

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
15 February 2007 (15.02.2007)

PCT

(10) International Publication Number
WO 2007/017099 A1

(51) International Patent Classification:

H04L 7/033 (2006.01) **G06F 1/12** (2006.01)
H04L 7/02 (2006.01)

(21) International Application Number:

PCT/EP2006/007326

(22) International Filing Date: 25 July 2006 (25.07.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

05425557.5 28 July 2005 (28.07.2005) EP

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

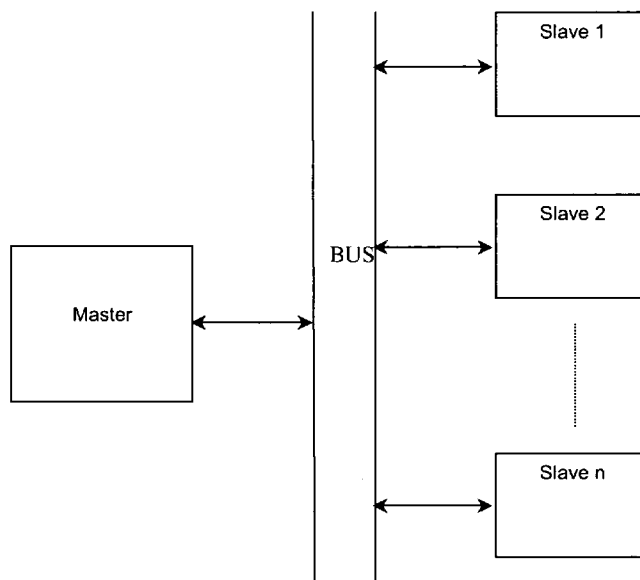
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

[Continued on next page]

(54) Title: METHOD FOR EXCHANGING INFORMATION AMONG DIGITAL UNITS IN A DISTRIBUTED SYSTEM



(57) Abstract: Method for exchanging information among digital units in a distributed system, with digital units being defined by at least a master node and slave nodes, comprising the step of transferring information references from said master node to said slave nodes, said information references being sampled with sampling time corresponding to a cycle time period defined by clock value of said master node; the method being characterized in that it comprises further steps of estimating the number of said information references sampled arrived to said slave node from said master node during a periodic reference time interval, and using said number to recalculate the master clock value, so that said slave nodes are able to reconstruct master node information reference during a following reference time interval.

WO 2007/017099 A1



— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search 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.

Method for exchanging information among digital units in a distributed system.

Technical field of the invention

The present invention relates to a method for exchanging
5 information among digital units in a distributed system.
Especially, the present invention can be advantageously
applied to solve communication problems in a distributed
digital control used to motion control of operating parts of
an automatic machine, in particular automatic packaging
10 machine, to which reference is made specifically in the
present technical description albeit implying no limitation
of the scope.

Background Art

15 An automatic machine is a complex multi-purpose mechanism
consisting of many operating heads directly acting on
products.

To obtain a good behavior of the machine, it is very
important a correct coordination among every part of it.

20 In the early days of automatism, first mechanisms were
coordinated in a mechanical way, i.e. via a main cam,
connected to the main shaft and creating a trajectory that
was the physical reference for the other elements of the
mechanism.

25 Nowadays, thanks to the evolving of electric motors, power
electronics and digital control and communications, the way
these elements are controlled has deeply changed.

The fundamental architecture is shown in the annex Figure 1.
As it can be seen, the motion control system of an automatic
30 machine is a distributed system.

It is composed by digital units, called nodes, exchanging
information with other units through a shared communication
bus.

In particular, there are one master node M, i.e. the central
35 unit, and many other slave nodes S_i , linked with the electro-
mechanical axes that have to be controlled.

Every digital node of the system executes a time-driven algorithm repeatedly triggered by its own internal clock, which is characterized by a nominal time interval (the so-called "cycle time").

5 In general, in modern complex systems, each digital node can execute different algorithms, "tasks", at the same time (multitask systems), each one characterized by its own cycle time. For this kind of systems the generalization of the communication and synchronization problem considered in the
10 following is straightforward. Instead of the communication between Master and Slave nodes, the communication between a particular task in the Master and a particular task in the Slave should be considered

Let ΔT and Δt_i be the cycle times of the master and of the i -
15 th slave respectively. Usually, they are designed to be equal or synchronized with a fixed integer ratio. Indeed, if no active synchronization is provided by the network system, this "design assumption" is not realistic, since each node clock is affected by inaccuracy, drift and jitter.

