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

(51) International Patent Classification[7]: D21F

(21) International Application Number: PCT/FI01/00324

(22) International Filing Date: 4 April 2001 (04.04.2001)

(25) Filing Language: Finnish

(26) Publication Language: English

(30) Priority Data:
20000796   5 April 2000 (05.04.2000)   FI
60/241,919   20 October 2000 (20.10.2000)   US

(71) Applicant *(for all designated States except US)*: LIQUM OY [FI/FI]; Ohjelmakaari 1, FIN-40500 Jyväskylä (FI).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: LAITINEN-VEL-LONEN, Sakari [FI/FI]; Jokirannantie 3 A 4, FIN-40420 Jyskä (FI).

(74) Agent: KESPAT OY; P.O. Box 601, FIN-40101 Jyväskylä (FI).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AT (utility model), AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, CZ (utility model), DE, DE (utility model), DK, DK (utility model), DM, DZ, EE, EE (utility model), ES, FI, FI (utility model), 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, SK (utility model), 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:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND SYSTEM FOR MONITORING AND ANALYZING A PAPER MANUFACTURING PROCESS
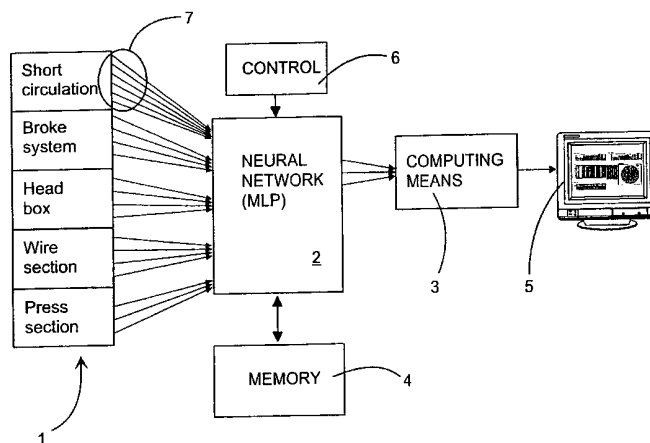
(57) Abstract: The invention concerns a method for monitoring and analyzing a paper manufacturing process, in which method a large number of quantities (x_i, t) are measured from the process, the measured quantities (x_i, t) are entered as an input vector (X, t) into a neural network, which, in response to the input vector, produces an output vector (Y, t) as a continuous quantity, at least one fingerprint consistent with a good process situation in regard of runnability, i.e. an optimal output vector (Y_o, t) is determined and stored in memory, the stored fingerprints and fingerprints or output vectors obtained in a normal process situation are compared substantially in real time, based on the comparison, a difference to be presented in a graphic form to the user is determined. According to the invention, a continuous time-dependent scalar quantity $k=k(t)$ to be presented as a result to the user is determined as a geometric distance between the instantaneous measured fingerprint (Y, t) and the taught fingerprint (Y_o), and the scalar quantity $k=k(t)$ is displayed via a display device to the user.

METHOD AND SYSTEM FOR MONITORING AND ANALYZING A PAPER MANUFACTURING PROCESS

Definition of the nature of the invention

5

The invention concerns a method and system for monitoring and analyzing a paper manufacturing process, in which method a large number of quantities are measured from the process and entered as an input vector into a neural network which
10 produces an output vector as a continuous quantity, and in which method at least one fingerprint representing a good process situation, i.e. an optimal output vector is defined, and fingerprints or output vectors obtained in a normal process situation are compared to the said optimal finger-
15 print(s) or output vector(s) substantially in real time and, based on this comparison, the difference is determined and presented to the user in a graphic form.

Background of the invention

20

Using teachable neural networks, large amounts of data can be effectively classified and links or groupings present in measurements and large masses of data can be revealed that are very difficult to detect via statistical calculation,
25 mathematical models and logical rules. The learning ability makes it possible to perform various functions with a reasonable accuracy by the aid of examples without detailed programming of all different situations and exceptions.

30 A neural network consists of simple computing elements, neurons, having a plurality of inputs and one response. A neural network is created by linking neurons to each other. The overall operation of the network is a combination of several weighted values which is difficult to understand via
35 individual weights. The weights in the neural network are generally determined by teaching using examples. There are a

2

fairly large number of different network structures and teaching algorithms.

