(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 May 2001 (31.05.2001)

PCT

(10) International Publication Number
WO 01/38946 A1

(51) International Patent Classification[7]: G05D 11/00, A01G 27/00

(21) International Application Number: PCT/IL00/00787

(22) International Filing Date: 26 November 2000 (26.11.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
133165 26 November 1999 (26.11.1999) IL

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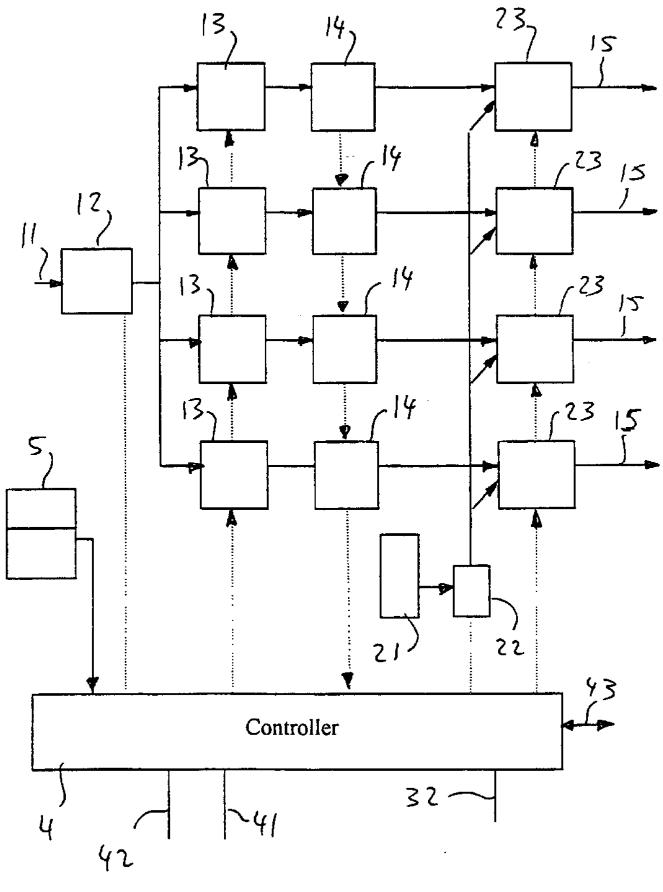
(81) **Designated States** *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

[Continued on next page]

(54) **Title:** IRRIGATION CONTROLLER SYSTEM AND METHOD



(57) Abstract: A system and method for controlling the irrigation process responsive to a measured plant water content. There are three basic aspects to the invention: An irrigation control system using infrared remote sensing (5); an irrigation controller (4) with means for processing signals from infrared remote sensors (5) and other sensors (14), and for generating irrigation control signals responsive to the information received from the various sensors, including the remote sensors. The valve (12) is controlled from controller (4). The controller (4) controls the secondary valves (13), the fertilizer valve (22) and the fertilizer pumps (23). The irrigation control system uses data readings from IR sensors in two frequency bands.

WO 01/38946 A1

— *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

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Irrigation Controller System and Method

Technical Field

This invention concerns irrigation controllers systems and methods. The invention relates in particular to such systems and methods for controlling the irrigation process responsive to measured plant water content.

Background Art

At present, there is a problem in measuring the actual amount of irrigation necessary, in real time.
The goal of irrigation systems has always been to optimize water use so that crop value is maximized, while the costs of water delivery are reduced to a minimum. This remains the test of irrigation efficiency today.

In the past, the solution to the water balance of a given soil, plant, atmosphere continuum was consistent with the state of art of extant irrigation technology. Irrigation schedules were calculated to periodically replenish accumulated soil water deficits. The frequency of water applications was a function of the water retention capacity of the volume of soil permeated by the root system.

While it was understood that this entailed cyclic variations in soil water availability, it was claimed that this mimicked natural intermittent soil wetting, and that plants evolved in a way that ensured optimal functioning under such a regime.

However, evolution develops optimal survival techniques, and not necessarily maximum profit. Biotechniques have improved on nature by developing more prurient varieties of almost all agricultural crops.

The quest for a solution to the plant water balance has seen the development of numerous mathematical models which integrate one or more soil, atmospheric or environmental variables. The weakness of these models lies in the fact that they include only variables external to the plant, while relating to the plant itself as if it was an inanimate hydraulic vessel.

Plant factors are considered to be constant, as if living processes do not affect plant water status, but this hardly reflects the truth of the matter. Evolution has armed plants with sophisticated systems by which they are able to regulate their internal water status. The tendency is conservative. That is, in the face of cyclic variations in their external environment, plant systems operate to maintain a steady state insofar as this is possible. However, endogenous regulatory systems do not always successfully deal with extreme conditions in the external environment.

Temporary water stress is a frequent condition experienced by most crop plants, and these periods of stress can seriously affect key plant functions. Farmers instinctively understand this and attempt to regulate key growth processes by controlling water application. In arid zones where precipitation is scarce or completely absent during the growing season, irrigation is a powerful agrotechnique.

The question is which of the numerous factors which affect plant water status should be monitored in order to assess the effects of the irrigation regime. In most instances only a small fraction of the many environmental factors are employed. Less frequently attempts are made to integrate both meteorological and soil factors. In only rare instances are plant variables included in the equations describing the dynamic balance of plant water content. Models which utilize only part of the factors involved must assume that the variables not considered remain constant, which is obviously not the case.

Consistent, reliable assessment of the soil–plant–atmosphere continuum has escaped even the most sophisticated models, while collection of input data to feed these models has become a complicated and expensive affair.

Traditional methods of measuring plant water content are destructive, require sophisticated laboratory equipment, and yield only an instantaneous picture rather than trends over time. For example, the use of the pressure bomb to estimate leaf water potential has proved to be a viable field instrument, but is destructive of the tissue it measures, and gives only a snapshot picture of water status. Various dendrometers have been devised which measure the expansion and contraction of plant tissue in response to changes in water status.

These instruments have opened new vistas in non-destructive monitoring of plant water status, but suffer from one or more of the following limitations as a signal for triggering water application as a real-time response to incipient water stress:

1) Insufficient resolution
2) Sensitive to the vagaries of ambient conditions and/or normal agrotechniques
3) Economic non-feasibility
4) Lack of consistent dependability over several growing seasons
5) The need for an extensive system of cables connecting the sensors to the controller
6) Require alternating current (LVDTs), not normally available in the field .

Remote sensing methods for estimating plant water content have been the subject of research over the past 30 years. The great majority of work has been based on satellite based observations covering large areas. Some research has employed airborne sensing systems. In most instances, this work has been based on the interpretation imaging-spectrographs, which is not applicable to the needs of our system.

There has been some research using hand-held photometers in geological/ geographical applications, including the measuring of vegetative water content. These works have a similarity with satellite systems, by using the same frequencies as LANDSAT 4 and LANDSAT 5, but were not able to achieve the degree of accuracy required by presently used irrigation systems.

Satellite spectrographs are usually active (they measure the reflectance of a signal broadcast from the satellite). They produce a picture, or map, normally depicting a rather wide spectrum, which then has to be interpreted according to empirically determined standards, normally contained in one of several packages.

It is an objective of the present invention to address the abovedetailed problems of precise irrigation in prior art.

Disclosure of Invention

It is an object of the present invention to provide a system and method for controlling the irrigation process responsive to a measured plant water content. The plant water content is measured in real time. Increasing the effectiveness of the irrigation system can achieve increased yields and reduced costs, while preventing a waste of water.

There are three basic aspects to the invention: An irrigation control system using infrared remote sensing means; an irrigation controller including means for processing signals from infrared remote sensors and other sensors, and for generating irrigation control signals responsive thereto; and a method for controlling the irrigation process responsive to the information received from the various sensors, including the remote sensors.