20 The main purpose of the master is the coordination of all the axes, usually obtained providing the slave nodes with velocity or position references to track for the actuators.

At run-time, every reference is sampled with a sampling time equal to the period of the cycle time of the master.

25 Then every sample is sent to the slave via a digital bus and collected by the slave with a sampling time equal to the slave cycle time.

It is important to note that not only the value of the sample is relevant, but also the corresponding time instant, even if
30 this information it is not directly provided with the data item.

Moreover, the exchanging mode of such information depends on the implementation of the communication system, i.e. the bus protocol.

35 Anyway, whatever the adopted protocol is, if the master broadcasts a data the slave will get it with a variable time

delay. So, it is possible to define the difference between the longer and the shorter delay as the jitter of the system. Finally, the transmission delay can increase owing to problems like data collision or traffic congestion on the network.

The aim of the present invention is therefore to provide an exchanging information method for overcoming the above-mentioned drawbacks.

Especially, the scope of the present invention is to solve the communication and synchronization transmission problems in a distributed system as above described.

Summary of the Invention

According to the invention, it is described a method for exchanging information among digital units in a distributed system, with digital units being defined by at least a master node and slave nodes, comprising the step of transferring information references from said master node to said slave nodes, said information references being sampled with sampling time corresponding to a cycle time period defined by clock value of said master node; the method being characterized in that it comprises further steps of estimating the number of said information references sampled arrived to said slave node from said master node during a periodic reference time interval, and using said number to recalculate the master clock value, so that said slave nodes are able to reconstruct master node information reference during a following reference time interval.

Brief description of the Drawings

The present invention will be described by way of example with reference to the attached drawings showing schematic and diagrammatic views of a preferred but not limiting embodiment of an exchanging information apparatus, in which:

- Fig. 1 shows a typical architecture of a distributed system;

- Fig. 2 is a schematic view, showing a sampling of the master (a), data transmission (b) and resampling of the slave (c);

- Fig. 3 shows a drift rate of a real clock;

5 - Fig. 4 shows a relation between the clocks during an interval time windows;

- Fig. 5 shows an algorithm implementation;

- Fig. 6a and 6b show a flow-chart of algorithm implementation of Fig. 5, respectively of the master samples handler procedure and slave samples handler procedure.

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Description of the preferred embodiments

The main scope of the present invention is to transfer the samples, with respect to their implicit temporal position, of a given trajectory from the master M to the slave S_i . If the internal clocks of both the nodes were perfectly synchronized, without any drift or digitalization error, a simple and effective communication could be obtained, despite of transmission delay and jitter, as shown in figure 2 (where $\Delta T/\Delta t$ is 2 and the clock ticks are assumed perfectly aligned).

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The waveform would be sampled with the known sample time ΔT of the master (fig. 2-a), then it would be transmitted to the slave with a delay and a jitter, whose bounds are known (fig. 2-b), and here resampled and reconstructed through interpolation by the slave with its own temporization Δt (fig. 2-c), only a fixed delay, multiple of Δt , has to be introduced to cope with the transmission channel non-ideality.

25

All these steps can be taken supposing the slave perfectly knows the value of $\Delta T/\Delta t$, the alignment between master and slave clock ticks and the maximum transmission delay. With these hypothesis the slave always knows when a valid data transmitted by the master is available and its temporization; therefore there is no need for a consistency data control. Indeed, the nominal value of a clock is not perfectly equal

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to its effective value.

For example, if 4 msec is the nominal value, the effective one could be 3.9999 msec or 4.001 msec, i.e. with a little drift and a corresponding drift rate (the shaded area shown in Fig. 3). Therefore, the actual relation between master and slave clocks is not exactly known.

A suitable low-level synchronization system can be provided by some digital communication busses, to avoid the above mentioned trouble and guarantee an almost perfect synchronization between the different node clocks. In the following, the case of no direct synchronization between the node clocks is considered, i.e. each node clock runs independently of the others.