Diversified descriptions of the principles and applications
5 of neural networks are to be found in the publications "Neurolaskennan mahdollisuudet"; Pasi Koikkalainen, Tekes 1994, and "Neural Computing Theory and Practise"; Philip D. Wassermann, New York 1989, ISBN 0-442-20743-2.

10 In a paper manufacturing process, the operator should be able to obtain concentrated information about how well the process is performing as compared with previously identified good situations. So far, the paper manufacturing process has been analyzed e.g. by the SOM (Self Oriented Map) technique. Quite
15 often, history data for a large number of variables is available in the form of various curves, of which the operator can select desired ones to be presented on his display. Generally, detecting a significant change in the set of history values is impossible because such changes are lost in
20 normal random variation. Therefore, a method is needed that allows the entire process situation to be analyzed using a neural network and divergent situations to be classified as early as possible to enable the operator to start searching for the cause that led to the situation.

25

Neural network solutions so far applied in the paper manufacturing industry have not produced satisfactory results. Analyzing the results is difficult for the user; especially the results obtained by the above-mentioned SOM method are
30 unclear.

Finnish patent application 941058 (Taipale) presents a method for the treatment of especially a paper manufacturing process. According to this application, a set of measurement
35 results from the process is fed into a neural network, e.g. a perceptron network, and, using a special algorithm, adjust-

3

able variables are corrected in order to correct the operating point of the process. The method aims at directly optimizing the quality of the final product, which is determined via 100 - 300 measurements for each machine roll.

5

European patent 815320 (Furumoto) discloses a method for process control of a paper machine by utilizing a neural network. A set of measurements comprises spectral values of the substances used, and statements regarding the quality of
10 the product are transmitted via the neural network and corresponding control signals are passed further to a so-called stock preparation stage. In this case, too, product quality is the primary control variable. Spectral (optical) measurements are ill suited for the determination of chemical
15 changes.

US specification 5,347,446 (Iino) presents a regulation system resembling the process and based on creating a model of the process. Computations produce a scalar cost function
20 as a result. In practice, creating a model is probably only possible in the case of limited processes. It is not possible to create a model for the entire paper machine by this method.

25 In general, the experiences about control processes designed to control the entire paper machine are not encouraging. Among other things, incidental factors have a considerable effect on the process, which means that a rationally calculated correction in itself produces more changes and insta-
30 bility.

Brief description of the invention

The object of the present invention is to achieve a new type
35 of method utilizing a neural network in a paper manufacturing process whereby the process can be more easily and accurately

analyzed and monitored than before. The basic idea of the invention is only to monitor the process in a reliable manner especially in regard of its runnability. The task of monitoring the quality of the final product is entrusted to other measurement processes because a high quality of a good process situation is generally always achieved when the process situation itself is equally stable. The primary aim of the method of the invention is to describe the runnability of a paper machine. The instant of occurrence of a change in the fingerprints can be seen from history data, so it is possible to find out what changes have taken place in the output variables at this instant. Correcting a bad situation is outside the scope of the present invention, because correcting a given output variable is not a straightforward task as a given difference may be the result of many factors. Local know-how is preferably utilized. The personnel of each plant know their own plant, and this special knowledge is important when the process is to be corrected after it has got into an unstable condition.

The features characteristic of the method of the invention are presented in the claims below.

The output vector of the neural network is processed so as to produce a scalar or otherwise unambiguous quantity. The processing consists of applying a mathematical algorithm, and this can be done using a general-purpose computer.

According to a preferred embodiment, a polar conversion of a continuous difference quantity, expressing the state and history of the process in an extremely concentrated form, is presented to the user. According to a third embodiment, both the aforesaid polar conversion and sets of history values are presented side by side to the user, so that, when the process gets into an abnormal state, it will be easier to establish the reason for this. Even incidental causes of process

instability can often be established by utilizing local know-
how because the precise instant of occurrence of a change can
be determined from history data. Preferably a multi-layer
perceptron neural network is used.

The other advantages and embodiments of the invention will be
described below in conjunction with examples of embodiments.

