannabis plant to produce intensities at a set of spectral bands, wherein the cannabis plant is one variety of a plurality of varieties of cannabis. The intensities are applied to a classifier so that the classifier provides one of an indication that the cannabis plant is NPK-deficient or an indication that the cannabis plant is NPK-sufficient, wherein the classifier has been trained using plants that include each of the plurality of varieties of cannabis.

[0004] In accordance with a further embodiment, a method includes placing a light sensor within a meter of a top of a plant and measuring intensities of each of a set of spectral bands of light reflected by the plant using the light sensor. The intensities are then used to classify the plant as NPK-deficient.

[0005] In accordance with a still further embodiment, a system includes a sensing system having a light sensor and a positioning system, wherein the light sensor measures intensities for light reflected from at least one cannabis plant at a plurality of spectral bands and the positioning system provides a position of the sensing system when the light sensor measured the intensities. A classifier receives the intensities and the position and provides a classification for the at least one cannabis plant at the position, wherein the classification indicates whether the at least one cannabis plant is NPK-deficient and the classification is based on the received intensities.

[0006] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a flow diagram of a method of classifying cannabis plants for nutrient applications.

[0008] FIG. **2** is a block diagram of a system for classifying cannabis plants and applying nutrients.

[0009] FIG. **3** is perspective view of an indoor grow operation.

[0010] FIG. **4** is an end view of the indoor grow operation of FIG. **3**.

[0011] FIG. **5** is an enlarged end view of a portion of the indoor grow operation.

[0012] FIG. **6** is bottom view of a sensing system in accordance with one embodiment.

[0013] FIG. **7** is a top view of the sensing system of FIG. **6**.

[0014] FIG. **8** is a bottom perspective view of the sensing system of FIG. **6** with a casing for the motor housing removed.

[0015] FIG. **9** is a top perspective view of the sensing system of FIG. **6** with an upper casing along the boom removed and an outer casing of the motor housing removed.

[0016] FIG. **10** is a top plan view of a sensor pod.

[0017] FIG. **11** is a top plan view of a second sensor pod.

[0018] FIG. **12** is a top plan view of third sensor pod.

[0019] FIG. **13** is a bottom plan view of the sensor pod of FIG. **12**.

[0020] FIG. **14** is a bottom plan view of a fourth sensor pod.

[0021] FIG. **15** is a cutaway view of a boom beneath three light sources.

[0022] FIG. **16** is a block diagram of electronics in a sensing system.

[0023] FIG. **17** is a flow diagram of a method of collecting data.

[0024] FIG. **18** is a block diagram of an exemplary server.

DETAILED DESCRIPTION

[0025] Early detection of nitrogen (N), phosphorus (P), and potassium (K) deficiencies (collectively NPK deficiencies) is important in maximizing yield of the plant. However, some plants, such as cannabis, appear green and healthy during early stages of growth even though they are not receiving enough NPK. As a result, growers have had to wait for the plants to show visible signs of NPK deficiency before being able to take action to correct the deficiencies.

[0026] The present inventors have discovered that NPK-deficient cannabis plants exhibit a change in the amount of light they reflect at near infrared wavelengths. This change occurs before the cannabis plants have any visible indications to a human grower of NPK-deficiency. The embodiments discussed below provide a system that uses the intensity of light reflected from cannabis plants at a collection of wavelengths, including near infrared wavelengths, to categorize cannabis plants as either being NPK-deficient or NPK-sufficient. Because the embodiments use near infrared wavelengths, NPK deficiencies are detected earlier than the prior art. The system can be used with multiple different varieties of cannabis plants even though NPK deficiencies cause different changes in light reflectance in different varieties of cannabis.

[0027] In accordance with one embodiment, the detection of the reflected light intensity is improved by placing the light sensors within a meter of the cannabis plant.

[0028] FIG. **1** provides a flow diagram of a method of identifying cannabis plants that are NPK-deficient and applying nutrients to correct the deficiencies. FIG. **2** provides a block diagram of a system **200** used to perform the method of FIG. **1**.

[0029] In step **100** of FIG. **1**, cannabis seeds are planted in soil or another growing medium. The grower then allows the seeds to grow for a period of time at step **102** so that the seeds become plants **202** with large enough surface areas to reflect sufficient light for classification. In accordance with one embodiment, the period of time in step **102** is fifteen days.