In general, the relation between the master and slave cycle times can be written as follows:

$$\frac{\Delta T}{\Delta t} = \frac{n}{m} + \Delta n,$$

where n , m are integer values and Δn is the number in interval $[0 \ 1/m[$.

At the design stage of the control system, a nominal relation between master and slave cycle times is defined as follows:

$$\left. \frac{\Delta T}{\Delta t} \right|_{\text{Nom}} = \frac{n_{\text{Nom}}}{m_{\text{Nom}}} + \Delta n_{\text{Nom}}$$

where, again, n_{Nom} , and m_{Nom} are integer and Δn_{Nom} is a number in interval $[0 \ 1/m[$; usually n_{Nom} , is sensibly larger than m_{Nom} is imposed equal to zero, for the sake of simplicity.

According to previously-mentioned node clocks non idealities, the following considerations can be derived:

- the actual values n , m , Δn are not exactly equal to n_{Nom} , respectively, owing to node clocks inaccuracy;
- the values n , m , Δn are not constant since:
 - long-term frequency of the node clocks is not perfectly

constant;

-jitter affects the node clocks.

The jitter between Master and Slave clocks determines the same effect as the jitter in the transmission delay, hence it can easily be compensated, according to the procedure illustrated in figure 2, assuming a suitable delay in reference reconstruction in the slave node.

Differently, the unknown mismatch of actual $\Delta T / \Delta t$ with respect to the nominal one and its long-term drifting cannot be compensated with a fixed delay as proposed in figure 2, since the drift error accumulates with the passing of time.

Possible consequences of this problem are a data can be overwritten before it has been used or the same data could be used twice, in both cases causing spikes in velocity trajectory and loss of synchronization with the other axes.

Algorithm proposed to solve the synchronization problem

The objective of the following algorithm is to reconstruct with a sampling time Δt the reference trajectory previously sampled by the master node with a sampling time ΔT knowing there are uncertainties on the data transmission (jitter) and, as mentioned before, the relation between the two clocks is not exactly known a-priori.

Moreover, also the following constraints have to be satisfied:

- a reconstruction with a minimum and constant, as possible, delay;

- no data loss or prediction.

First of all, as the reconstruction is done using the slave cycle time, Δt , the slave clock will be assumed as the global time of the system (i.e. other clocks will be characterized and represented with respect to the slave clock).

Therefore the time basis will have a Δt granularity and at each tick of such clock a reconstructed trajectory sample has to be generated.

In order to manage the transmission delay and jitters (due to transmission channel and master and slave clocks inaccuracy) a suitable delay can be used as indicated in figure 2.

On the other hand, to cope with the effects of the drift of ΔT with respect to Δt (due to the fact that actual $\Delta T/\Delta t$ is not equal to $(\Delta T/\Delta t)_{\text{Nom}}$), a periodic resynchronization of the data coming from the master (with respect to the global time defined by the slave) must be defined, introducing in this way a data flow control.

The basic idea is to estimate how many data samples arrive from the master to the slave during a periodic reference time window; this information can then be used by the slave to recalculate the master clock value.

Using this new local knowledge of the master clock, the slave will be able to reconstruct the master reference trajectory during the following reference time window.

Let's consider a fixed number n of slave samples and define a length for reference time window of $n \cdot \Delta t$.

Supposing for simplicity that master and slave are in perfect relation, i.e. the equation $n \cdot \Delta t = m \cdot \Delta T$ is satisfied, it is possible to define a master clock having a granularity equal to $(n \cdot \Delta t)/m$, similarly as it is done for the slave.

Moreover, suppose that the starting time of the two time basis is the same.

The Fig. 4 shows the relation between the two clocks within a reference time window in the simple case of $n=4$, $m=3$.

So, it is possible to define:

- m , the number of samples provided by the master and used in a time window;

- n , the number of samples created by the slave in a time window;

- i , the i -th sample provided by the master and used in a time window, with $i=0, \dots, m$;

- s , the s -th sample created through interpolation by the slave in a time window, with $s=0, \dots, n$;

- T_i , the time instant of the i -th sample, that will be equal to $i \cdot \Delta T$;

- t_s the time instant of the s -th sample, that will be equal to $s \cdot \Delta t$.

