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(54) Weighted throttle adaptation

(57) The present invention relates to a system and method for controlling an air/fuel relationship of an internal combustion engine having a throttle and an intake manifold. It comprises means for calculating a true throttle area based on sampled measurements of operational data and models of variables, where each data sample is weighted by a weight factor determining its importance. Means are provided for estimating parameters of a correction equation through comparing the true throttle area to a modelled throttle area and minimizing the estimation error through optimization. Also provided are means for using the correction equation for controlling the air/fuel relationship of the internal combustion engine.

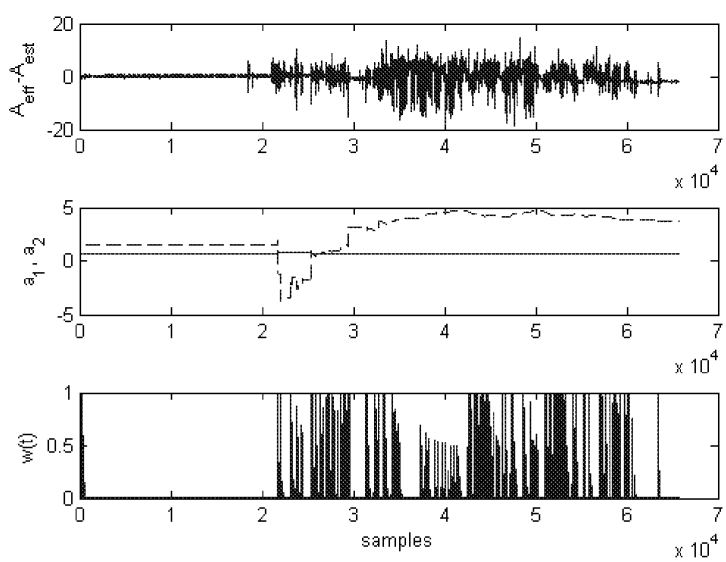

Fig. 3

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Description

TECHNICAL FIELD

[0001] The present invention is related to a system for controlling an air/fuel relationship of an internal combustion engine having a throttle and an intake manifold in accordance with the preamble of claim 1.

BACKGROUND OF THE INVENTION

[0002] Throttle area is an important parameter in air-mass flow computation for an internal combustion engine. A nominal throttle area is given, that describes a new throttle, which is the throttle without any contamination.

[0003] When estimating air flow through an internal combustion engine a throttle model is often used that includes the throttle area. The modelled throttle area may deviate from the true throttle area, due to dirt loading of the throttle during use and also somewhat due to individual differences between throttles. Throttle area adaptation is a well known method for compensating for such deviations. Throttle area adaptation uses measurements and models of variables that under some circumstances may be used to calculate the true throttle area. The parameters of a correction equation may be estimated through comparing the true throttle area to the modelled throttle area.

[0004] However, a problem with this standard approach is that when a long time is spent at one operating point, e.g. when idling or cruising at constant speed, the correction equation will be adapted to completely remove the error at this specific operating point. This will have the effect that the parameter estimation is locally optimal, but may be far from a desired globally optimal estimate. In other words, the correction is "over fitted" to that particular operating point and at the next transient the correction will cause the area estimate to degenerate instead of improve.

[0005] The problem of over fitting estimates is well known and is a natural problem when the data used is not uniformly distributed. Mathematically this implies that a cost function to be minimized will inadvertently give the more frequent data points a higher importance. In this way the estimates will be erroneous and will fit the data points that are more frequent while the other data points are given less importance.

[0006] Some previous attempts to address the above problems have been based on the concept of solutions using a correction equation which is not sensitive to unevenly distributed samples. In practice this means that such a solution is limited to a low degree of freedom of the correction equation, possibly estimating only one parameter. Another such solution is to limit the adaptation to idle only, in combination with a correction equation which gives a small impact on greater throttle angles.

[0007] Although, these kinds of solutions avoid the risk of worsening the problem due to over fitting, they do not utilize the full potential of throttle area adaptation.

SUMMARY OF THE INVENTION

[0008] An object of the present invention is to provide an improved system for controlling an air/fuel relationship of an internal combustion engine having a throttle and an intake manifold that may eliminate or at least reduce the problems described above.