[0030] At step **104**, a hyper-spectral light sensor **204** in a sensing system **206** is moved to a position over plants **202**. In accordance with one embodiment, sensor **204** is positioned within a meter of the top of plants **202**. At step **106**, sensor **204** obtains intensity levels of light reflected by plants **202** at a set of selected hyper-spectral bands. In accordance with one embodiment, the set of hyper-spectral bands include 2.1 nm wide bands centered at 725.57, 732.05, 992.83, 854.39, 792.9, and 712.62 nm, which are all in the near infrared range (700 nm-1400 nm). In one such embodiment, these hyper-spectral bands are used for multiple varieties of cannabis plants, even though the varieties have different morphologies. This provides a single system that can work with multiple different varieties of cannabis, thereby reducing the number of systems needed to implement the present embodiments.

[0031] At step **107**, a current position of light sensor **204** and the intensities of the reflected light are stored in a memory **208** of sensing system **206** as position and spectral intensities **210**. The current position is provided by a positioning system **212** in sensing system **206**. In accordance with one embodiment, positioning system **212** comprises a motor controller that is able to determine the position of light sensor **204** based on the number of rotations of a drive motor that moves light sensor **204** over the plants. In other embodiments, positioning system **212** comprises a Global Positioning System (GPS) that provides the position of light sensor **204** using signals received from satellites. Position and spectral intensities **210** include a separate light intensity for each hyper-spectral band in the set of hyper-spectral bands obtained by light sensor **204**.

[0032] At step **108**, position and spectral intensities **210** are transmitted by a network interface **214** of sensing system **206** to a server **216** through a network **218**. In accordance with one embodiment, network **218** includes a wide-area network such as the Internet. Position and spectral intensities **210** are stored in a memory **217** in server **216** and are provided to a classifier **220** executed by server **216**.

[0033] At step **109**, classifier **220** uses the spectral intensities in position and spectral intensities **210** to classify the position as either NPK-deficient or NPK-sufficient.

[0034] In accordance with one embodiment, classifier **220** is a Neural Network Multilayer Perceptron (MLP). MLP is an artificial neural network that is trained using supervised machine learning. It is a more complicated process than a simple linear classifier and can analyze a substantial amount of data. In other embodiments, classifier **220** is a Stepwise Discriminant Analysis (STDA), a Quadratic Discriminant Analysis, or a random forest classifier. Those skilled in the art will recognize that these are examples of possible classifiers and other classifiers may be used as classifier **220**. In accordance with one embodiment, classifier **220** is trained using light intensities measured from a plurality of different varieties of cannabis plants. As a result, classifier **220** is able to classify multiple different varieties of cannabis as being either NPK-deficient or NPK-sufficient.

[0035] At step **112**, the class provided by classifier **220** is stored with the position as position and NPK class **222**.

[0036] At step **114**, sensing system **206** determines if there are more plant positions to be evaluated. If there are more plant positions, sensing system **206** moves to a different position and steps **104-112** are repeated for the new position.

[0037] When sensing system **206** has collected spectral intensities at all desired plant positions and classifier **220** has produced an NPK class for each position at step **114**, nutrient application values are set for each position at step **116**. In particular, a nutrient calculator **224** uses the NPK class **222** and a date of planting **226** for the position to calculate an amount of nutrients that should be applied to the position. If the NPK class is NPK-sufficient, the nutrient application value is set to a minimum value, which in many cases will be zero. If the NPK class is NPK-deficient, the nutrient application value is set so as to overcome the NPK deficiency while ensuring that an excessive amount of nutrients is not applied to the position. Human growers are alerted to conditions that require intervention or changes to nutrient applications. In particular, date of planting **226** is used to estimate the date of harvest and the nutrient value is selected so that the plant has sufficient NPK to reach the harvest date but there is a minimum amount of NPK left at the position after the harvest date. The nutrient application value is stored with the position as an entry **228** in memory **217**.

[0038] At step **118**, the nutrient application values for each position are provided to a nutrient application system **230** through network **218** or some other network. In accordance with one embodiment, nutrient application system **230** is a nutrient feed line that is able to provide different amounts of nutrients to different positions in a grow operation. In other embodiments, nutrient application system **230** is a movable fertilization system equipped with a positioning system that is able to determine when the fertilization system is at a desired position and is able to apply a desired amount of nutrients at that position. Nutrient application system **230** uses the nutrient application values to provide the appropriate amount of nutrients to each position at some point during a multi-day period, such as four days for example. In accordance with one embodiment, the nutrients are provided as soon as possible during the multi-day period. In other embodiments, the nutrients are provided over the course of the multi-day period.