In the novel irrigation control system, by directly monitoring the plant, it is possible to obtain a continuous and current record of plant water status, in real time. Accordingly, the novel system measures canopy moisture content by remote sensing. Our present system relies on measuring of canopy reflectance of solar irradiance.

According to a second aspect of the invention, a novel irrigation controller having unique features is disclosed. The controller includes means for receiving signals from various sensors and for generating irrigation control signals responsive thereto.

Furthermore, an irrigation control method being implemented in software and having novel features is disclosed.
The software contains the algorithms of an irrigation regime calculated to regulate rather than to respond to water stress after the fact.
Such a regime has been shown to lead to significant savings in water use, while at the same time improving both yield quantities and quality.

According to another aspect of the invention, a novel irrigation system comprises three integrated elements:

1) An instrument which remotely senses canopy water content
2) A controller having novel structure and programs
3) An in-place automatic irrigation system based on mini or micro-emitters.

According to the present invention, the novel sensing system reads canopy reflectance in two frequencies in the infra-red. One which water absorbs heavily, and a second frequency which water does not absorb the solar radiation (this band is used as a reference). This allows canceling out variations in the intensity of solar irradiation.

Furthermore, the controller includes an emergency program to be triggered in the event of malfunction of the main sensor based system.

The novel controller only includes the essential functions required in an irrigation system, to achieve ease of use together with a lower cost. Additional options requiring software and/or hardware will be added on a modular basis in response to specific user requirements.

Further objects, advantages and other features of the present invention will become obvious to those skilled in the art upon reading the disclosure set forth hereinafter.

Brief Description of Drawings

The invention will now be described by way of example and with reference to the accompanying drawings in which:

Fig. 1 illustrates an irrigation system using the novel controller.

Fig. 2 details a functional diagram of the irrigation system.

Fig. 3 details one embodiment of a dual wavelength remote sensing device.

Fig. 4 illustrates a multizone remote sensor unit.

Fig. 5 details the structure and operation of an irrigation controller.

Fig. 6 details another embodiment of the irrigation controller.

Fig. 7 illustrates a distributed, multi-controller irrigation system.

Fig. 8 illustrates an irrigation control method.

Fig. 9 details data structures used in the irrigation control method.

Fig. 10 details multisensor data structures for the irrigation control method.

Modes for Carrying out the Invention

A preferred embodiment of the present invention will now be described by way of example and with reference to the accompanying drawings.

The description details the three basic aspects of the invention:

1. An irrigation control system using infrared remote sensing means is described with reference to Figs. 1, 2, 3 and 4.

2. An irrigation controller including means for processing signals from infrared remote sensors and other sensors, and for generating irrigation control signals responsive thereto, is described with reference to Figs. 5, 6 and 7.

3. A method for controlling the irrigation process responsive to the information received from the various sensors, including the remote sensors, is illustrated with reference to Figs. 8, 9 and 10.

Fig. 1 illustrates an irrigation system using the novel controller 4.
The system includes a main valve 12 that controls water to the system. The valve 12 is controlled from the controller 4. The controller 4 also controls the secondary valves 13, the fertilizer valve 22 and the fertilizer pumps 23.
The fertilizer valve 22 and pumps 23 serve to add fertilizer from a fertilizer tank 21 to the irrigation water. The irrigation water is

outputted through the water pipes 15 to the irrigated area. The fertilizer subsystem is optional. Liquid fertilizer may be added to the irrigation water. The amount of fertilizer may be programmed in the controller 4.

Controller 4 receives inputs from a sensing device 5, that are used to compute the required water supply to the irrigated areas.
The water meters 14 readings are input to the controller 4 to allow better control of the irrigation process.

The novel system is composed of three integrated elements:

1) An instrument 5 which remotely senses canopy water content. A dual band infrared sensor may be used, as detailed below.

2) A controller 4 programmed to activate and read signals from the sensing device 5, interpret the data and activate an irrigation system in accordance with the concept of "real time" water application in response to incipient plant water stress as outlined in the present disclosure.

3) An in-place automatic irrigation system. The system may be based on mini or micro-emitters. These may include, for example, drippers, micro-sprayers or mini-sprinklers.

One of the delightful features of plant life lies in the fact that plants themselves are continuously assessing their own water status, both elegantly and accurately.

The system according to the present invention aims to bypass the futile efforts of science, and go directly to the final integration as it is manifested in the plant itself. That is, by directly measuring the water content in the plant using IR sensors, a better irrigation regime can be achieved.

In short, by directly monitoring the plant, it is possible to obtain a continuous and current record of plant water status.

Accordingly, the novel system measures canopy moisture content by remote sensing, using sensing means 5. The present system relies on measuring of canopy reflectance of solar irradiance. The irrigation controller 4 evaluates the readings of the infrared sensor means 5 to compute the required water supply to each area.

Sensor means 5 may include a single infrared (IR) device that scans a monitored section, or a linear array or an area array as known in the art. Optical IR filters (not shown) may be used to measure radiation only in the desired frequencies or wavelengths.
The sensor 5 measures the water content using noncontact measurements of reflected radiation.

Controller 4 has some unique features. The hardware features of the irrigation controller are detailed below.

Further novel features of controller 4 include its software, which is used to implement the algorithms of an irrigation regime. The implemented method has been devised to regulate, rather than to respond to water stress after the fact. That is, water is applied as a real-time response to incipient stress as signaled by the remote sensing system.
Such a regime has been shown to lead to significant savings in water use, while at the same time improving both yield quantities and quality.

An electrical power supply 31 can be used to power up the controller 4 as well as the other electrical devices in the system. Various supplies may be used, for example 12 Vdc or 220 Vac or 110 Vac.

In one embodiment (not shown), the system is powered by a 12 Vdc rechargeable battery, that is constantly recharged by a solar panel.

Fig. 2 details a functional diagram of the irrigation system.
Water inlet 11 is connected to a main valve 12 that controls water to the system. The valve 12 is controlled from the controller 4. The controller 4 also controls the secondary valves 13, the fertilizer valve 22 and the fertilizer pumps 23.

The fertilizer valve 22 and pumps 23 serve to add fertilizer from a fertilizer tank 21 to the irrigation water. The irrigation water is output through the water pipes 15 to the irrigated area.

Controller 4 receives inputs from a sensing device 5, that are used to compute the required water supply to the irrigated areas. The water meters 14 readings are input to the controller 4 to allow better control of the irrigation process.

The system may further include a user interface (input) 41, for example a keyboard or graphic means like a mouse or trackball. It may also include an user interface (output) 42, for example a Cathode Ray Tube (CRT) , an alphanumeric display or other output means, all connected to the controller 4.

Optionally, the system may include a communication link 43 , to allow communications with other irrigation controllers, a remote user etc. via wires or wireless, or to the Internet.

An electrical power supply input 32 delivers electric power to the system. Various types of electrical power may be used, as detailed elsewhere in the present disclosure.

Among the unique features of the system are the sensing device 5 and the accompanying controller software in controller 4. The system is preferably compatible with automated drip irrigation systems in general use in Israel and abroad.

The sensing device 5 preferably has the following properties:

1) Capable of detecting changes in canopy water content of as little as +/- 0.2% . This precision is achievable with sensors operating near the monitored canopy, operating on specific narrowband frequency ranges. Satellite or airborne systems have succeeded in measuring changes in water content of +/-2%, which are not sufficient to drive the algorithms or software to achieve the necessary exactitude in water application.

2) Mountable on an elevated platform, enabling azimuthal and elevation adjustment for measurement in alternate distinct plots. It may include (not shown) means for attaching to pylons or other things. It may also include rotable positioner means or other means for mechanically changing the orientation of the sensor.

3) Dependability unaffected by all natural conditions and cultural practices.

4) radiation sensing in two frequency bands, a primary band that is absorbed by water (for example at a wavelength of about 1920 nm) and a secondary band that is insensitive to water content (for example about 800 nm). Thus, the measurement is not affected by variations in the solar radiation.

