Aspects of input part of embedded systems

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***Abstract*—**In the standard routines there is not used a elimination of all problem from disturbances of the way of signal from sensor to intern input of microcontroller. Regularly the primary (the first) signal form sensor has a small level of voltage. Environment of the way of signal includes some different sort of noises, it has influences of interferences. It can degrade the signal up to level without a possibility of using. During process of signal condition any technical and program means have to use. The basic technical means perform a verification range, limits effects of disturbing interference of external environment and makes filtration. Other way there are software methods where value or signal is tested according to real range or after existent model, speed of change of rising or dropping, does statistical balancing values, verification of uncertainties and errors of measurement and next operations. Significant application of those areas is used by precise and professional embedded units.

***Keywords*—** interference disturbance, judgment of values, range limitation, signal condition, statistical balancing, uncertainty of measurement.

I. Introduction

Quality of signal condition out of sensors or readers according to measurement on continual production processes in chemistry, on manipulation of petroleum, in power engineering and in other regions of industry significantly influences function of control and monitoring systems.

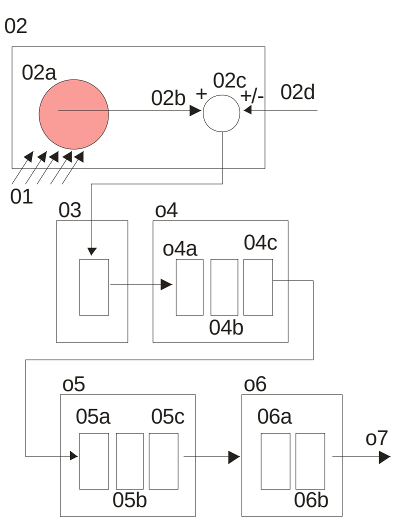

Fig. 1 Detail scheme of signal condition

01- extern stimulation, 02- sensor, 03- transducer, 04- additional HW, 05-input part of MC, 06-SW parts, 07-output. Detail scheme of signal condition shows fig.1.

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Random fluctuation and errors from measurement incurred in measuring circuit , disturbance of interference in environment of signals and next influences they may depreciate function of advanced control systems as far as to peril safety factor and quality of production.

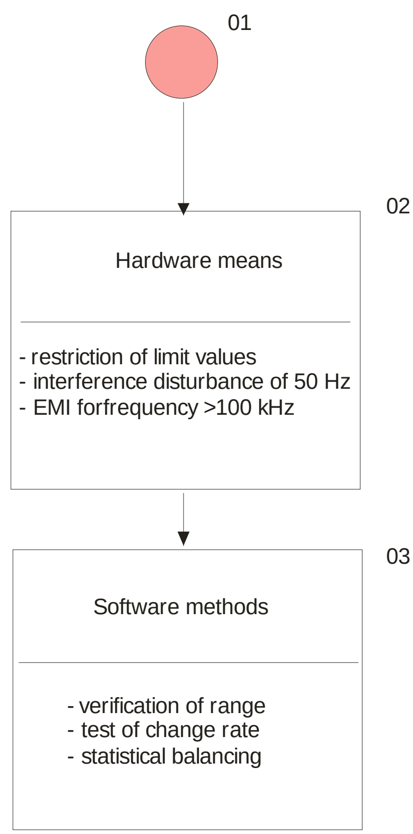

Fig. 2 Block scheme of signal condition of sensors

Which are the possibilities to remove these problems and to ensure the high - quality functions of informatics and control systems? There are on the one hand engineering units and on the other side some programmable methods. A scheme is in the fig.2.

The other look on processes of acquisition and data processing is showed in the fig. 3 for processes of measurement of physical quantities and information reading. The processes are divided in function blocks A1- A5, on transmission of signals, data and information up 01 to 05 with additional operations and in blocks SW1 and SW2 of program processing.