[0039] At the end of the multi-day period, sensing system **206** or server **216** determines if the harvest date has been reached for all plants in the grow operation at step **120**. If at least one plant has not been harvested, the method returns to step **104** and steps **104-120** are repeated. Thus, at the end of each multi-day period, the plants are reclassified. This allows plants that had been classified as NPK-sufficient to be reclassified as NPK-deficient if the amount of NPK provided to the plants is no longer sufficient. In addition, it allows plants that were classified as NPK-deficient to be reclassified as NPK-sufficient if the nutrients applied in step **118** were effective in overcoming the NPK deficiency. By reclassifying the plants, the amount of nutrients applied to the plants can be minimized while ensuring that the plants are receiving enough NPK.

[0040] When all of the plants have been harvested, the method of FIG. **1** ends at step **122**.

[0041] FIG. **3** provides a perspective view of a grow operation **300** that provides one example of an environment in which various embodiments may be practiced. FIG. **4** provides a side view of grow operation **300**. Grow operation **300** includes two vertically stacked plant beds **302** and **304** that each support a plurality of plants **306** and **308**. Plant beds **302** and **304** are supported on a plurality of posts such as posts **309**, **310**, and **312**. Plant beds **302** and **304** include a watering and feeding system, not shown for simplicity. A collection of light sources **313** that includes light sources **314**, **316**, **318**, **320**, and **322** are supported on the bottom of plant bed **302**. A second collection of light sources **323** that includes light sources **324**, **326**, **328**, **330**, **332**, **334**, **336**, **338**, and **340** are supported by a separate structure (not shown), which typically consists of a ceiling structure of a building in which grow operation **300** is housed. Grow operation **300** also includes two sensing systems **350** and **352**, which are also referred to as movable sensor platforms and self-propelled sensing systems. Each sensing system includes a boom, such as boom **360** and a motor housing, such as motor housing **362**. Boom **360** includes a collection of sensor pods discussed further below. Motor housing **362** includes a battery, an integrated circuit board, a motor, and a support interface that support the sensing system on a rail, such as rails **364** and **366**.

[0042] As shown in FIG. **4**, boom **360** of sensing system **350** extends between collection of light sources **323** and plants **306** and boom **360** of sensing system **352** extends between collection of light sources **313** and plants **308**. In accordance with one embodiment, boom **360** of sensing systems **350** and **352** is positioned within a meter of the top of the respective plants **306** and **308**. This allows the sensors in booms **360** to measure conditions close to the plants in each plant bed.

[0043] FIG. **5** shows an enlarged side view of motor housing **360**, rail **366**, and post **310**. As shown in FIG. **5**, rail **366** is mounted to an L-bracket **500** that in turn is mounted to post **310** using bolt **502** and **504**. Rail **366** is mounted to L-bracket **500** using a bolt **506** and a nut **508** with the head bolt **506** placed in a channel **510** of rail **366**. In other embodiments, L-bracket **500** is mounted to post **310** using a U-shaped bar that passes around post **310** and through L-bracket **500**. Two nuts are then applied to the ends of the U-shaped bar to tighten L-bracket **500** against post **310**.

[0044] In FIG. **5**, the support interface of sensing system **350** is seen to include a drive wheel **512**, a top guide **514**, and a guide wheel **516**. Drive wheel **512** is connected to a motor discussed further below and rotates against rail **366** in order to move sensing system **350** along rail **366**. Top guide **514** and guide wheel **516** extend into grooves **518** and **520** in rail **366** and thereby support sensing system **350** on rail **366** such that boom **360** is cantilevered from rail **366**. As a result, sensing systems **350** and **352** are only supported on one side allowing for easier installation, lower cost, and easier access to the plants in the plant bed from the side of the plant bed without the rail.

[0045] As shown in FIGS. **3-5**, sensing system **350** is a moveable sensor platform, configured to be supported exclusively by rail **366** and to move along rail **366**. In other words, sensing system **350** is does not require a connection to any element other than rail **366**.

[0046] As shown in FIGS. **3-5**, sensing systems **350** and **352** are supported on the same structure that supports the plant beds. In particular, posts **309**, **310**, and **322**, support beds **302** and **304**, and rails **366** and **364**, which in turn support sensing systems **350** and **352**. By using the same structure to support the plant beds and the support sensing systems, the embodiments create a compact structure for the grow operation thereby improving access to the plants in the plant bed and limiting the amount of square feet taken up by the sensing system. In other embodiments, the rails are supported on posts that are separate from the structure that supports the plant beds.