5 For the initialization of the algorithm, values for n and m have to be chosen. This choice can be based on the nominal value of ΔT and Δt and it has to satisfy the equation $n \cdot \Delta t = m \cdot \Delta T$.

n will be the same for every reference time window, while m will be changed according to its estimation (but it will be considered constant inside a given time window).

The slave reference trajectory samples will be calculated starting from the master original samples by means of a linear interpolation formula.

15 As we need two original samples to obtain one or more interpolated value, there must be a buffer to store the master samples (see Fig 5).

This buffer will be managed using a FIFO (First In First Out) policy: as soon as a new master sample is received, it is stored at the end of the buffer; when a new sample is needed for the slave samples calculation, it is extracted from the head of the buffer.

20 The last two data extracted from the buffer are always the two values to interpolate; in the following we will call them $x_{previous}$ (e.g. the sample at time T_1) and x_{next} (e.g. the sample at time T_2).

The number of samples in the buffer should always be "big enough" to guarantee that the buffer is never empty when a new sample is needed for the slave samples calculation (buffer underrun), but "not too big", to avoid extreme delays in the reference trajectory reconstruction. So we can set a buffer reference level to maintain.

35 The condition that must be satisfied to keep using the current $x_{previous}$ and x_{next} values for the slave samples calculation is the following:

$$t_s \geq T_i$$

As soon as this condition is not valid, a new sample has to be extracted from the buffer and $x_{previous}$ and x_{next} must be re-defined accordingly.

5 Considering that $t_s = s \cdot \Delta t$, $T_i = i \Delta T$ and $n \cdot \Delta t = m \cdot \Delta T$, the previous condition can be rewritten as:

$$s \leq i \cdot \frac{n}{m}.$$

Defining now

$$s' = s \cdot m$$

10 and

$$i' = i \cdot n$$

where $s = 0, \dots, n$ and $i = 0, \dots, m$,

the previous condition can be rewritten as:

$$s' \leq i'$$

15 As mentioned before, if this condition is satisfied, the s -th interpolated value x_s , can be obtained via a linear interpolation between the x_{next} and $x_{previous}$ master samples.

Once we have reached the end of a reference time window, the estimation of how many samples being used in the next time window (the new m value) is achieved, i.e. it is defined the
20 granularity of the next time window.

The estimation can be done monitoring the buffer level and using a standard regulator (e.g. a deadbeat regulator).

In particular the estimation process can be divided into two
25 different steps:

a) the calculation of an \tilde{m} value by simply evaluating how many data have been received during the last time window;

b) the calculation of the actual m value starting from the former \tilde{m} value and applying a correction factor in order to
30 guarantee that the buffer level is maintained close to a user defined buffer reference level.

With reference to abocecited step a), the calculation can simply consider how many original values have been used and what is the variation in the buffer level.

35 If the buffer level at the end of a reference time window is

greater than the buffer level at the beginning of the time window, the number of the received data is greater than the data that have been used.

With reference to step b), the correction factor can be proportional to the difference between the actual buffer level and the reference buffer level.

If necessary, the insertion of a dead-zone can be considered (i.e. the correction factor can be activated only if the difference between the actual buffer level and the reference buffer level is greater than a given value).

Once the new m value is available, i and s can be resetted to 0 and the algorithm can start the slave samples calculation in the next reference time window.

If the two clocks were in perfect relation, after the first m value estimation, the m value would be the same for all of the time windows.

The presence of the jitter and of the Δn produces a varying m from one time windows to the other.

The effect of these variations is that the velocity trajectory has a little step up or down, depending on how much m increases or decreases in relation with its value. In order to reduce the effect of these variations, the n value should be chosen "big enough".

In fact, the error accumulated during a time window will be spread in the following time window.

Obviously, the higher is m , the lower is the incidence of the error.

Algorithm implementation

The intent of this section is to show an implementation of the above synchronization algorithm (see Fig. 5).

The algorithm implementation can be splitted up into two different procedures:

- the master samples handler procedure
- the slave samples handler procedure

The master samples handler procedure has to be executed as

soon as a new reference trajectory sample is received by the slave from the master (therefore with a nominal period of ΔT). Basically this procedure is responsible for the insertion of the master samples in the FIFO buffer.