The block A1 is created of physical environment (temperature, parameters of liquids,..) or data carrier (barcode, tag of RFID, picture, sound) and it is scanned of sensing elements from a block A2 and the primary signals are converted in signals of electric unified voltage . In face of entrance into central unit is registered the block A4 for additional hardware check - up of signal. There is safe no overfullfilment of limit value, removing of disturbance using circuits of galvanic separation and filtration of bad frequency of way of band filter.

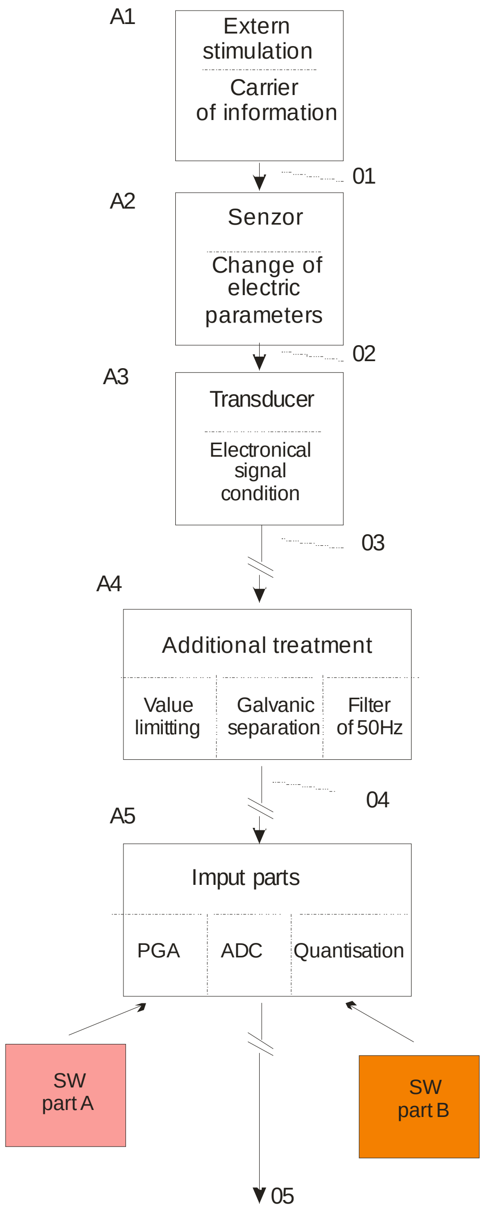

Fig. 3 Scheme of input part of signal condition

Input part of central unit, the block A5, has parts to input signal conditioning mean of PGA, an analog numerical conversion and quantization. Next to the hardware part includes the block also a part of software to verification of range, tendency and setting sampling and to computation accordance with existent functional relation, to statistic processing and to statistic balancing. [1]

The extern stimulations are some parameters of environment. There are the main value of temperature, pressure, flow, liquid or gas quality, speed, distance, energy eg. (see fig.4)

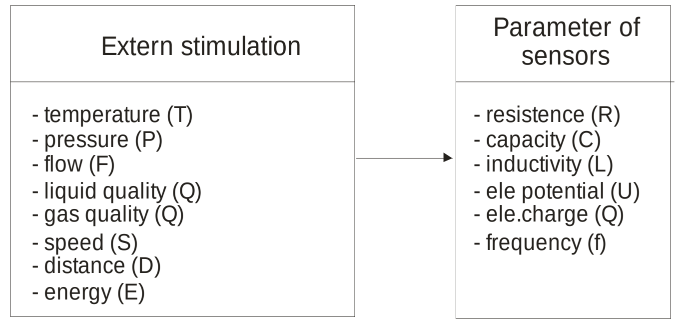

Fig. 4 Influence of sensor parameters accordance extern stimulation

The extern stimulation does different changes of electric parameters of sensor. A big range of sensors has a transform it into the change of electrical resistance. The table 1. shows some possibly examples.