[0047] As sensing systems **350**, **352** move along their respective rails, they are positioned over different plants in their respective plant beds and under different sets of lights that are positioned over their plant beds. Since the sensing system is self-propelled, it controls its movement over the plants allowing it to control the linear density of sensor values collected over the plants. In addition, because the sensing system is able to move relative to the plants, when sensing is not being performed, the sensing system can move to a position where it is not between the lights and any particular plant. This ensures that each plant receives as much light as possible when sensing is not taking place.

[0048] FIG. **6** provides a bottom view of sensing system **350**. FIG. **7** provides a top view of sensing system **350**. FIG. **8** provides a bottom perspective view of sensing system **350** with a casing for the motor housing removed and FIG. **9** provides a top perspective view of sensing system **350** with an upper casing along boom **360** removed and an outer casing of housing **362** removed. Although sensing system **350** is shown in FIGS. **6-9**, sensing system **352** is identical to sensing system **350**.

[0049] As shown in FIGS. **6** and **8**, the support interface includes not only drive wheel **512**, top guide **514** and guide wheel **516** but also a second top guide **614** and a second guide wheel **616**. Top guides **514** and **614** each include a tongue that extends into groove **518** of rail **366**. Top guides **514** and **614** also include two downward facing surfaces, one on each side of the tongue, designed to rest on and slide along the top of rail **366**.

[0050] Guide wheels **516** and **616** include a central portion that extends into groove **520** of rail **366** and two side portions above and below the central portion that engage with a side of rail **366**. Guide wheels **516** and **616** are free to spin along their respective central axis and in accordance with one embodiment are not driven by a motor.

[0051] Drive wheel **512** is driven by an electric motor **800** shown in FIG. **8**. In accordance with one embodiment, motor **800** is an encoded worm drive motor that provides accurate control of the amount of rotation of drive wheel **512**. In such motors, magnetic encoders on the shaft of the motor provide an indication of the number of degrees the motor has rotated. This makes it possible to determine how many degrees drive wheel **512** has rotated and to thereby determine the linear movement of sensing system **350** along the rail. Thus, in this embodiment, electric motor **800** acts as part of positioning system **212** of FIG. **2** by providing the position of sensing system **350** along the rail. This in combination with an identifier for the plant bed that sensing system **350** is positioned over provides complete position information for the light sensors within sensing system **350**.

[0052] As shown in FIG. **6**, a bottom casing **604** of boom **360** includes to apertures **600** and **602** and as shown in FIG. **7**, an upper casing **706** of boom **360** includes three apertures **700**, **702**, and **704**.

[0053] As shown in FIG. **9**, sensing system **350** also includes an integrated circuit board **900** and an internal battery **902**. Integrated circuit board **900** includes electrical components used to control movement of sensing system **350**, to collect sensor data and images using sensors and cameras in boom **360**, to determine when and how long to charge the internal battery **902**, and to transmit the collected sensor data and images to an external server through a wireless connection. Battery **902** provides electrical power to the components of integrated circuit board **900** as well as motor **800** used to move sensing system **350**.

[0054] As shown in FIG. **9**, boom **360** contains five sensor pods **904**, **906**, **907**, **908**, and **910**. FIG. **10** shows a top plan view of sensor pod **904**, FIG. **11** shows a top plan view of sensor pod **908**, and FIG. **12** shows a top plan view of sensor pod **906**. In FIGS. **10**, **11**, and **12**, sensor pods **904**, **908**, and **906** are shown to contain respective upward facing multi-spectral light sensors **1000**, **1100**, and **1200**. In accordance with one embodiment, light sensors **1000**, **1100**, and **1200** are identical to each other and each is capable of measuring the intensity of various bands of light including bands in the visible spectrum, the ultraviolet spectrum, and the infrared spectrum. Specifically, light sensors **1000**, **1100** and **1200** are each able to measure light intensities in bands centered at 725.57, 732.05, 992.83, 854.39, 792.9, and 712.62 nm. In FIG. **12**, sensor pod **906** is shown to also include a deep ultraviolet sensor **1202** that senses light in a deep ultraviolet bandwidth.