The resolution of the system is dependent on the bandwidth of the measurement, the number of integrations performed within a frame time, as well as the amplitude of the signal and the ability of the controller to read the signal down to the necessary resolution. A suitable analog to digital converter is included, having the required number of bits for the desired resolution.

The present sensing system is based on reading canopy reflectance of solar radiation concurrently in two frequencies in the infra-red.
One which water absorbs heavily, and a second which water does not absorb the solar radiation (this band is used as a reference). This allows to cancel out variations in the intensity of solar irradiation.

By dividing the signal frequency reflectance in the primary band by the reference signal, variations in the intensity of solar irradiation are canceled out.
The controller 4, after subjecting the signals to analysis is capable of estimating plant water content with an accuracy of +/- 0.2% which is adequate for driving the irrigation regime. The controller program has a capability for all functions that irrigation controllers currently on the market feature, such as automated fertigation and high and low flow cut-off.

Irrigation method

A. Data regarding water content is collected at fixed time intervals, for example every 30 seconds. Each sample measures the water content by measurements in two frequency bands as detailed above, and by computing the ratio therebetween. Thus, the measurements are not affected by variations in the solar radiation.

B. A moving window average is computed. A possible window may be used, for example a Hamming window. In one embodiment, a moving average of 120 data samples is calculated.

C. The value of the present moving average is compared with a predetermined minimum value or a previously computed average.

D. If the present average is lower than the minimum or the previous average, then secondary valves 13 are opened and a short irrigation pulse is delivered, whose duration is proportional to the delta of the current and to previous hour averages.

The method is further detailed with reference to Figs. 8, 9 and 10.

Thus, in the above method the irrigation is based on preventing rather than relieving water stress. Water monitoring in real time allows for fast response in delivering water on time, on demand. This novel concept requires an ability to sense incipient declines in water content in vegetation, and to respond with short irrigation pulses proportionate to the rate of decline.

An important concept for our system is the Incipient Water Stress, which is defined as a decline in water content from maximum (pre–dawn) values. Many attempts have been made to define various formulas for computing threshold values of water stress which can be employed in the decision to when and how much water to apply. A weakness common to these systems is that information is obtained after the fact, not in real time. The novel approach in the present system and method measures the water stress in real time, an approach that allows for fast response to correct a water stress that begins to develop.

The controller program also includes an optional standard irrigation program based on time or volume as is in general use. This optional program also serves as an emergency program to be triggered in the event of malfunction of the main sensor based system. The controller is housed in a user–friendly package, easily operated by users unfamiliar with electronic hardware. Information exchange between the controller and user are characterized by a conversational question and optional answer approach, pull–down menus, and a minimum of user dependent initiatives.

Irrigation controller software currently on the market suffers from a profusion of esoteric, seldom utilized options, and complicated user interfaces. The operator is required to insert fixed times and durations of irrigations, based on recommended values for the cultivar, age of the section, season, etc. This presupposes a bi-weekly reprogramming of the controller.

In the novel system, however, only the essential options are included in the basic model. The system is easy to operate: after the initial calibration, there is no further necessity for operator intervention.

Prior art controllers are unnecessarily sophisticated. Programming requires a response to as many as 30 inquiries, where in most cases 4 or 5 items are sufficient. They have the capability of irrigating as many as 20 subsections, but rarely are there more than four sub-sections irrigated from the same irrigation head. Thus, a simple controller is advantageous both in cost and ease of operation.

The novel controller with its modular structure allows for the addition of options as desired. These options may include, among others:

a) automatic flushing of filters

b) liquid fertilizer application through the irrigation system

c) inlet jacks for temperature, relative humidity, wind velocity and/or soil moisture gauges, etc.

d) additional sections to be irrigated.

Additional options requiring soft and/or hardware may thus be added on a modular basis in response to specific user requirements.

Preferably, the sensing element and the controller are contained in a single unit situated on the border of the irrigated section. It can be built into a unit protected from the elements. A major advantage is that the sensor is not located within the canopies but rather exterior to the irrigated area, where it is not subject to the vagaries of various agrotechniques like spraying, picking, etc.

The very fact that the instrumentation is located outside of the irrigated section, and thus less vulnerable, will add to the longevity of the system.

The system structure described above simplifies installation and does not require any cables within the irrigated section. In addition, a rotating sensing device can measure water characteristics of plants in several adjacent sections. Moreover, since the viewing area may include a significant proportion of the total section canopy, one sensor device may be sufficient, rather than several sensors spotted throughout the section as in prior art systems.

Whereas satellite spectrographs are usually active and monitor a large area, the present system uses only specific wavelength to precisely monitor a small area that is to be irrigated. The present system is passive, using solar radiation reflected off the canopy.

The signals in the chosen wavelengths are highly linearly related to the relative water content of the viewed vegetation.

Fig. 3 details one embodiment of a dual wavelength remote sensing device, which may be used to implement the sensing device 5 in Figs. 1 and 2. The sensing device includes first infrared (IR) sensor 51 operating at a wavelength W1 first signal conditioning means 52, including for example an amplifier and a low pass filter.

A second IR sensor 53, operating at a wavelength W2, is used with second signal conditioning means 54, having a structure similar to that of means 52. Actually, a close match in the properties of means 52 and 54 is highly desirable, to allow reliable detection of water content.

The signals from the two detectors may be processed in signal processing means 55, for example using a ratio computation means (a divider). Means 55 removes, or greatly reduces, the influence of the solar radiation intensity on the measured plant water content.
communication means 56, for transferring the measurement results to a controller or computer

Thus, the remote sensing device includes a first sensor 51 operating at a wavelength W1 which water absorbs heavily, and a second sensor 53 at a wavelength W2 which water does not absorb the solar radiation. The second band is thus used as a reference. The illustrated structure may be used to cancel out variations in the intensity of solar irradiation.

By dividing the signal frequency reflectance in the primary band by the reference signal, variations in the intensity of solar irradiation are canceled out.

In one embodiment of the invention, the means 55 is included in the sensing device, as illustrated above. In another embodiment (not shown), the output signals from both sensors 51 and 53 are transferred to the controller 4, and the normalization is performed there.

Fig. 4 illustrates a multizone remote sensor unit. The unit can include, for example, a sensor housing 501 with several openings 511, 521, 531 , each used by a dual sensor (not shown) such as the sensing device illustrated in Fig. 3. Each sensing device can monitor a crop area such as the monitored crop areas 512, 522, 532 respectively.

Fig. 5 details the structure and operation of an irrigation controller, which may be used to implement the controller 4 in Figs. 1 and 2.
A computer 401, such as a personal computer (PC), or a laptop computer is used to actually control the irrigation system.

An interface means 402, is used for input/output (I/O). Means 402 may output signals over output control lines 403, for example to irrigation valves , sensors parameter settings, etc.

A sensor conditioning means 404 may include, for example, amplifiers and filters. Means 404 can also include analog to digital converters (ADC), which can be used for amplifying and conditioning of sensors signals received over input lines 405.

In a preferred embodiment, a highly sensitive ADC is used in sensor conditioning means 404. The ADC is capable of performing precise measurements of the sensors signals.

For example, a 18 bit multichannel oversampling (Sigma-Delta) ADC may be used. Such ADC components are manufactured by Maxim, for example.

The multichannel ADC can be used to concurrently measure a plurality of sensors.

The novel use of high sensitivity ADCs in sensors signals conditioning allows to convert low power signals into a digital format, which allows further signal processing with no degradation in signal quality.

Sensor data can be processed locally or at a remote location.

The operation of the controller is as follows:

Sensors information, received through means 404 and means 402, is processed in the computer 401 using predefined methods. The resulting irrigation plan is implemented by applying control signals through

Fig. 6 details another embodiment of the irrigation controller.

A dedicated controller device 411 is used to control the irrigation system.