Table 1 Examples extern stimulation and primary signals of sensor

Parameter of primary signal of sensors	Examples of extern stimulation
Resistance (R)	Temperature, pressure, flow, liquid quality, distance.
Capacity (C)	Pressure, moisture, distance.
Inductivity (L)	Pressure, gas quality, speed, distance, electrical energy.
Electric potential	Temperature, flow, liquid quality, gas quality, speed, electrical energy.
Electric charge	Temperature, pressure, power.
Frequency	Flow, distance, electrical energy.
Time period	All capacity sensors.

Other passive sensors generally use as the primary signals change of resistance, capacity, inductivity or frequency. The active sensors generate as a primary signal the electrical potential (thermocouple, inductive flow meter, parameter pH, tachogenerator) or the electric charge (piezo-ceramic, pyro-electrical).

Next step of signal condition is converting of primary signals of sensors into electric analog or binary signals or into time period. Analog signal is voltage of different range, eg. From 0 V up to 2,5V. The signal inputs via analog inputs and it is converted in bytes.

The fig.5 shows the schemes of converting the primary signal of sensors into analog voltage. The standard circuit is bridge. Fig.5a can change od resistance R_s into analog voltage U_{out}. There is DC bridge. Other bridge circuits are AC bridge. There is supply of $U_{N,AC}$. The input can have capacitive sensor C_s, fig.5b or inductive sensor L_s, fig.5c. The active sensors with primary voltage signal use only instrument operational amplifier. There is possibly to gain au to 10000 times.

The active sensors with charge primary signal have to convert into voltage FET transistor, fig 5e. Special converting uses fig.5f, there is converting the primary signals of passive sensors into frequency (see fig.5f).

Very special circuit is on fig.5g. There is converted a capacitive sensor into time period. There is measured time interval between start and get the 63,2% value of spring of Y_{max}.

The binary signals have a level log.0 (eg. from 0 V to 0,7 V) and log.1 (eg. from 2,2 V to 5 V) . The binary signal brings value about stand of extern stimulation (value is between log.0 or log.1. Oder value can be periodical or non-periodical frequency (sinus signal, PWN signal atc.). The special binary signal gives a value of time period defining between two binary signal.

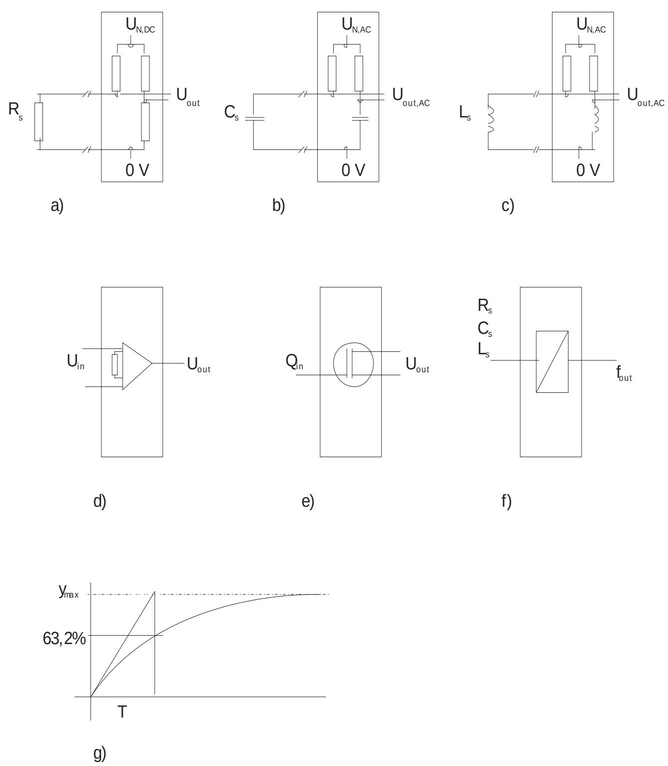

Fig.5 Scheme of converting the primary sensor signal into voltage

II. Technical means of signal condition

Standard technical means provide basic function of instrument from sensors up to embedded or central units. There are at the beginning the sensors working on physical principles, when outer stimulates of measured environment changes most often electrical characteristics or parameters of matter of sensor and systems . The non-unified primary signal out sensors is specific, e.g . alternation of electrical resistance, capacities and inductivities, changes of electric potential or electric charge and there is necessary it electronically set up to unified signal, most frequently as a voltage DC in the range from 0 V up to 10V or current 4- 20 mA. By these operations but there are increased some problems from electric disturbance and therefore this chain has to add specific elements , like to limit maximum signal value, galvanic separation etc.