Brief description of illustrations

In the following, the invention will be described in detail
with reference to the attached drawings, wherein

Fig. 1   presents a general arrangement for implementing the
          method of the invention,

Fig. 2   presents a preferred user interface to a neural
          network, especially a presentation reducing the
          process data into a concentrated form.

Detailed description of the invention

Typically, 20 - 30 variable quantities, consisting of various
flow, temperature, consistency and pH values and data ob-
tained from preferably electrochemical sensors, are measured
from the manufacturing process. These variable quantities
form an input vector $(\overline{X}, t)$ for a neural network, and an
output vector $(\overline{Y}, t)$ is generated from them by means of the
neural network. During the teaching phase, an optimal output
vector $(\overline{Y}_0, t)$ has been established. The continuously measured
output vector is compared to this optimal output vector, and
the difference is produced in a graphic form clearly visible
to the user. In practice, it has been found that this task
can be best accomplished by using a multi-layer perceptron
(MLP) neural network, and the difference to be presented in a
graphic form is generated as a scalar quantity $k=k(t)$ ex-
pressing the geometric distance between the instantaneous
measured fingerprint $(\overline{Y}, t)$ and the taught fingerprint $(\overline{Y}_0)$.

The geometric distance is computed e.g. as a Euclidean distance.

$$k = \sqrt{\sum_n \left(y_i - y_{io}\right)^2}$$

A polar conversion $k(\varphi, t)$ is determined from the scalar quantity $k = k(t)$ according to the formula: $\varphi(t) = t/T * 2\pi$, where T is a selected trend $r(t) = k$.

The invention pertains to a paper machine environment as presented in Fig. 1. In most cases, a system according to the invention for use in conjunction with a paper machine 1 can be constructed using general-purpose computers provided with a display device 5 which are provided with an application implementing a neural network 2, computing means 3 and a memory 4. The system is connected to the paper machine 1 partly using existing measuring channels, partly via measuring sensors installed for this purpose. In this example, preferably a multi-channel electrochemical sensor 7 is connected to the short circulation of the paper machine. The control 6 and installation of the neural network 2 are preferably implemented using either the same or a separate computer. The broke system, headbox, wire section and press section are measured at least via the process data. Electrochemical measurements in at least some of these provide a substantial addition to the initial data. In the light of latest information, measurement of smell emitted by process liquids also looks promising. The electrochemical measurements include polarization, galvanostatic or only resting potential measurements.

The dimension of the output vector of the neural network is generally in the range of 3 - 15; in the examples in Fig. 1

and 2, it is 3 (with 21 input quantities). The minimum
dimension is the number of categories to be distinguished.

Fig. 2 presents a preferred user interface to the neural
network, in which a carefully selected set of data is dis-
played in a graphic form to the user. In this example, an
array of bars 11, "Grade profile", in the upper right-hand
part of the display represents a fingerprint consistent with
a good process situation, i.e. dimensionless values of the
measured quantities presented as bars. Correspondingly,
displayed on the left is an array of bars 12, "Online pro-
file", in which the instantaneously measured values are
presented as dimensionless values and bars. Presented in the
lower left-hand part of the display is a third array of bars
14, "Difference profile", showing the difference between each
measured value and the corresponding optimal fingerprint
value as a corresponding bar. The arrays of bars can natu-
rally be presented as a continuous curve, although in both
cases the same information is presented.

By observing the arrays of bars themselves, it is practically
not possible to monitor the process because any changes that
may occur are lost in random variation. Instead, the user is
offered very concentrated information about the process
situation via a graph 10, "Quality radar", in which a time-
dependent difference quantity is presented as a polar conver-
sion $k(\varphi,t)$. As long as the dot representing the difference
quantity obtained is circulating near the origin, the process
is well under control. In an abnormal situation, the dot will
move away from the origin. Changes in the difference quantity
can be readily detected over a trend period whose length is
selected e.g. so that it covers three working shifts.

In addition, the display presents a set of history values 13,
"Color chart", showing bars which have been generated from
the measured quantities (x_i) over a period of time corre-

8

sponding to a multiple of the trend, successive measurement values being displayed as a bar 13' of brightness/color information in which each value (x_i, t_n) is shown as a transverse line of corresponding brightness/color. If the brightness/color of the bar remains unchanged, then its value has not varied, whereas confirmed changes are clearly visible as variations in bar color/brightness. Moreover, each bar in the set of history values can be presented as a separate curve 15 according to selection 15'.