A computer 401 is now used just as an input/output device. It can be used to load parameters into controller device 411.
Output control lines 403 can be used, for example, to transfer control signals to irrigation valves , sensors parameter settings, etc.

Sensor conditioning means 404, for example amplifiers and filters. Means 404 can also include analog to digital converters (ADC). The means 404 are used for amplifying and conditioning of sensors signals received over input lines 405.

The computer interface means 402 can be used for input/output (I/O). The I/O functions may include sending signals over output control lines 403, for example to irrigation valves , sensors parameter settings, etc.
The sensor conditioning means 404 can include, for example, amplifiers and filters. Means 404 may also include analog to digital converters (ADC). Means 404 can be used to amplify sensors signals received over input lines 405.

In a preferred embodiment, a sensitive ADC (not shown) is used, which is capable of performing precise measurements of the sensors signals.

The operation of the controller is as follows:
Sensors information, received through means 404 and means 402, is processed in the computer 401 using predefined methods. The resulting irrigation plan is implemented by applying control signals through

Fig. 7 illustrates a distributed, multi-controller irrigation system.

A computer 401 is used here as an interface between a technical support office 421 and a plurality of controller devices 411, 412, 413, 414.

This distributed structure allows a plurality of controller devices to be remotely controlled and monitored over a communication link, such as the Internet. Other link types may be used as well, for example local microwave links or optical links or a combination thereof.

Thus, the irrigation of a large crop area can be controlled from a central location 421. Alternately, the central office 421 can be used for technical support, troubleshooting and update of irrigation parameters. Seasonal changes in irrigation parameters, for example, can be implemented in a fast and effective method using this distributed structure.

The irrigation method basically includes the following processes:

A. Data regarding water content is collected at fixed time intervals, using a remote infrared sensor. The sensor preferably uses two infrared wavelengths, as detailed elsewhere in the present disclosure.

B. the data is evaluated to find whether the vegetation needs more water. Data averaging may be performed to improve the system precision.

The measured water content may be compared with previous readings or with a fixed threshold. A decision is reached, whether it is required to activate the irrigation system

C. if more water is needed, then activating an irrigation system to deliver water to the vegetation.

D. repeating steps (A) through (C) sequentially.

Fig. 8 illustrates in more detail an irrigation control method.

The method may include the following processes:

A. Reading sensors data (61) . Sensors data normalization and/or calibration, if required.

B. Creation and maintenance of a data structure for storing the sensors data (62). A possible structure is first in-first out (FIFO), as detailed below with reference to Figs. 9 and 10.
Computation of running averages and storage in suitable data structures.
A FIFO structure may be used to store most recent averages.

C. Irrigation-related computations, and arriving at a decision, whether to irrigate the vegetation now (63). Checking the decision, whether to activate irrigation, and activating either step (64) or (65) accordingly.

D. Activation of irrigation (64), if necessary

E. Deactivation of irrigation (65), if required based on the decision of processing in step (63) above

F. Check whether there is a sensors malfunction (66). Go to step (61) if sensors are OK. Go to step (67) if there is a sensor malfunction. That is, the process is performed sequentially all the time, to continuously monitor the crop and perform a a more effective irrigation process, provided there is no sensors malfunction.

G. Sensor malfunction emergency program (67).

In another embodiment of the invention, the sensors control is activated at specific time intervals. For example, at night there is no sunlight, and a different irrigation regime may be implemented.

Fig. 9 details one embodiment of data structures used in the irrigation control method.

A first in-first out (FIFO) is illustrated with sensors data on a time axis 7.

The last, most recent sensor data sample 71 is inserted into the FIFO after the previous samples 72, 73, 74 have been shifted left one place. Thus, sample 71 is the last sample (T0), sample 72 is the previous sample (T-1), sample 73 is (T-2) and sample 74 is (T-N).

The last P samples are used to compute a running average, whose last value A0 is entered into another FIFO as average 75. Prior to entering average 75, the previous averages such as 76 and 77 have been shifted left one place.

Fig. 10 details multisensor data structures for the irrigation control method.

Thus, the last measurement may include a water content sample 71 as well as an earth measurement 711 and a temperature value 712, and more optional measurements.
The FIFO now stores a plurality of sensors data for each measurement instant, down to values 74, 741, 742 stored there.

The plurality of sensors measurements, kept over time, allows to implement a better irrigation computation method, to achieve a more reliable estimate of the need to irrigate the crop, at any instant in time.

It will be recognized that the foregoing is but one example of an apparatus and method within the scope of the present invention and that various modifications will occur to those skilled in the art upon reading the disclosure set forth hereinbefore.

Claims

1. An irrigation system comprising:

A. IR noncontact sensing means for generating electrical signals responsive to water content in vegetation; and

B. an irrigation controller means connected to the IR sensing means and including means for evaluating, in real time, the electrical signals from the sensor means and for generating irrigation control signals responsive to the electrical signals.

2. The irrigation system according to claim 1, wherein the IR sensor means includes means for measuring reflectance solar radiation in two frequency bands, comprising a first band wherein solar radiation is absorbed by water, and a second band wherein solar radiation is not absorbed by water.

3. The irrigation system according to claim 2, further including means for computing the ratio between a signal in the first band wherein solar radiation is absorbed by water, to a signal in the second band wherein solar radiation is not absorbed by water.

4. The irrigation system according to claim 1, wherein the IR sensor means comprises a single IR sensor, a linear array or an area array.

5. The irrigation system according to claim 1, wherein the IR sensor means further includes optical IR filter means.

6. The irrigation system according to claim 1, further including irrigation means activated by the controller.

7. The irrigation system according to claim 1, further including in–place automatic irrigation system based on mini or micro–emitters, activated by the controller.

8. The irrigation system according to claim 1, further including drippers, micro–sprayers and/or mini–sprinklers, activated by the controller.

9. The irrigation system according to claim 1, further including means for delivery of a fertilizer through the irrigation water.

10. The irrigation system according to claim 1, further including earth sensors or temperature sensors or relative humidity probe means for delivery of a fertilizer through the irrigation water.

11. An irrigation controller means comprising:

A. an input channel for receiving signals from IR noncontact sensing means;

B. computing means for computing values for irrigation control signals, responsive to the signals from the IR sensing means;

C. an output channel for outputting the irrigation control signals to an irrigation system.

12. The irrigation controller according to claim 11, wherein the input channel includes a first part for receiving first signals relating to a first frequency band and second signals relating to a second frequency band, and wherein the computing means further include means for computing the ratio of the first signals to the second signals.

13. The irrigation controller according to claim 11, wherein the input channel includes further inputs for additional sensors.

14. The irrigation controller according to claim 11, wherein the input channel further includes a high sensitivity analog to digital converter.

15. The irrigation controller according to claim 14, wherein the analog to digital converter comprises a multichannel oversampling (Sigma-Delta) ADC.

16. An irrigation control method comprising the steps of:

A. Data regarding water content is collected at fixed time intervals, using a remote infrared sensor;

B. the data is evaluated to find whether the vegetation needs more water; and

C. if more water is needed, then activating an irrigation system to deliver water to the vegetation.

17. The irrigation control method according to claim 16, wherein in step (A) data from additional sensors is also collected, and wherein the additional data is also is evaluated in step (B) to determine whether more water is required.

18. The irrigation control method according to claim 16, wherein in step (B) a running average of the data is computed prior to the data evaluation.

19. The irrigation control method according to claim 16, wherein in step (B) values related to the present measurement are compared with values of a previous measurement to find whether the vegetation needs more water.

20. The irrigation control method according to claim 16, wherein in step (B) values related to the present measurement are compared with a fixed threshold to find whether the vegetation needs more water.

21. The irrigation control method according to claim 20, wherein the threshold is updated according to temporal expected variations in vegetation characteristics.

22. The irrigation control method according to claim 16, wherein in step (A) the time intervals are about 30 seconds long each.

23. The irrigation control method according to claim 19, wherein the previous measurement has been performed about a hour before the present measurement.