[0009] According to a first aspect of the present invention this object is achieved in accordance with claim 1, which specifies a system for controlling an air/fuel relationship of an internal combustion engine having a throttle and an intake manifold, characterised in that it comprises: means for calculating a true throttle area based on sampled measurements of operational data and models of variables where each data sample is weighted by a weight factor determining its importance and; means for estimating parameters of a correction equation through comparing the true throttle area to a modelled throttle area and minimizing the estimation error through optimization; and means for using the correction equation for controlling the air/fuel relationship of the internal combustion engine.

[0010] A further object of the present invention is to provide an improved method for controlling an air/fuel relationship of an internal combustion engine having a throttle and an intake manifold that may eliminate or at least reduce the problems described above.

[0011] According to a second aspect of the present invention this object is achieved in accordance with claim 7, which specifies a method for controlling an air/fuel relationship of an internal combustion engine having a throttle and an intake manifold, characterised in that it comprises the steps of: calculating a true throttle area based on sampled measurements of operational data and models of variables where each data sample is weighted by a weight factor determining its importance and; estimating parameters of a correction equation through comparing the true throttle area to a modelled throttle area and minimizing the estimation error through optimization; using the correction equation for controlling the air/fuel relationship of the internal combustion engine.

[0012] Further embodiments are listed in the dependent claims.

[0013] It will be appreciated that features of the invention are susceptible to being combined in any combination without departing from the scope of the invention as defined by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] By way of example only, embodiments of the present invention will now be described with reference to the accompanying drawings wherein:

Figure 1 schematically illustrates in a first subplot the difference between the actual and the estimated effective area, in a second subplot the two estimation parameters, and
in a third subplot the weight when no weighting in accordance with the present invention is applied.

Figure 2 schematically illustrates a histogram over the sampled data points.

Figure 3 schematically illustrates in a first subplot the difference between the actual and the estimated effective area, in a second subplot the two estimation parameters, and
in a third subplot weighting in accordance with the present invention.

Figure 4 schematically illustrates a weight distribution in accordance with the present invention.

[0015] Still other objects and features of the present invention will become apparent from the following detailed description considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for purposes of illustration and not as a definition of the limits of the invention, for which reference should be made to the appended claims. It should be further understood that the drawings are not necessarily drawn to scale and that, unless otherwise indicated, they are merely intended to conceptually illustrate the structures and procedures described herein. The same reference numerals will be used for illustrating corresponding features in the different drawings.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0016] For the purpose of increasing the fuel efficiency of an internal combustion engine while at the same time reducing the concentration of harmful materials contained within its exhaust gas, it is necessary to measure a mass of intake-air sucked into the internal combustion engine, accurately, and also control a mass of fuel injection, such that the air/fuel ratio may be kept at a target air/fuel ratio, which is determined by the operating condition thereof.

[0017] Thus, the present invention relates to a system for controlling an air/fuel relationship of an internal combustion engine based on throttle area adaptation using measurements and models of variables to calculate a true throttle area. Measurements may comprise measurements of pressure in an intake manifold of the internal combustion engine up-stream and down-stream of the throttle, throttle angle, temperatures at various locations in the intake manifold etc.. Through comparing the true throttle area to a modelled throttle area, parameters of a correction equation may be estimated. It especially addresses the problem of over fitting the estimates. This is a natural problem when the data used in the identification is not uniformly distributed. Mathematically this implies a cost function to be minimized, which usually is on the following form:

$$V(\theta) = \sum_{t=0}^{T} e^{2}(t,\theta)\,, \tag{1}$$

which will inadvertently give the more frequent data points a higher importance. In (1) e is the estimation error, θ is the estimation parameter vector or the argument of the optimization problem and t is time. This way the estimates will be erroneous and will fit the data points that are more frequent while the other points will be given less importance.

[0018] For solving this problem, it is proposed to use weighted adaptation, i.e. an adaptation which is based on the optimization of a weighted loss function. Thus, in order to avoid this problem, the data from the measurements may be weighted, i.e. the cost function receives data weighted by a factor which determines its "importance" in the optimization problem. The cost function may then be represented as,

$$\overline{V}(\theta) = \sum_{t=0}^{T} w(t)e^2(t,\theta) \tag{2}$$

where $0 < w(t) \leq 1$ is the weighting factor.