In addition to the time-dependent scalar quantity $k=k(t)$, other parameters can naturally also be computed, although, on the other hand, any extra result information may be confusing to the user.

Since the runnability of the machine is influenced by the electrochemical surface charges which are present on different rollers, wires and felts and which, with time, further have an effect on the accumulation of dirt in the machine, the most advantageous alternative will probably be to measure the electrochemical values of the initial materials, especially those of the liquid flows in pulp production and process waters, as inputs to the neural network. The detection of smell of the waters will also be advantageous in this connection because certain changes, e.g. microbiological reactions produce a distinct smell trace before they can be discerned in the electrochemistry.

CLAIMS

1. Method for monitoring and analyzing a paper manufacturing process, in which method

5   a large number of quantities (x_i, t) are measured from the process,

the measured quantities (x_i, t) are entered as an input vector $(\overline{X}, t)$ into a neural network, which, in response to the input vector, produces an output vector $(\overline{Y}, t)$ as a

10 continuous quantity,

at least one fingerprint consistent with a good process situation in regard of runnability, i.e. an optimal output vector $(\overline{Y}_o, t)$ is determined and stored in memory,

the stored fingerprints and the fingerprints or

15 output vectors obtained in a normal process situation are compared substantially in real time,

based on the comparison, a difference to be presented in a graphic form to the user is determined,

characterized in that

20   a continuous time-dependent quantity $k=k(t)$ to be presented as a result to the user is determined as a geometric distance between the instantaneous measured fingerprint $(\overline{Y}, t)$ and the taught fingerprint $(\overline{Y}_o)$, and

the aforesaid quantity $k=k(t)$ for the period of a

25 selected trend T is displayed via a display device to the user.

2. Method as defined in claim 1, characterized in that a multi-layer perceptron network (MLP) is selected as the

30 neural network to be used.

3. Method as defined in claim 1 or 2, characterized in that a polar conversion $k(\varphi, t)$ to be presented in a graphic form is generated from the said quantity $k=k(t)$ as follows:

35 $\varphi(t) = t/T * 2\pi$, where T is the selected trend

$r(t) = k$.

4. Method as defined in claim 3, _characterized_ in that a set of history values is determined from the measured quantities (x_i, t_n) over a period of time corresponding to a multiple of the trend, by periodically saving the dimensionless value

5 (y_i, t_n) of each input quantity, which is stored and coded so as to produce brightness/color information, said values being displayed graphically in succession as a bar (13') in which each value (y_i, t_n) is visible as a transverse line or similar area of corresponding brightness/color.

10

5. Method as defined in claim 4, _characterized_ in that both a graph of the polar conversion $k(\varphi, t)$ and the history bars (13) are presented to the user at the same time, especially via the same display.

15

6. Method as defined in any one of the preceding claims 3 - 5, _characterized_ in that the information presented to the user on the same display additionally comprises the measured quantities and the good fingerprint as sets of values con-

20 verted into a dimensionless and graphic form, e.g. into sequences of bars (11, 12).

7. Method as defined in any one of the preceding claims 2 - 6, _characterized_ in that a set of difference quantities $(\overline{Y}_o -$

25 $\overline{Y})$ together with a sequence of times is presented to the user in a graphic form.

8. Method as defined in any one of the preceding claims 1 - 7, _characterized_ in that the dimension of the output vector of the neural network is in the range of 3 - 10, preferably

30 equaling the number of categories to be distinguished.

9. System for monitoring and analyzing the paper production process in a paper machine (1), said system comprising

a neural network (2) having inputs for the entering
of a large number of quantities (x_i, t) measured from the
process and outputs for the delivery of a response, and

computing means (3) for the processing of the
5 response, and

storage means (4) for the storage of a fingerprint
consistent with a good process situation, i.e. an optimal
output vector $(\overline{Y}_o, t)$,

means for comparing substantially in real time the
10 stored fingerprints and the fingerprints or output vectors
obtained in a normal process situation and for determining on
the basis of the comparison a difference to be presented to
the user,