24. The irrigation control method according to claim 16, wherein in step (A) the data includes readings from IR sensors in two frequency bands, comprising a first band wherein solar radiation is absorbed by water, and a second band wherein solar radiation is not absorbed by water.

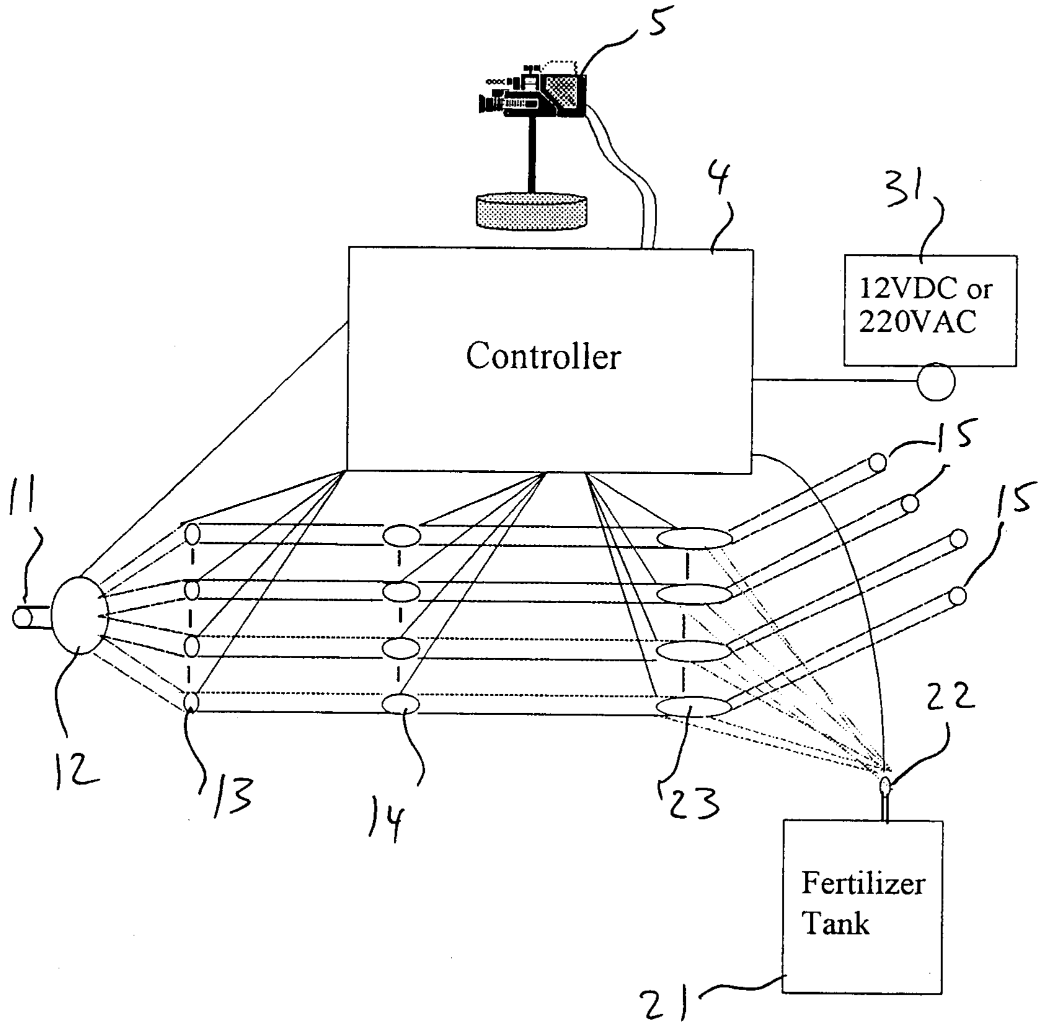

5
4
31