[0019] When a long time is spent in the same operating point, the measured data samples for adaptation will be given a lower weight, i.e. the samples will not be fully taken into consideration in the optimization. This will cause the adaptation to freeze before the error is fully removed in one operating point. When a new operating point is reached the weight is again increased in order to allow adaptation at full speed.

[0020] Thus, the solution of the optimization problem is:

$$\hat{\theta} = \arg\min \overline{V}(\theta) \tag{3}$$

[0021] This optimization problem may be solved in a number of ways. In the following a preferred method is presented, namely the recursive weighted least squares method.

[0022] The way to address this problem by this method is by finding the least squares solution. This method is well documented in literature in both its explicit form and its recursive form.

[0023] The recursive weighted least squares algorithm is given by:

$$\begin{aligned}
\hat{\theta}(t) &= \hat{\theta}(t-1) + K(t)\left(y(t) - \varphi^T(t)\hat{\theta}(t-1)\right) \\
K(t) &= P(t-1)\varphi(t)\left(\lambda / w(t) + \varphi^T(t)P(t-1)\varphi(t)\right)^{-1} \\
P(t) &= \left(I - K(t)\varphi^T(t)\right)P(t-1)/\lambda
\end{aligned} \tag{4}$$

where $e(t) = y(t) - \varphi^T(t)\hat{\theta}(t\text{-}1)$, $\varphi(t)$ are the regressors, $y(t)$ is the measurement and λ is the forgetting factor used in the algorithm.

[0024] An alternative, and simpler, way of addressing this problem is by minimizing the instantaneous error, i.e. using the cost function:

$$\overline{J}(\theta) = \frac{w(t)e^2(t,\theta)}{2} \tag{5}$$

where the parameter adaptation is given by the gradient of this loss function:

$$\hat{\theta}(t) = \hat{\theta}(t-1) - \gamma w(t)e(t)\frac{\partial e}{\partial \theta} \tag{6}$$

where γ is the search step.

[0025] There exist a number of alternative ways of constructing a weighting function. One simple approach is to filter the throttle angle or nominal area. Such a filter should have high pass characteristics such that following a change in operating point the output is high for a certain time. This will remove the negative effect of non-varying operating points on the estimation algorithm.

[0026] Another alternative is to use a continuously updated histogram with a forgetting factor. As long as the bin of the actual operating point in the histogram contains a low or moderate fraction of the samples, the weight is high. When the fraction of samples in the bin of the operating point exceeds a desired amount, the associated weight is reduced.

The reduced weight should also reduce the forgetting factor, such that the update of the histogram is consistent with the use of samples.

[0027] Some examples of weighting functions will be given below. The commonality for these functions is that they tend to return a small weight if the data point is often encountered and a high weight otherwise.

[0028] One simple way to exclude a situation where many consecutive, equal or slowly varying points are received is by using a differential weighting, i.e. the weight is generated by the filtered data points where the filter has a derivative action.

$$w(t) = \left| \frac{d}{dt} y_f(t) \right| + \varepsilon, \tag{7}$$

where $y_f(t)$ is typically a low-pass filtered version of the measurement.

[0029] A more advanced method of weighting the data is by classifying and counting the data points. In this way the number of data points from each group U_i, accounted for in the optimization is limited. One such algorithm is:

$$\begin{cases} x_i(t+1) = \left(1 - \dfrac{w(t)}{\tau}\right) x_i(t) + \dfrac{w(t)}{\tau} \delta_i \\ w(t) = 1 - \dfrac{sat_{[\alpha,\beta]}(x_i(t)) - \alpha}{\beta - \alpha} \end{cases}, \tag{8}$$

where

$$\delta_i(t) = \begin{cases} 1, & y \in U_i \\ 0, & otherwise \end{cases}, \qquad sat_{[\alpha,\beta]}(x(t)) = \begin{cases} \beta, & x > \beta \\ x, & \alpha \le x \le \beta \\ \alpha, & x < \alpha \end{cases}.$$

[0030] Above, α, β, τ are tuning parameters. The first two are self explanatory while the third is a time constant that act as a forgetting factor for the counted data points.