[0055] FIG. **13** shows a bottom plan view of sensor pod **907**, which contains a downward facing light sensor **1300** that is identical to upward facing light sensor **1200** on the top of sensor pod **906** but faces downward instead of upward. Thus, light sensor **1300** is also capable of measuring light intensities in the infrared region including in spectral bands centered at 725.57, 732.05, 992.83, 854.39, 792.9, and 712.62 nm. Sensor pod **907** also contains a deep ultraviolet sensor **1302** that is identical to deep ultraviolet sensor **1202**, a range finder **1308** that measures the distance between sensor pod **907** and the top of the plant canopy directly below boom **360**, and a camera **1306** that is able to capture an image of the plants below boom **360**.

[0056] FIG. **14** is a bottom plan view of sensor pod **910** and shows that sensor pod **910** includes a CO_2 sensor **1402** that measure carbon dioxide, a humidity sensor **1404** that measures the relative humidity in the space immediately adjacent to boom **360**, and a temperature sensor **1406** that measures the temperature of the space immediately adjacent to boom **360**.

[0057] FIG. **15** shows a cutaway view of boom **360** beneath three light sources **1500**, **1502**, and **1504**. As shown in FIG. **15**, apertures **700**, **702**, and **704** in boom case **706** allow light from light sources **1500**, **1502**, and **1504** to reach light sensors **1000**, **1100**, and **1200** on sensor pods **904**, **908**, and **906** as well as deep ultraviolet sensor **1202** on sensor pod **906**. In particular, light from light source **1500** is received by light sensor **1000** on sensor pod **904**, light from light source **1502** is received by light sensor **1200** on sensor pod **906** and light from light source **1504** is received by light sensor **1100** on sensor pod **908**. Each aperture is protected by a clear lens that passes all ultraviolet, visible, and infrared light. As a result, each light sensor **1000**, **1100**, and **1200** provides information about the amount of light provided by a respective light source. This allows sensing system **350** to detect when a particular light source is not providing optimal lighting for plant growth. For example, if light source **1502** were providing less than a desired amount of light in a particular frequency band, the light received at sensor **1000** of sensor pod **906** would be less than the light received at light sensors **1100** and **1200**. This would allow an operator to determine that light source **1502** needs to be repaired or replaced. Note that the deficiency in a light source may not be apparent to a person since the deficiency may be at a frequency band that cannot be detected by the human eye.

[0058] As shown in FIG. **15**, aperture **600** in the lower casing of boom **360** allows light reflected from the plants to reach downward facing light sensor **1300** and downward facing deep ultraviolet sensor **1302**. The intensity of the reflected light measured by downward facing light sensor **1300** in combination with the intensity of the light detected by upward facing light sensors **1000**, **1100**, and **1200** provides a means to detect what light is being absorbed by the plants. In particular, for each bandwidth of light of interest, a difference in intensity can be determined between the light that is received by light sensors **1000**, **1100**, and **1200** and the reflected light that is received by light sensor **1300**. Similarly, a difference in the intensity of deep ultraviolet light sensed by upward facing deep ultraviolet sensor **1202** and the intensity of deep ultraviolet light sensed by downward facing deep ultraviolet sensor **1302** can be determined. The differences can then be compared to each other. Bandwidths with larger differences are considered to have been absorbed by the plant more than bandwidths with smaller differences.

[0059] Infrared light emitted by the plants is also received by infrared sensor **1310** through aperture **600**. The received infrared light can be used to estimate the temperature of the plants which in turn can be used to determine Vapor Pressure Deficiency, an important growing metric.

[0060] As shown in FIG. **15**, CO_2 sensor **1402**, humidity sensor **1404**, and temperature sensor **1406** extend out of an opening **602** in boom **360** so that these sensors are able to measure the CO_2 level, humidity level, and temperature outside of boom **360** at the current position of boom **360**. In accordance with one embodiment, a seal is provided between pod **910** and the portion of boom **360** around opening **602** so as to limit the amount of external air and moisture that reaches the interior of boom **360**.

[0061] Together, circuit board **900**, motor **800**, and drive wheel **512** form a movement subsystem configured to move the sensors and camera in boom **360** between the plants and the light sources.