12VDC or
220VAC
Controller
11
15
15
22
12
13
14
23
Fertilizer
Tank
21

Fig. 1

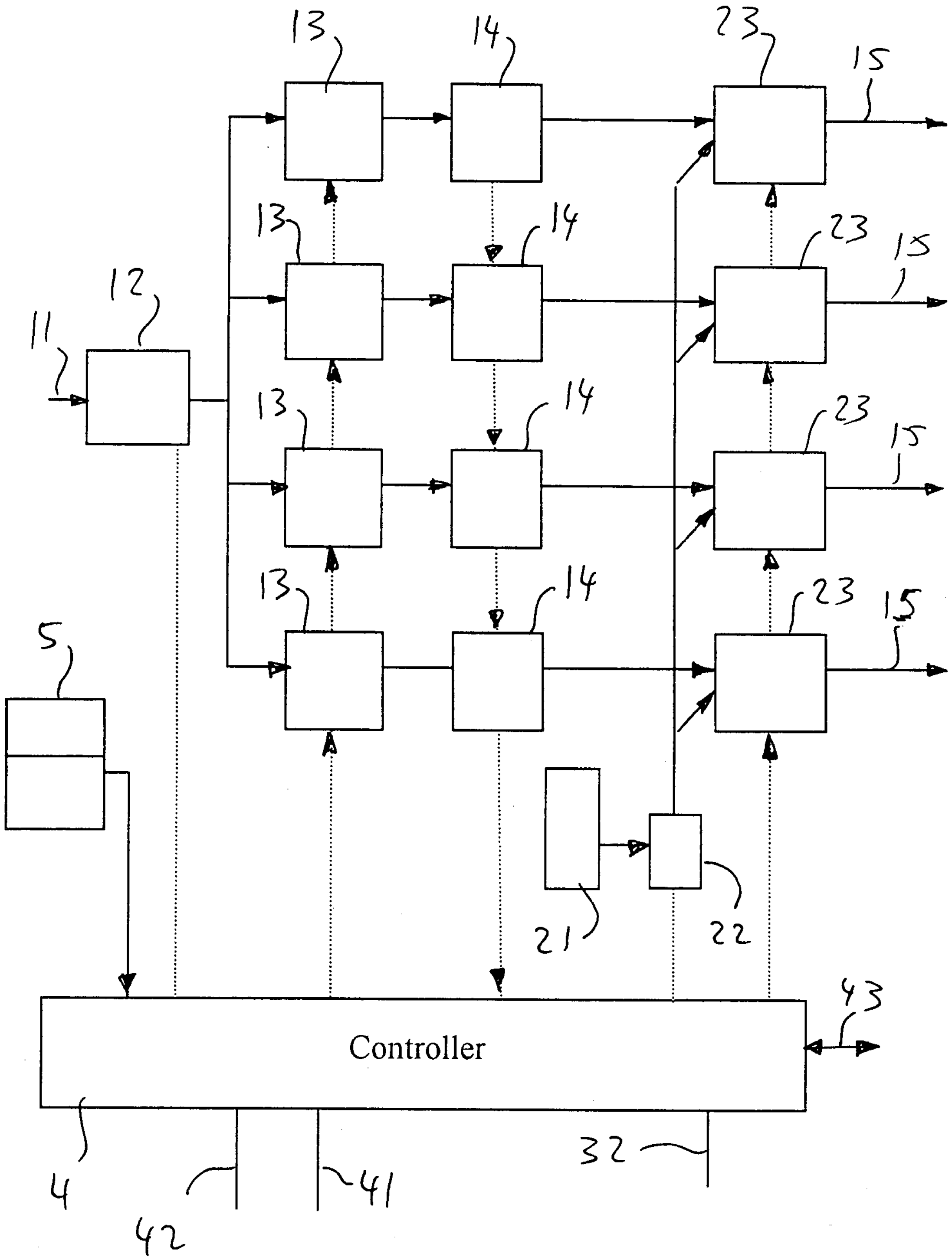


Fig. 2

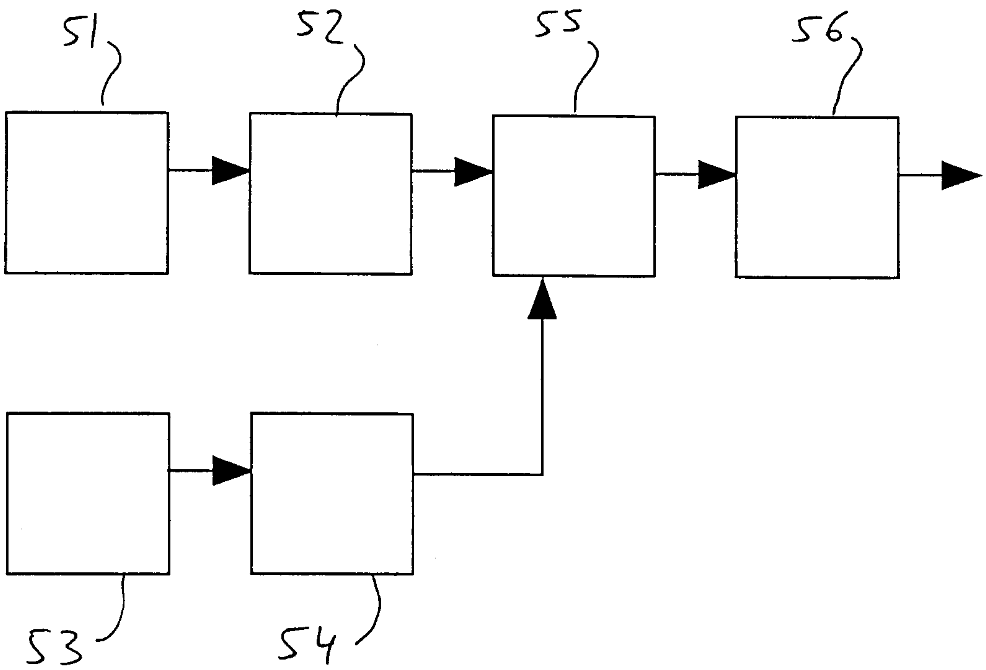


Fig. 3

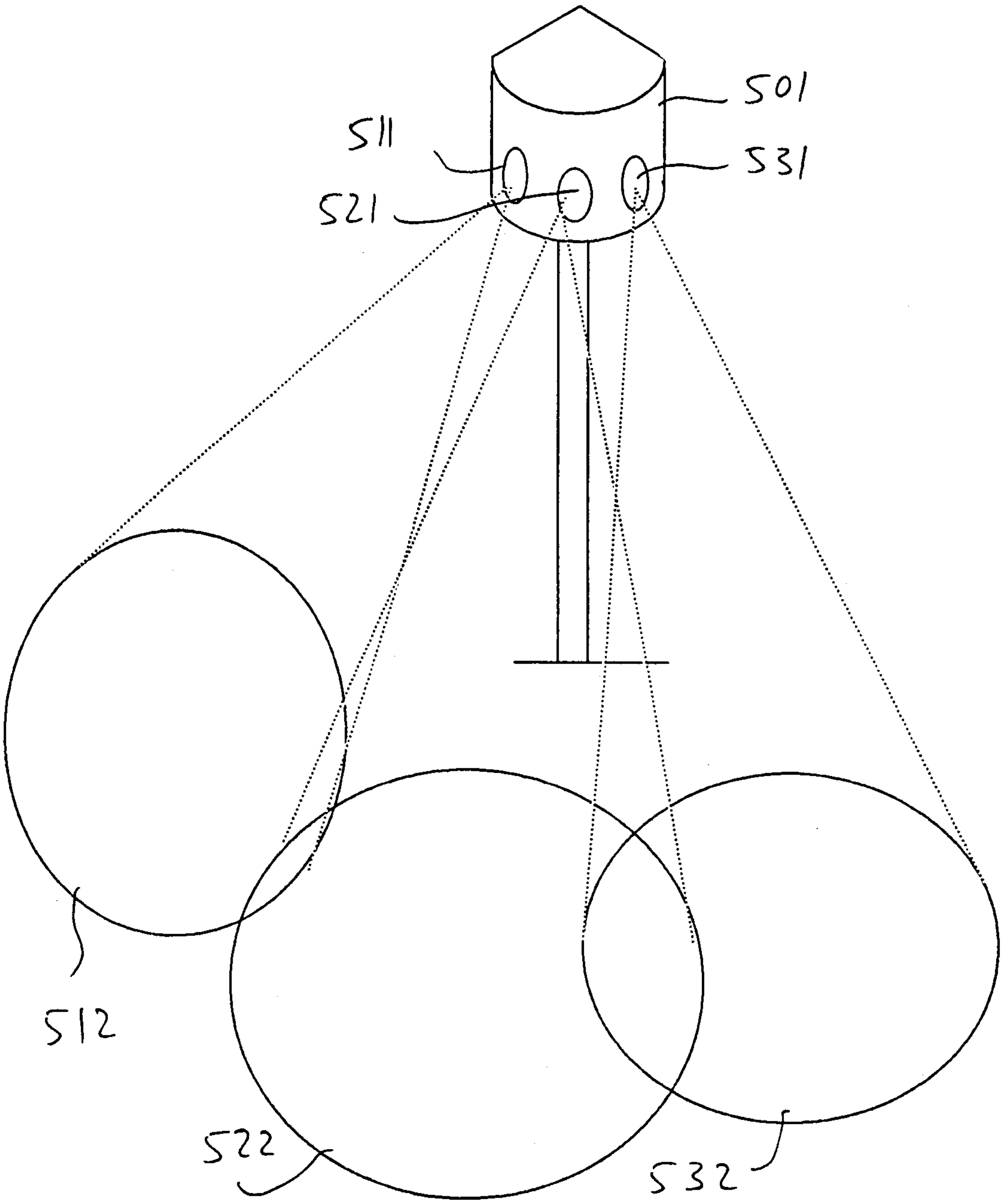


Fig. 4

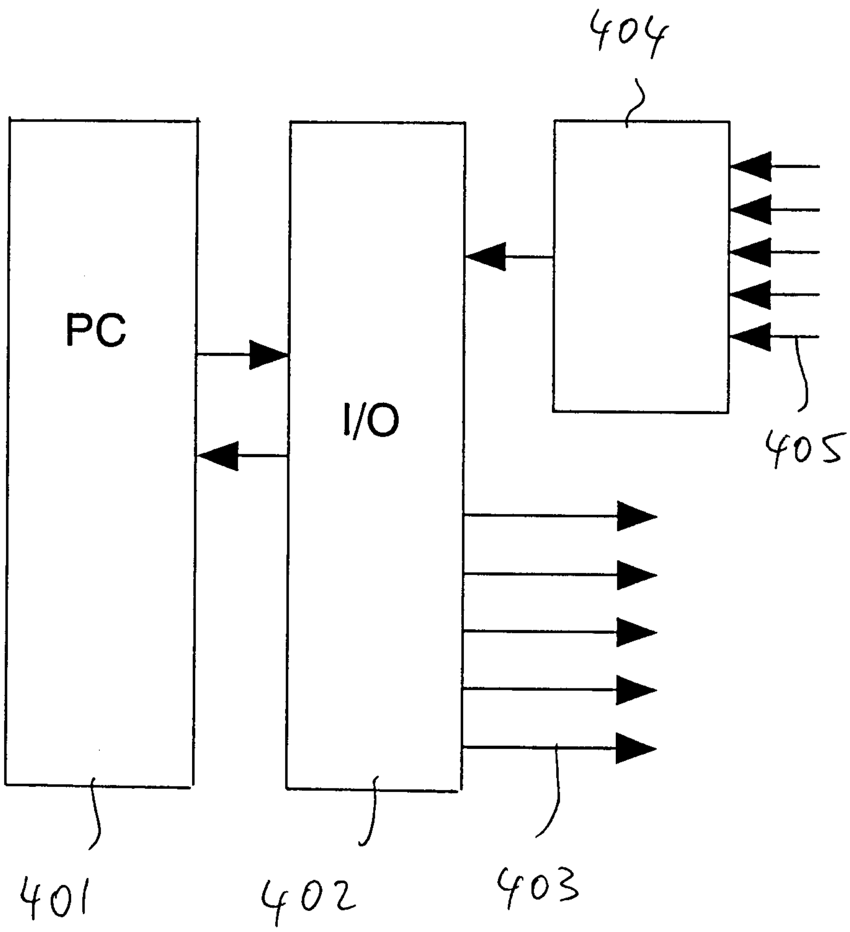


Fig. 5

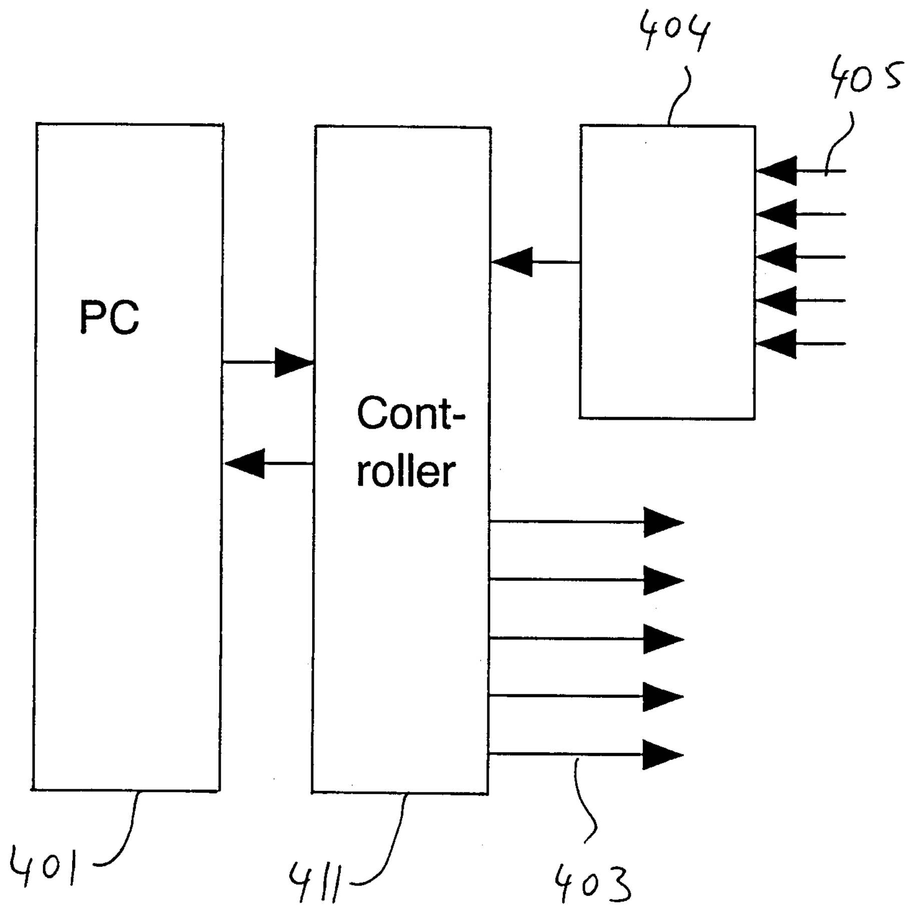