[0031] As previously mentioned solutions without weighting would have to use a correction equation which is not sensitive to unevenly distributed samples. In practice this would mean that they would be limited to a low degree of freedom of the correction equation, possibly estimating only one parameter. Another solution would be to limit the adaptation to idle only, in combination with a correction equation which gives a small impact on greater throttle angles. Although, these kinds of solutions, without weighting, avoid the risk of worsening the problem due to over fitting, they do not utilize the full potential of throttle area adaptation. Using the here proposed weighted adaptation a correct equation best fitted to eliminate the different sources of errors may be chosen. A high quality estimate of parameters in an effective correction equation will provide a high quality throttle area estimate which ultimately will improve lambda and emissions.

[0032] The considered application in accordance with the present invention is that of adaptation of throttle area for contaminated throttles in internal combustion engines. Throttle area is an important parameter, in air-mass flow computation. A nominal throttle area is given, that describes a new throttle, i.e. the throttle without any contamination. Due to dirt loading on the throttle during usage and also individual differences between throttles, the modelled throttle area may deviate from the true area. To compensate for this, throttle area adaptation is the preferred method.

[0033] Throttle area adaptation uses measurements and models of variables that under some circumstances may be used to calculate the true throttle area. Through comparing the true throttle area to the modelled throttle area, the parameters of a correction equation may be estimated. In the following an affine correction is considered, however, as will be evident to the person skilled in the art, the method may be easily used for higher order corrections as well.

[0034] In the following performed simulations will be presented which explore only the case based on the preferred recursive least squares estimation. Similar results may however be obtainable for a pure gradient method as well.

[0035] For reference, simulation results without weighting, i.e. all samples given the weight one, are shown in Figure 1. The first subplot shows the difference between the actual and the estimated effective throttle area. The second subplot shows the two estimation parameters while the third subplot shows the weight, i.e. in this case one. Notice that the estimates are erroneous at the beginning of the sequence due to lack of excitation.

[0036] Figure 2 shows a histogram over the data. Notice that most of the data points are sampled when the throttle is up to 20% opened.

[0037] Figure 3 shows the same data set as above with sorting based weighting in accordance with algorithm 8 as presented above. Observe that the estimation is switched off during lack of excitation, i.e. shortly after the start of the sequence, due to the fact that the weight factors at that time are very small.

[0038] Figure 4 shows the distribution of the weights resulting from the algorithm. Notice that the first bin is reduced by a factor of 100 for ease of readability as a large majority of all samples are awarded a very low weight.

[0039] In accordance with the present invention is also envisaged an Engine Control Unit, which comprises a system as described above.

[0040] The Engine Control Unit (ECU), also known as an Engine Management System (EMS), is an electronic system which controls various aspects of an internal combustion engine's operation. For providing the functionalities as described above the ECU may comprise one or more of the following: an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that execute one or more software or firmware programs, a combinational logic circuit, or other suitable components that provide the described functionality.

[0041] Furthermore, in accordance with the present invention is also envisaged an automotive vehicle, which comprises such an Engine Control Unit.

[0042] Still further, in accordance with the present invention is also envisaged an automotive vehicle, which comprises a system as described above.

[0043] Modifications to embodiments of the invention described in the foregoing are possible without departing from the scope of the invention as defined by the accompanying claims.

[0044] Expressions such as "including", "comprising", "incorporating", "consisting of", "have", "is" used to describe and claim the present invention are intended to be construed in a non-exclusive manner, namely allowing for items, components or elements not explicitly described also to be present. Reference to the singular is also to be construed to relate to the plural and vice versa.

[0045] Numerals included within parentheses in the accompanying claims are intended to assist understanding of the claims and should not be construed in any way to limit subject matter claimed by these claims.

[0046] Thus, while there have been shown and described and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions and substitutions and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art. For example, it is expressly intended that all combinations of those elements and/or method steps which perform substantially the same function in substantially the same way to achieve the same results are within the scope of the invention. Moreover, it should be recognized that structures and/or elements and/or method steps shown and/or described in connection with any disclosed form or embodiment of the invention may be incorporated in any other disclosed or described or suggested form or embodiment as a general matter of design choice. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

Claims

1. System for controlling an air/fuel relationship of an internal combustion engine having a throttle and an intake manifold, **characterised in that** it comprises:

   means for calculating a true throttle area based on sampled measurements of operational data and models of variables where each data sample is weighted by a weight factor determining its importance and;
   means for estimating parameters of a correction equation through comparing the true throttle area to a modelled throttle area and minimizing the estimation error through optimization; and
   means for using the correction equation for controlling the air/fuel relationship of the internal combustion engine.