5 The slave samples handler procedure has to be executed (periodically) with the slave sampling time Δt .

This procedure is the most important, as it is responsible for the master samples extraction from the buffer, the slave samples calculation and the m value estimation.

10 The procedure is responsible for the control of the buffer level as well.

According to Fig. 6, a simple flow chart for each of the above procedures is shown.

15 Algorithm initialization

For a proper initialization of the algorithm, the following conditions must be satisfied:

$$m = (\Delta t_{nom} / \Delta T_{nom}) * n$$

$$i' = s' = 0$$

20 Buffer Level = Buffer Reference Level + Delta, with Delta > 0 where n and the Buffer Reference Level are user-defined parameters.

Claims

1. Method for exchanging information among digital units in a distributed system, with digital units being defined by at least a master node and slave nodes, comprising the step of
5 transferring information references from said master node to said slave nodes, said information references being sampled with sampling time corresponding to a cycle time period defined by clock value of said master node; the method being characterized in that it comprises further steps of
10 estimating the number of said information references sampled arrived to said slave node from said master node during a periodic reference time interval, and using said number to recalculate the master clock value, so that said slave nodes are able to reconstruct master node information reference
15 during a following reference time interval.
2. Method according to claim 1, characterized in that said recalculation is realized by a linear interpolation and by using a buffer for storing more master node samples.
3. Method according to claim 2, characterized in that said
20 buffer is a first in - first out type buffer.
4. Method according to any claim from 1 to 3, characterized in that said slave nodes are linked with respective electromechanical axes of an automatic packaging machine, the motion of which is to be controlled.
- 25 5. Method according to any preceding claims from 1 to 4, characterized in that said information references comprise at least a couple of values, one of such value being a time value.