[0062] FIG. **16** provides a circuit diagram of the electrical components in sensing system **350**. As shown in FIG. **16**, battery **902** provides power to circuit board **900** and each of motor **800**, camera **1306**, range finder **1308**, temperature sensor **1406**, humidity sensor **1404**, upward facing light sensors **1000**, **1100**, and **1200**, upward facing deep ultraviolet sensor **1202**, downward facing light sensor **1300**, downward facing infrared sensor **1310**, downward facing deep ultraviolet sensor **1302**, and CO_2 sensor **1402**. Battery **902** includes two external contacts **1600** and **1602** that are used to recharge battery **902** when sensing system **350** has positioned itself at a docking station. Circuit board **900** includes a collection of sensor interfaces **1604** that are connected to camera **1306**, range finder **1308**, temperature sensor **1406**, humidity sensor **1404**, upward facing light sensors **1000**, **1100**, **1200**, upward facing deep ultraviolet sensor **1202**, downward facing light sensor **1300**, downward facing infrared sensor **1310**, downward facing deep ultraviolet sensor **1302**, and CO_2 sensor **1402**. Sensor interfaces **1604** receive data from the sensors and cameras and provide that data to a processor **1606**. Processor **1606** is further connected to a motor interface **1608**, which is further connected to motor **800**. Motor interface **1608** receives instructions from processor **1606** to actuate motor **800** and based on the instructions applies current pulses to motor **800** so as turn motor **800** a desired number of degrees.

[0063] Processor **1606** is also connected to a memory **1610** which contains a schedule **1612**, a sensor collection routine **1614** and an image collection routine **1616**. Schedule **1612** indicates when sensor collection routine **1614** should be executed and when image collection routine **1616** should be executed. Processor **1606** uses a time provided by a clock **1618** and scheduled times provided by schedule **1612** to determine when to execute sensor collection routine **1614** and image collection routine **1616**.

[0064] Memory **1610** also includes images **1620** collected by camera **1306** and sensor data **1622** collected by range finder **1308**, temperature sensor **1406**, humidity sensor **1404**, upward facing light sensors **1000**, **1100**, **1200**, upward facing deep ultraviolet sensor **1202**, downward facing light sensor **1300**, downward facing infrared sensor **1310**, downward facing deep ultraviolet sensor **1302**, and CO_2 sensor **1402** at different locations. In accordance with one embodiment, as images and sensor data are received from sensor interfaces **1604** they are stored in memory **1610** together with identifying information such as the time and date at which the images/sensor data were received and the position of the boom along the rail when the sensor data/images were received.

[0065] In accordance with one embodiment, memory **1610** also includes a collection of plant locations **1624** that indicate the position of plants within the plant bed. Plant locations **1624** may be entered by hand or may be determined from images collected by camera **1506**.

[0066] Processor **1606** is in wireless communication with server **216** through a wireless interface **1652** and a router **1654**, which form network interface **214** of FIG. **2**. In particular, wireless interface **1652** communicates wirelessly with router **1654**, which routes data packets provided by processor **1606** to server **216** through the internet **218**. Using this communication link, processor **1606** is able to forward images **1620** and sensor data **1622** to server **216** and is able to receive instructions from server **216** including changes to sensor collection routine **1614** and changes to image collection routine **1616** as well as changes to schedule **1612**.

[0067] FIG. **17** provides a flow diagram of a method performed when executing sensor collection routine **1614**. At step **1700**, processor **1606** determines if it is time for sensor data collection. This can be determined from schedule **1612**, which indicates times when data collection is to take place, and clock **1618**, which indicates the current date and time. Additionally, or alternatively, processor **1606** can determine that it is time for sensor data collection based on an external command received through wireless interface **1652** that requests that sensor data be collected. The external command can be received from server **216** or from another device that is in wireless communication with processor **1606**. If it is not time for data collection, processor **1606** waits for the scheduled time and/or for a command to be received while charging the battery if needed.

[0068] When the time for data collection arrives, processor **1606** instructs motor **800** to turn drive wheel **512** so as to place boom **360** at a desired position set in sensor collection routine **1614**. When boom **360** arrives at the desired location, processor **1606** collects sensor data from range finder **1308**, temperature sensor **1406**, humidity sensor **1404**, upward facing light sensors **1000**, **1100**, **1200**, upward facing deep ultraviolet sensor **1202**, downward facing light sensor **1300**, downward facing infrared sensor **1310**, downward facing deep ultraviolet sensor **1302**, and CO_2 sensor **1402**.

[0069] At step **1706**, processor **1606** stores the sensor data as sensor data **1622** in memory **1610** along with the position along the plant bed where the data was collected and the time and date at which the data was collected. At step **1708**, processor **1606** determines if the sensing system has reached the end of the plant bed. If the sensing system has not reached the end of the plant bed, processor **1606** sends an instruction through motor interface **1608** to motor **800** to cause the motor to rotate the drive wheel so that the sensing system moves laterally along the rail. Steps **1704**, **1706**, and **1708** are then repeated at the new position along the rail.