2. System according to claim 1, **characterised in that** it comprises a weighting function arranged for weighting each data sample such that the sample is given a low weight if a predetermined time is spent in the same operation point and such that the weight of the sample is increased when a new operating point is reached.

3. System according to claim 2, **characterised in that** the weighting function is provided through filtering a throttle angle or a nominal throttle area using a filter having high pass characteristics, such that following a change in

operating point, the output is high for a predetermined time.

4. System according to claim 2, **characterised in that** the weighting function is provided using a continuously updated histogram with a forgetting factor, where as long as the bin of an actual operating point in the histogram contains a predetermined low or moderate fraction of the samples, the weight is high, and when the fraction of the samples in the bin of the operating point exceeds a predetermined amount, the associated weight is reduced.

5. System according to any one of claims 1 to 4, **characterised in that** the minimizing the estimation error through optimization are arranged to perform this optimization using the recursive weighted least squares method.

6. System according to any one of claims 1 to 4, **characterised in that** the minimizing the estimation error through optimization are arranged to perform this optimization using the gradient method.

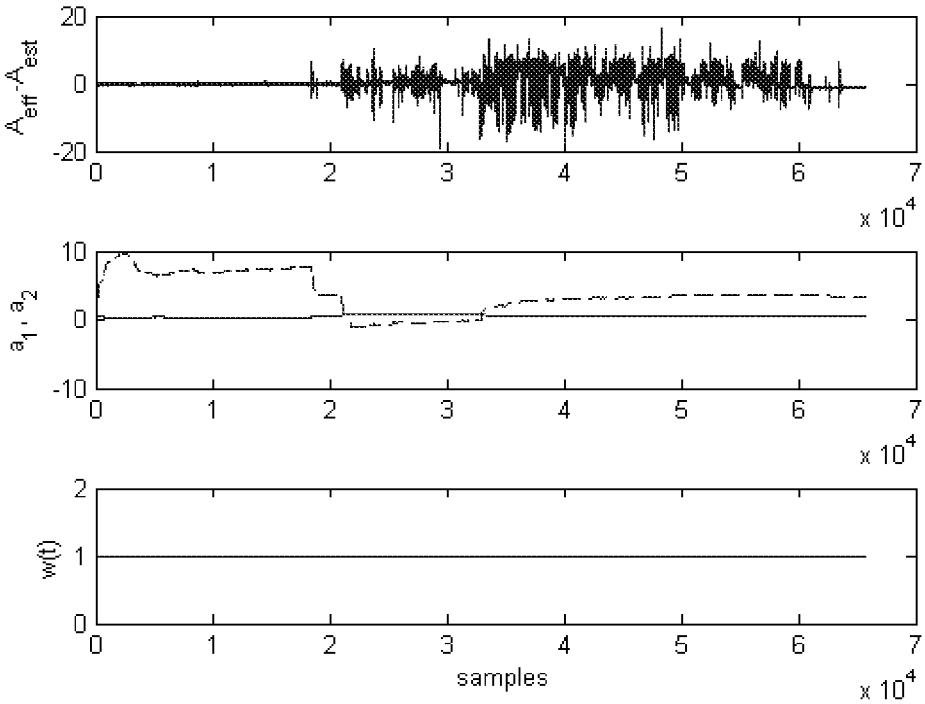
7. Method for controlling an air/fuel relationship of an internal combustion engine having a throttle and an intake manifold, **characterised in that** it comprises the steps of:

   calculating a true throttle area based on sampled measurements of operational data and models of variables where each data sample is weighted by a weight factor determining its importance and;
   estimating parameters of a correction equation through comparing the true throttle area to a modelled throttle area and minimizing the estimation error through optimization;
   using the correction equation for controlling the air/fuel relationship of the internal combustion engine.