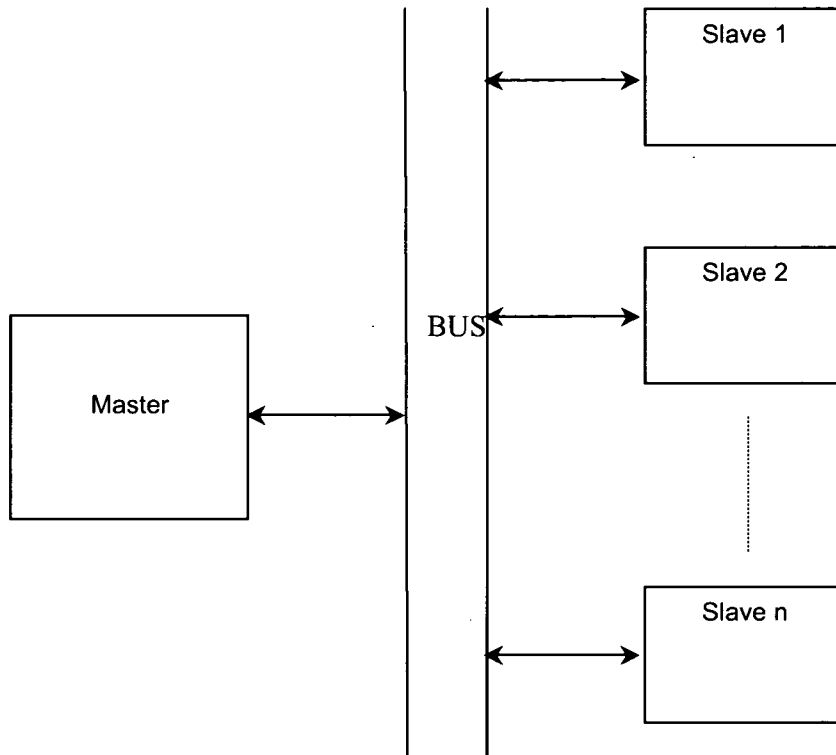


FIG. 1

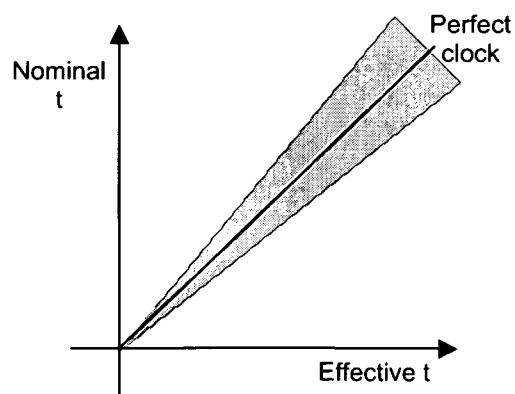


FIG. 3

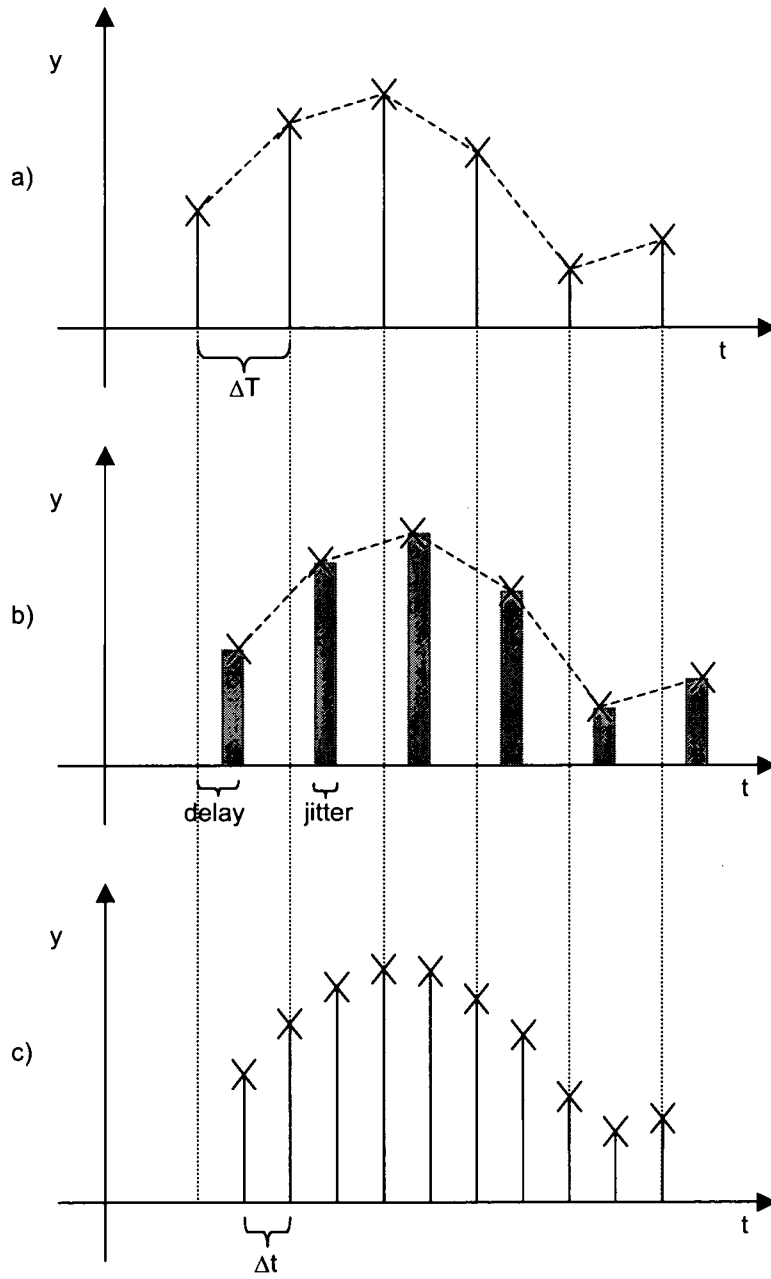


FIG. 2

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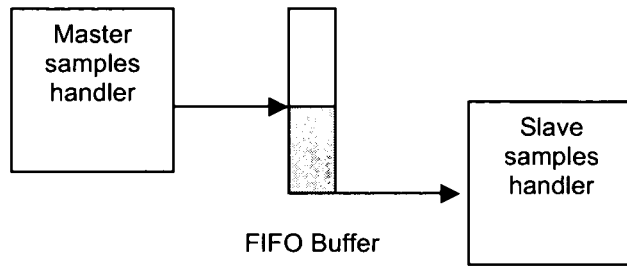