a display device (5) for displaying the difference
15 in a graphic form,

<u>characterized</u> in that said neural network (2) has
been adapted to implement a multi-layer perceptron network
(MLP), and

the computing means (3) have been adapted to deter-
20 mine from the output vector a continuous time-dependent
scalar quantity $k=k(t)$ as a geometric distance between the
instantaneous measured fingerprint $(\overline{Y}, t)$ and the taught
fingerprint $(\overline{Y}_o)$, and

the display device (5) has been adapted to display
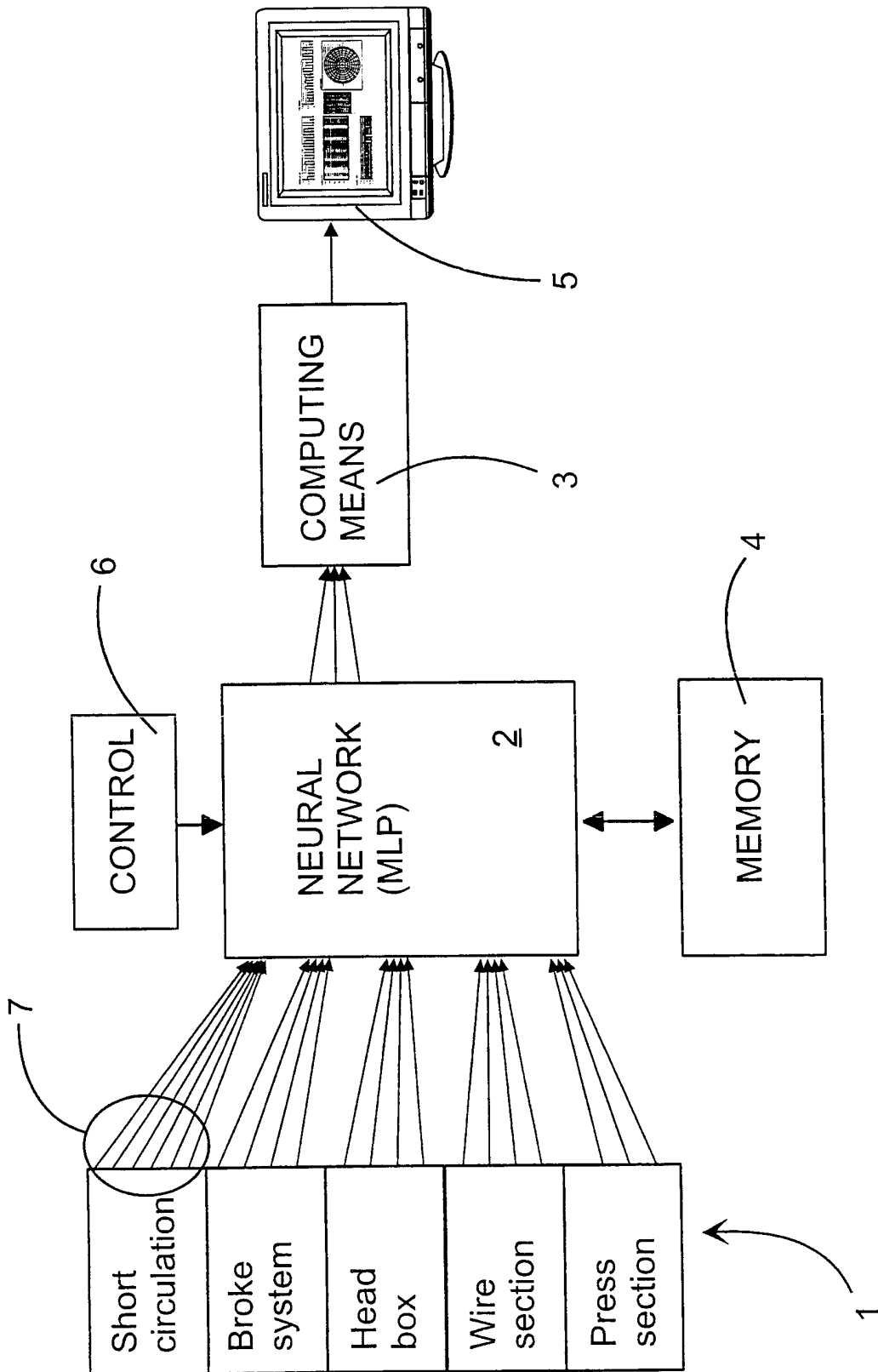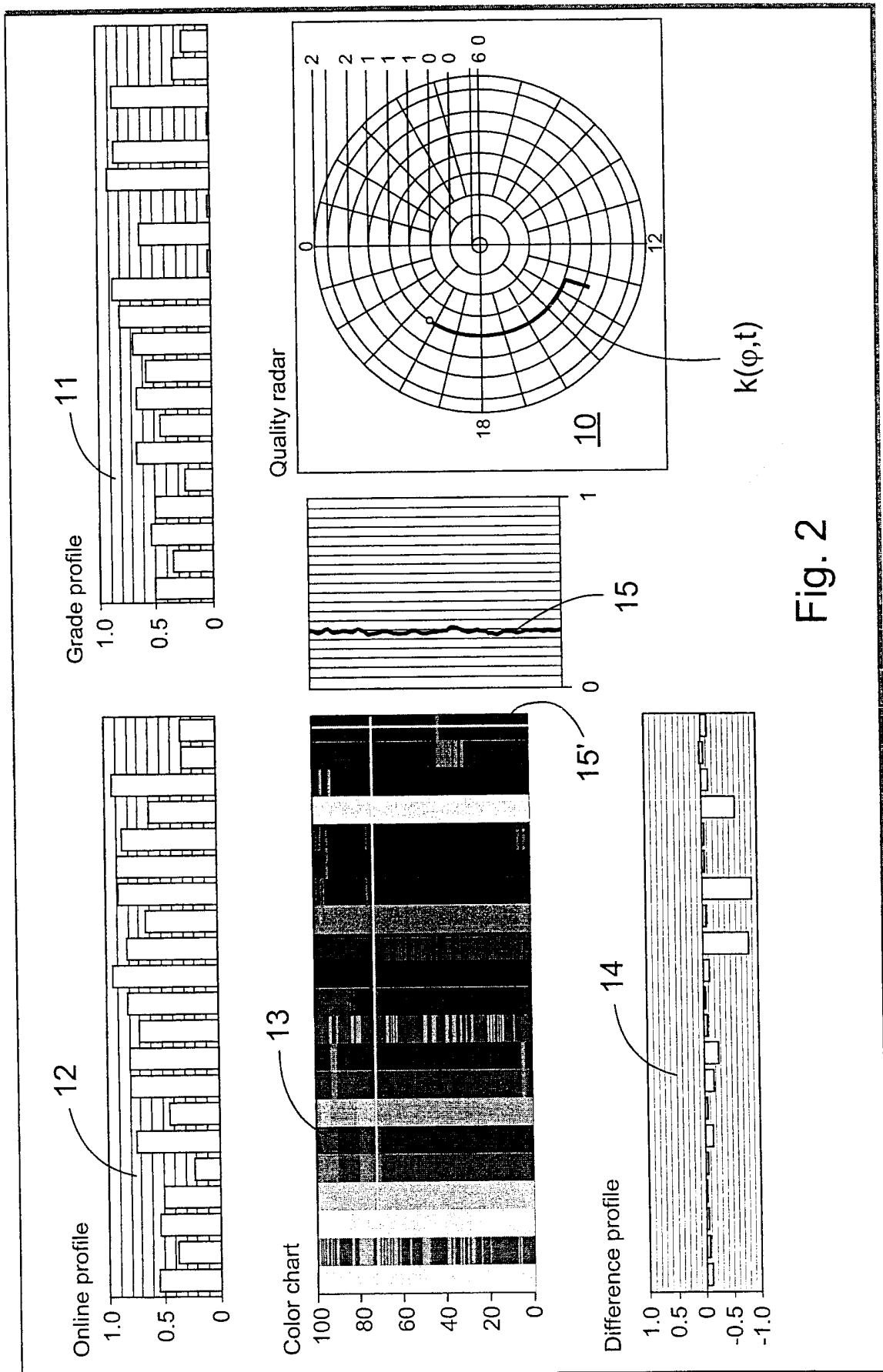25 the said scalar quantity $k=k(t)$.

Fig. 1

Fig. 2