8. An Engine Control Unit **characterised in that** it comprises a system according to any one of claims 1 to 6.

9. An automotive vehicle **characterised in that** it comprises an Engine Control Unit according to claim 8.

10. An automotive vehicle **characterised in that** it comprises a system according to any one of claims 1 to 6.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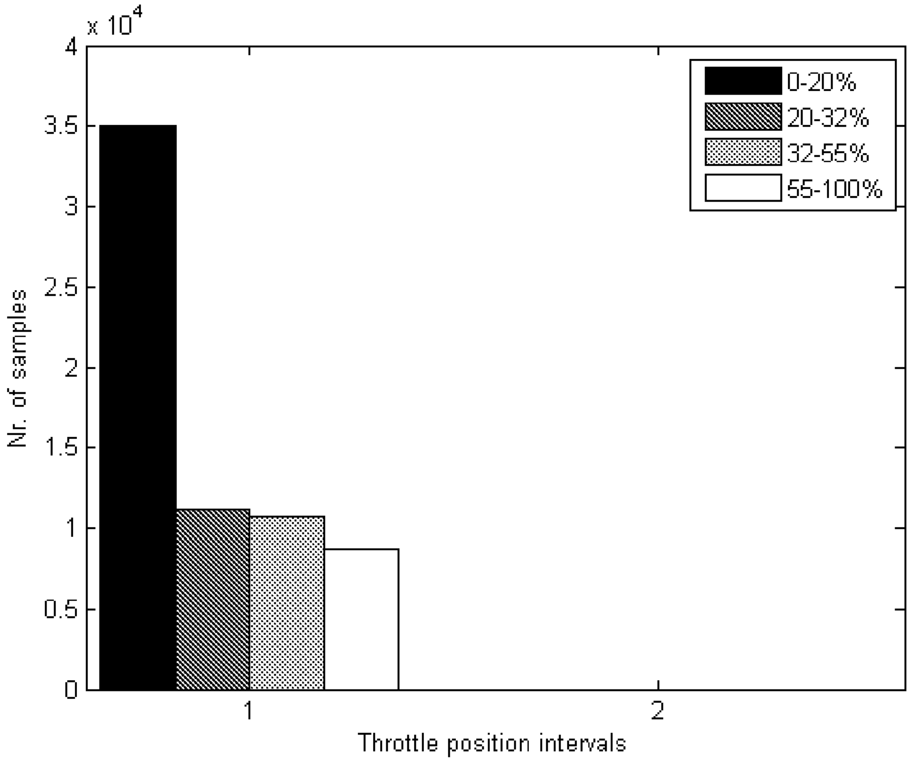
samples
x 10^4

Fig. 1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3
2.5
2
1.5
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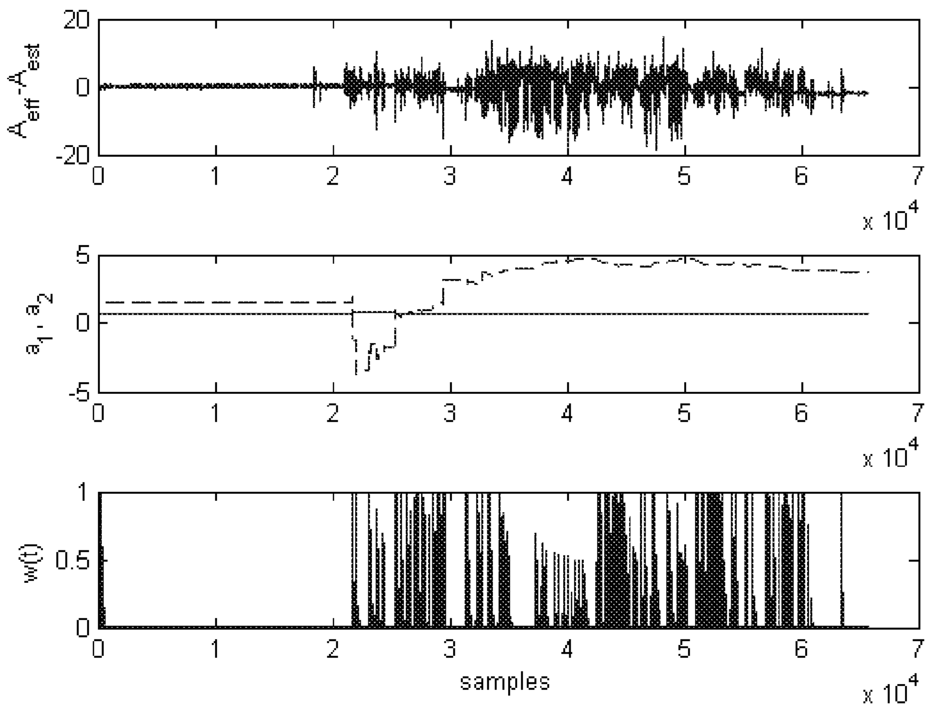
20-32%
32-55%
55-100%