FIG. 5

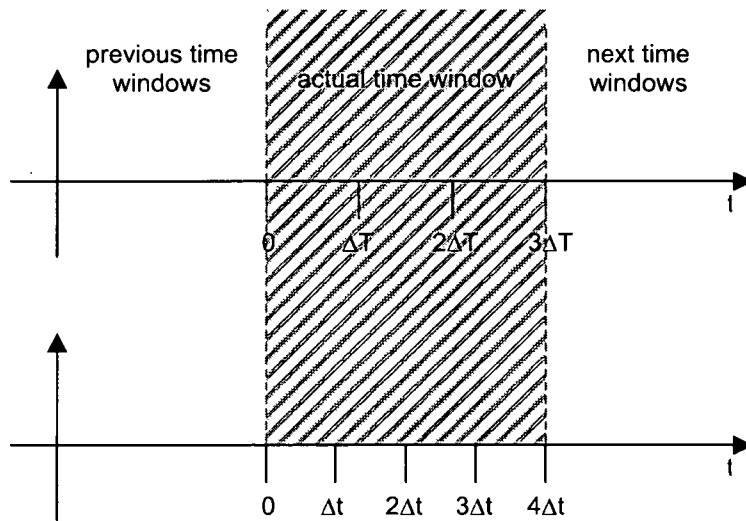


FIG. 4

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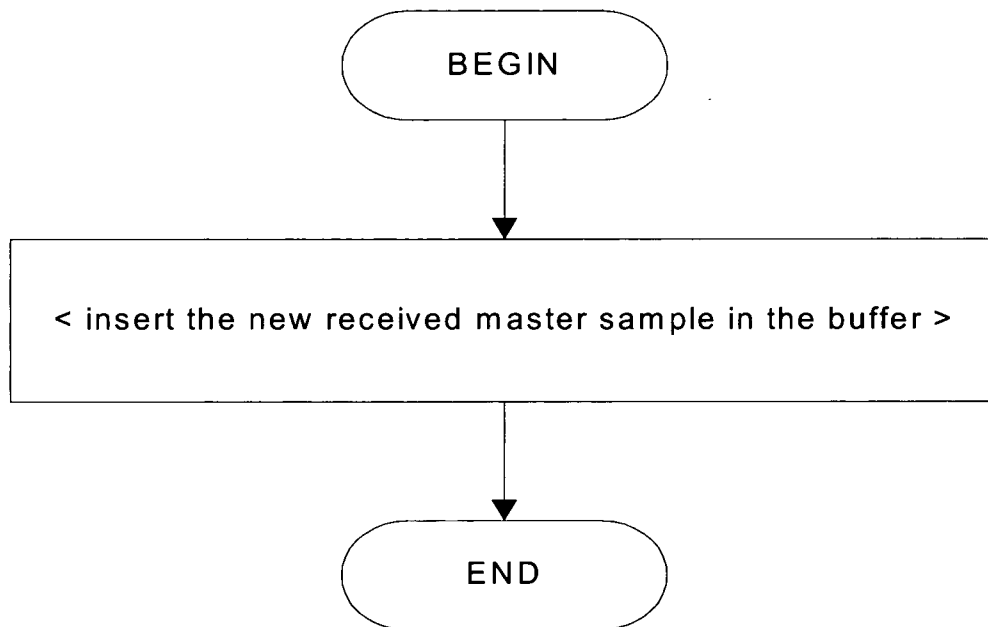