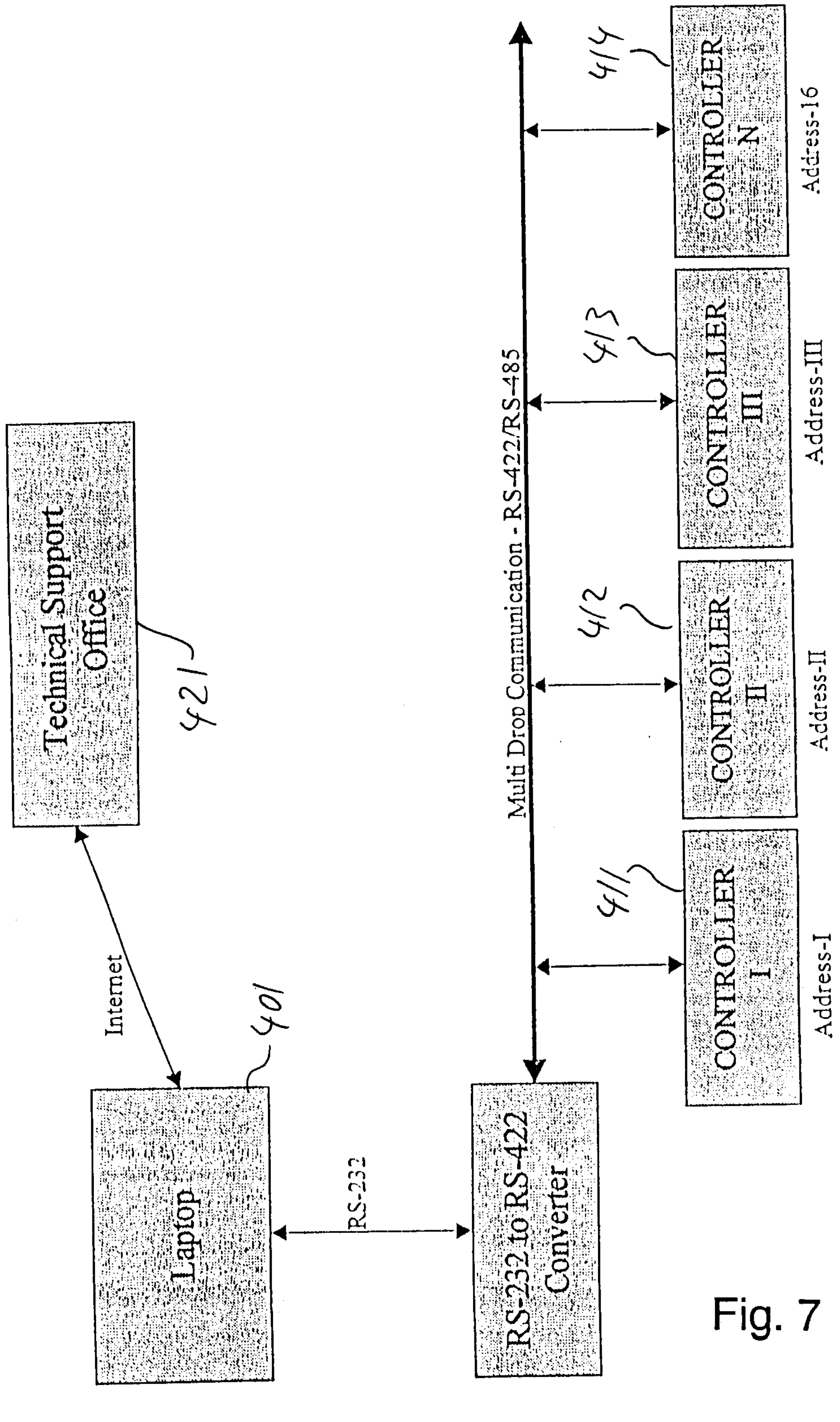


Fig. 6


Technical Support Office
421
Internet
401
Laptop
RS-232
RS-232 to RS-422 Converter
Multi Drop Communication - RS-422/RS-485
CONTROLLER I
Address-I
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CONTROLLER II
Address-II
412
CONTROLLER III
Address-III
413
CONTROLLER N
Address-16
414