[0070] When the sensing system reaches the end of the plant bed, processor **1606** sends an instruction to motor **800** to return the sensing system to a docking station at step **1710**. While motor **800** is turning drive wheel **512** to cause sensing system **350** to return to the docking station, processor **1606** transmits sensor data **1622** to server **216** through wireless interface **1652**, router **1654**, and internet **1656** at step **1712**. Processor **1606** then waits until it is once again time for sensor data to be collected. In accordance with one embodiment, sensor data is collected once per hour over the entire length of the plant bed. In accordance with one embodiment, sensor data **1622** includes reflected light intensities measured by downward facing light sensor **1300** in spectral bands in the infrared region and the positions at which those light intensities were measured. In addition, the sensor data returned to server **218** includes an identifier for either sensing system **350** or the plant bed that sensing system **350** is positioned over so that server **218** has a complete indication of the position of sensor **1300** when the light intensities were measured.

[0071] In the embodiments shown in FIGS. **5-17**, the plants in the plant beds are cannabis plants. These cannabis plants can include a single variety of cannabis or a plurality of different varieties of cannabis plants.

[0072] Although the system above discusses NPK-deficiency, the system can also be used to detect overwatering and underwatering of plants.

[0073] Although the sensing system shown in FIGS. **5-17** moves along a rail, in other embodiments, the sensing system is part of an unmanned aerial vehicle (UAV) that flies over the plant beds. In such UAV embodiments, the UAV flies within a meter of the top of the cannabis plants. Such UAV embodiments can be used with indoor grow operations or with outdoor farms. In such UAV embodiments, the positioning system is a global positioning system and the light sensor operates in the same way as discussed above for light sensor **1300**. The UAV also include a processor, like processor **1606**, and a wireless interface, like wireless interface **1602**, that permits the UAV to transmit light intensities and positions to server **216**.

[0074] FIG. **18** provides an example of a computing device **10** that can be used to as any of the servers described above. Computing device **10** includes a processing unit **12**, a system memory **14** and a system bus **16** that couples the system memory **14** to the processing unit **12**. System memory **14** includes read only memory (ROM) **18** and random-access memory (RAM) **20**. A basic input/output system **22** (BIOS), containing the basic routines that help to transfer information between elements within the computing device **10**, is stored in ROM **18**. Computer-executable instructions that are to be executed by processing unit **12** may be stored in random access memory **20** before being executed.

[0075] Embodiments of the present invention can be applied in the context of computer systems other than computing device **10**. Other appropriate computer systems include handheld devices, multi-processor systems, various consumer electronic devices, and the like. Those skilled in the art will also appreciate that embodiments can also be applied within computer systems wherein tasks are performed by remote processing devices that are linked through a communications network (e.g., communication utilizing Internet or web-based software systems). For example, program modules may be located in either local or remote memory storage devices or simultaneously in both local and remote memory storage devices. Similarly, any storage of data associated with embodiments of the present invention may be accomplished utilizing either local or remote storage devices, or simultaneously utilizing both local and remote storage devices.

[0076] Computing device **10** further includes an optional hard disc drive **24**, an optional external memory device **28**, and an optional optical disc drive **30**. External memory device **28** can include an external disc drive or solid state memory that may be attached to computing device **10** through an interface such as Universal Serial Bus interface **34**, which is connected to system bus **16**. Optical disc drive **30** can illustratively be utilized for reading data from (or writing data to) optical media, such as a CD-ROM disc **32**. Hard disc drive **24** and optical disc drive **30** are connected to the system bus **16** by a hard disc drive interface **32** and an optical disc drive interface **36**, respectively. The drives and external memory devices and their associated computer-readable media provide nonvolatile storage media for the computing device **10** on which computer-executable instructions and computer-readable data structures may be stored. Other types of media that are readable by a computer may also be used in the exemplary operation environment.

[0077] A number of program modules may be stored in the drives and RAM **20**, including an operating system **38**, one or more application programs **40**, other program modules **42** and program data **44**. In particular, application programs **40** can include programs for implementing any one of modules discussed above. Program data **44** may include any data used by the systems and methods discussed above.

[0078] Processing unit **12**, also referred to as a processor, executes programs in system memory **14** and solid state memory **25** to perform the methods described above.

[0079] Input devices including a keyboard **63** and a mouse **65** are optionally connected to system bus **16** through an Input/Output interface **46** that is coupled to system bus **16**. Monitor or display **48** is connected to the system bus **16** through a video adapter **50** and provides graphical images to users. Other peripheral output devices (e.g., speakers or printers) could also be included but have not been illustrated. In accordance with some embodiments, monitor **48** comprises a touch screen that both displays input and provides locations on the screen where the user is contacting the screen.