FIG. 6a

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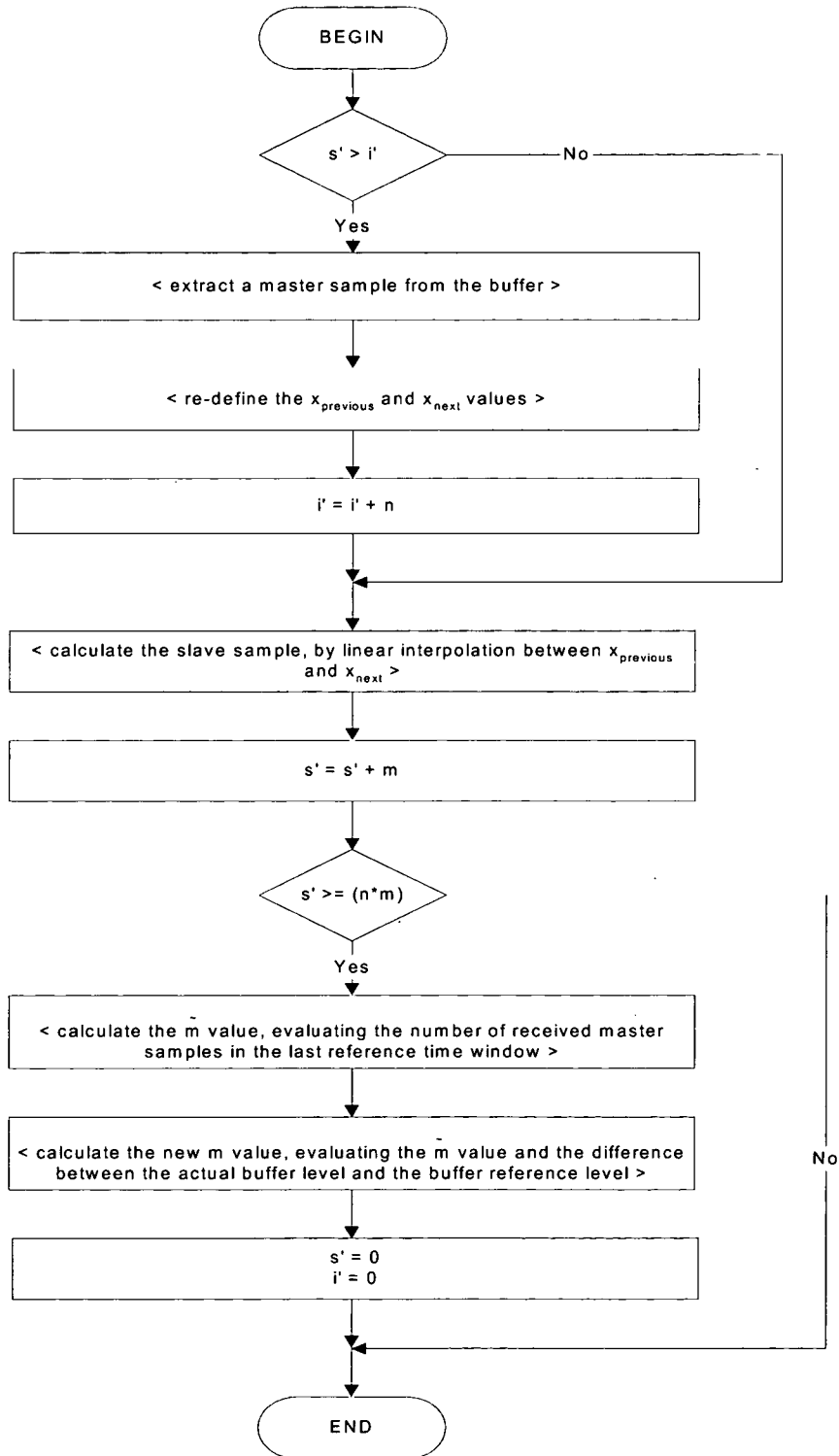


FIG 6b

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2006/007326

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L7/033 H04L7/02 G06F1/12

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)
H04L G06F

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 practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/062332 A1 (DABRAL SANJAY ET AL) 1 April 2004 (2004-04-01) abstract; claims 1-5,9,11,12,14-23; figures 3,6,7 paragraphs [0001], [1319] - [0021], [0023], [0024], [0026], [0027], [0030], [0033], [0034]	1-5
X	US 6 134 285 A (LO ET AL) 17 October 2000 (2000-10-17) abstract; claims 1,4-9,11,14,15,21; figures 3,4,5a,5b,6-8 column 1, line 21 - line 41 column 1, line 66 - column 2, line 19 column 4, line 1 - line 17 column 5, line 10 - line 52 column 6, line 7 - line 46 column 10, line 12 - line 61	1,3-5
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Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search

20 September 2006

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Name and mailing address of the ISA/
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Wolters, Robert

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2006/007326

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 312 671 A (INTERNATIONAL BUSINESS MACHINES CORPORATION) 26 April 1989 (1989-04-26) abstract; claims 1,2; figures 3,6,7 column 4, line 38 - line 41 column 4, line 53 - column 5, line 32 column 6, line 22 - line 47 -----	1,3-5
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/EP2006/007326

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