Fig. 7

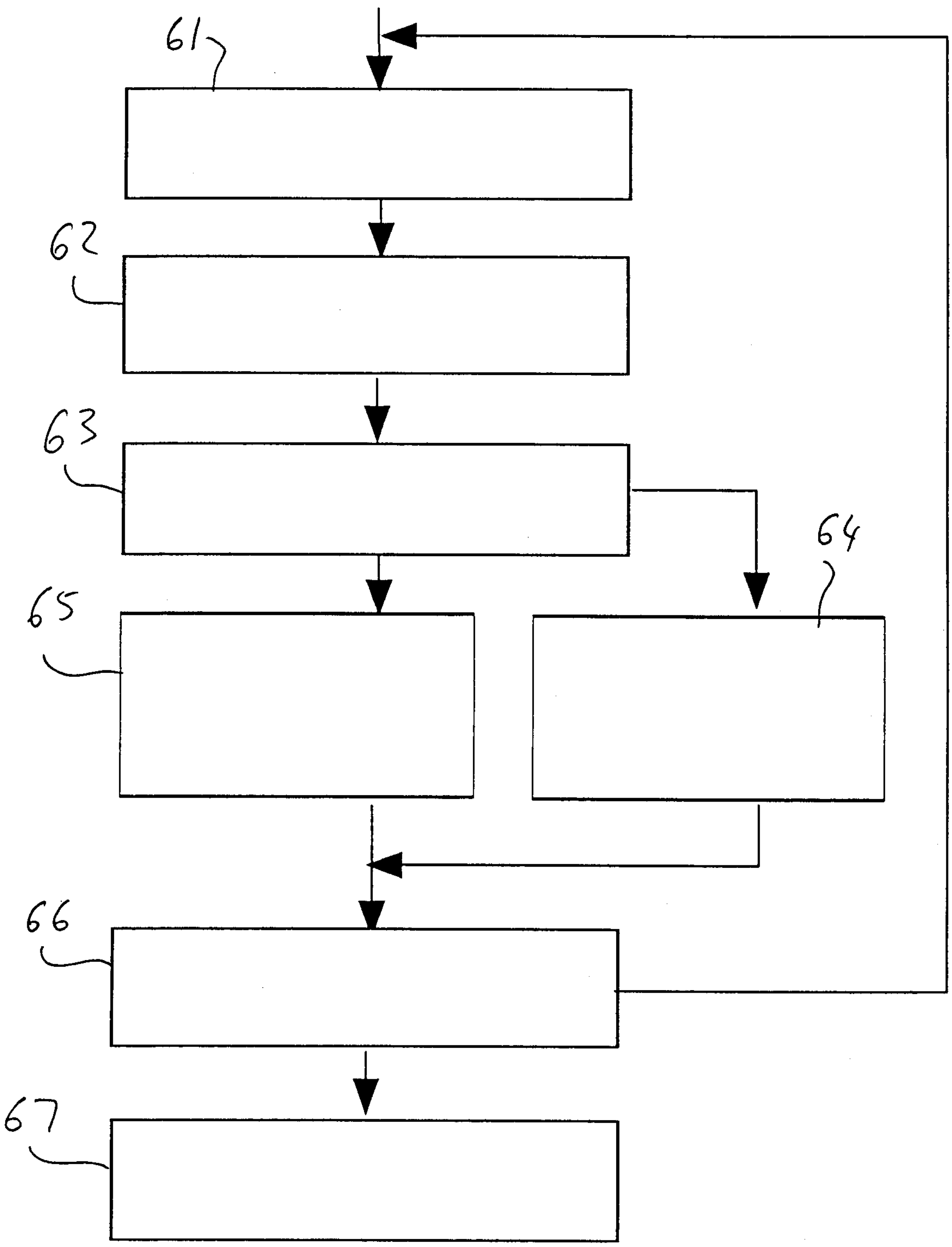

Fig. 8

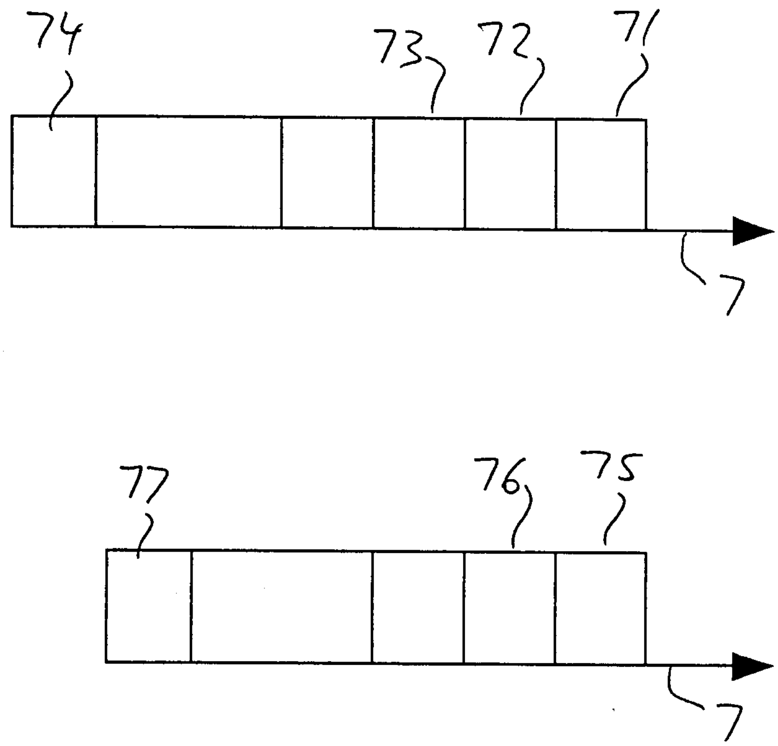

Fig. 9

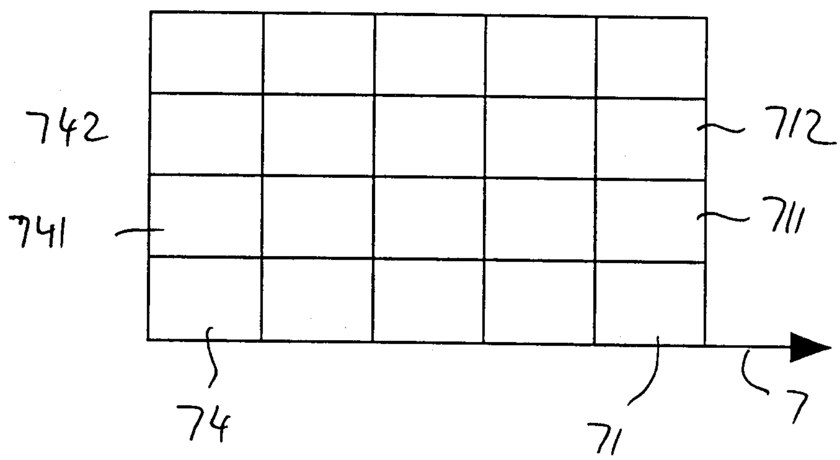

Fig. 10

INTERNATIONAL SEARCH REPORT	International application No. PCT/IL00/00787

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G05D 11/00; A01G 27/00
US CL : 700/284, 14; 239/63, 69
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)
U.S. : 700/284, 14; 239/63, 69; 137/624.11

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,015,366 A (HALL, III) 5 April 1977; Abstract, Col. 7-8, Col. 17-36, Fig. 5, 6, 15	1-6; 8-13; 16-17; 19-24 --- 7, 14, 15, 18
Y	US 5,156,179 A (PETERSON et al.) 20 October 1992 (20.10.1992); Col. 3-4	7
Y	US 5,884,224 A (McNABB et al.) 16 March 1999 (16.03.1999), whole document	14, 15
Y	US 4,876,647 A (GARDNER et al.) 24 October 1989 (24.10.1989), whole document	18
A	US 4,755,942 A (GARDNER et al.) 5 July 1988 (05.07.1988); whole document	1-24
A	US 5,870,302 A (OLIVER) 9 February 1999 (9.02.1999); Whole document	1-24

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 April 2001 (03.04.2001)	27 APR 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer William A. Grant Peggy Harrod Telephone No. 703-305-9600

Form PCT/ISA/210 (second sheet) (July 1998)