Fig. 2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x 10^4
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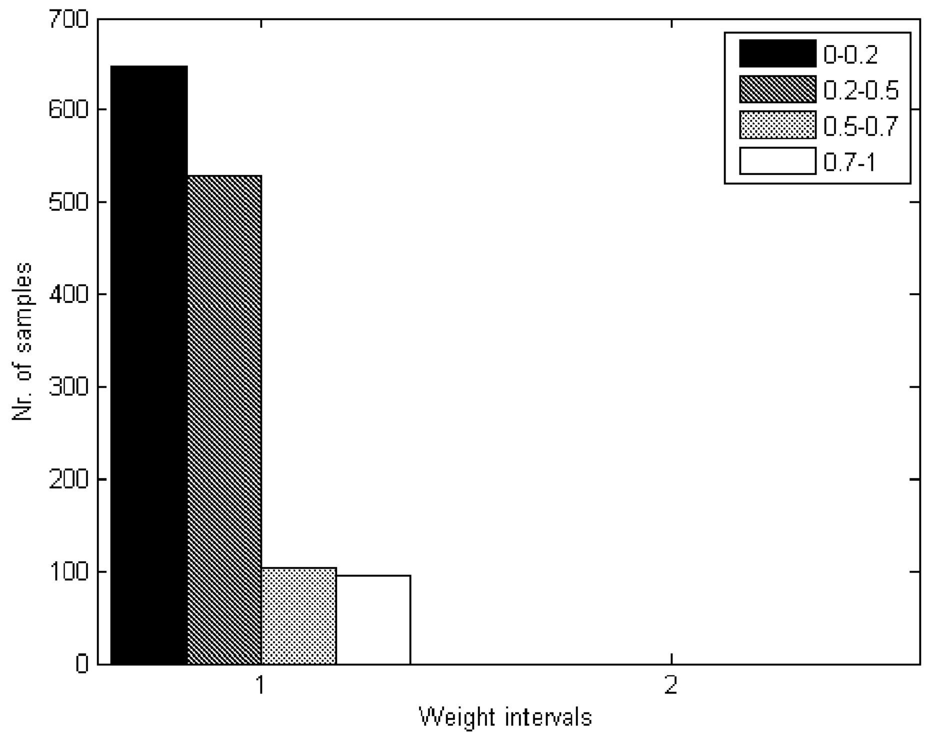
0
w(t)
samples
x 10^4

Fig. 3


700
600
500
400
300
200
100
0
Nr. of samples
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2
Weight intervals
0-0.2
0.2-0.5
0.5-0.7
0.7-1

Fig. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 11 0342

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2003/196639 A1 (BAUERLE PAUL ALAN [US]) 23 October 2003 (2003-10-23) * paragraphs [0026] - [0029], [0034] - [0036]; figure 8 *	1,7	INV. F02D41/24 F02D11/10
A	US 2005/187699 A1 (STAMM DAVID A [US] ET AL) 25 August 2005 (2005-08-25) * paragraphs [0018], [0019] *	1	
A	DE 10 2006 035372 A1 (DENSO CORP [JP]) 16 May 2007 (2007-05-16) * paragraphs [0048], [0055] - [0059] *	1	
A	US 6 957 140 B1 (BAUERLE PAUL A [US] ET AL) 18 October 2005 (2005-10-18) * column 4, line 4 - column 5, line 12 * * column 7, line 1 - line 45 *	1	
			TECHNICAL FIELDS SEARCHED (IPC)
			F02D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	12 November 2007	Pileri, Pierluigi

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 07 11 0342

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12-11-2007

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82