[0080] The computing device **10** may operate in a network environment utilizing connections to one or more remote computers, such as a remote computer **52**. The remote computer **52** may be a server, a router, a peer device, or other common network node. Remote computer **52** may include many or all of the features and elements described in relation to computing device **10**, although only a memory storage device **54** has been illustrated in FIG. **18**. The network connections depicted in FIG. **18** include a local area network (LAN) or wide area network (WAN) **56**. Such network environments are commonplace in the art. The computing device **10** is connected to the network through a network interface **60**.

[0081] In a networked environment, program modules depicted relative to the computing device **10**, or portions thereof, may be stored in the remote memory storage device **54**. For example, application programs may be stored utilizing memory storage device **54**. In addition, data associated with an application program may illustratively be stored within memory storage device **54**. It will be appreciated that the network connections shown in FIG. **18** are exemplary and other means for establishing a communications link between the computers, such as a wireless interface communications link, may be used.

[0082] Although elements have been shown or described as separate embodiments above, portions of each embodiment may be combined with all or part of other embodiments described above.

[0083] Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms for implementing the claims.

What is claimed is:

1. A method of identifying NPK-deficiency comprising:

measuring intensities of light reflected from a cannabis plant to produce intensities at a set of spectral bands, wherein the cannabis plant is one variety of a plurality of varieties of cannabis;

applying the intensities to a classifier so that the classifier provides one of an indication that the cannabis plant is NPK-deficient or an indication that the cannabis plant is NPK-sufficient, wherein the classifier has been trained using plants that include each of the plurality of varieties of cannabis.

2. The method of claim **1** wherein the set of spectral bands is selected before measuring the intensities and is independent of the variety of the cannabis plant.

3. The method of claim **1** wherein measuring the intensities of reflected light comprises placing a light sensor within a meter of a top of the cannabis plant.

4. The method of claim **1** wherein the set of spectral bands comprise spectral bands in the near infrared range.

5. The method of claim **4** wherein the set of spectral bands comprise spectral bands centered at 725.57, 732.05, 992.83, 854.39, 792.9, and 712.62 nm.

6. The method of claim **1** wherein measuring the intensities of reflected light comprises measuring the intensities before there is any visible indication of a nutrient deficiency in the cannabis plant.

7. The method of claim **1** further comprising:

determining a nutrient application value based on the indication that the cannabis plant is NPK-deficient; and

using the nutrient application value to apply nutrients to the plant.

8. A method comprising:

placing a light sensor within a meter of a top of a plant;

measuring intensities of each of a set of spectral bands of light reflected by the plant using the light sensor; and

using the intensities to classify the plant as NPK-deficient.

9. The method of claim **8** wherein the plant comprises a cannabis plant.

10. The method of claim **8** wherein the spectral bands comprise spectral bands in the near infrared range.

11. The method of claim **8** wherein measuring intensities comprises measuring intensities before there is a visible indication of NPK-deficiency.

12. The method of claim **8** wherein the set of spectral bands is independent of a variety of the plant.

13. The method of claim **8** wherein using the intensities to classify the plant comprises applying the intensities to a classifier trained using a plurality of varieties of cannabis.

14. The method of claim **8** wherein the set of spectral bands comprise spectral bands centered at 725.57, 732.05, 992.83, 854.39, 792.9, and 712.62 nm.

15. A system comprising:

a sensing system comprising a light sensor and a positioning system, wherein the light sensor measures intensities for light reflected from at least one cannabis plant at a plurality of spectral bands and the positioning system provides a position of the sensing system when the light sensor measured the intensities; and

a classifier, receiving the intensities and the position and providing a classification for the at least one cannabis plant at the position, wherein the classification indicates whether the at least one cannabis plant is NPK-deficient and the classification is based on the received intensities.

16. The system of claim **15** wherein the sensing system positions the light sensor within a meter of a top of the at least one cannabis plant.

17. The system of claim **15** wherein the classifier provides the classification before the at least one cannabis plant shows visible signs of NPK-deficiency.

18. The system of claim **15** wherein the classifier is trained using a plurality of different varieties of cannabis plants.

19. The system of claim **15** wherein the plurality of spectral bands comprise at least one spectral band in the infrared range.

20. The system of claim **15** further comprising a nutrient application system that applies nutrients at the position based on the classification for the at least one cannabis plant at the position.

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