Specific operation is affected already in electronic circuit on exit of sensors or at connection with converter. There is e.g. and wiring to compensation of longitude of cables, correction of other parallel influences,. There is also a limitation of influence of electromagnetic interference, by using twisting and shielded cables. [2,3,4]

A. Limitation of signal maximum

Enter data are in real environment effected by many factors first of all influences of other electric systems. One from many consequences there is unfair or and dangerous increasing signal level. Like first and basic procuration is limitation of value of amplitude of signal via using added electronic circuits.

As a tested solution can be bring in wiring accordance with fig.6.

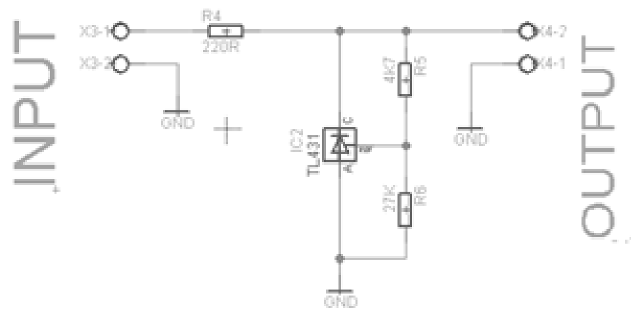

Fig. 6 Circuit with the voltage reference TL431

The circuit serves has a protective or regulative function on input. The circuit with programmable voltage reference LM431 was experimentally created for behaving as an ideal Zenner diode. Saturation voltage of IC was set to 2.9V. The output has a maximum constant voltage according to values of resistors of R5 and R6.

This circuit was tested and simulated, its static and dynamic behaviors in the environment of Matlab Simulink and was compared with real circuit of data measurements.

B. Remove and limitation influence of electric interference

A source of electric disturbance and overruning limit values there is the electromagnetic interference. Electromagnetic interference (EMI) is a process of emission and immission of electromagnetic field or electromagnetic radiation. Emission generates electromagnetic field or radiation from electric devices or electrical lines into free space. Immission is a state of environment where is created field and accordance with concrete conditions this field affects other electrical equipment. [2]

Coupling between elements of EMI is realized by cable as galvanic structure or in environment as capacitive or inductive structure. General view on EMI shows “Fig.7 Scheme of general view on EMI”. [1]

Scheme of generating of disturbing harmonic voltage under EMI and their incidence on measuring circle is showed in “Fig.5 Influence of interference voltage to measured signal”. Source of data signal has voltage U_m and it is carried over signal in unit A2 with load resistance Ri of unit of signal processing and carry over signal give upon input device A2 load angle resistance Ri troop for signal processing.

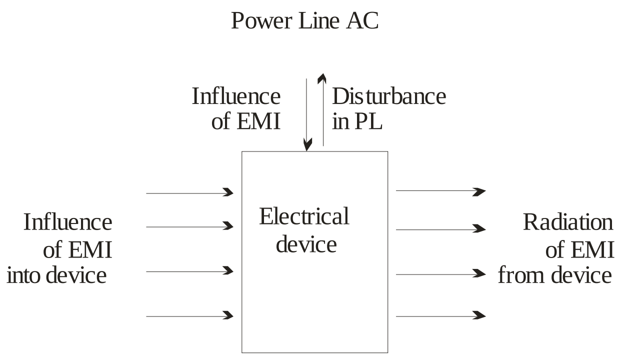

Fig.7 Scheme of general view on EMI

Power phasic lead uses electric current I_{inter} about voltage U_{inter}. Power control interferential field functions over capacity coupling C1, C2 on signal lead. Magnetic interferential field B1 is transformed to the signal circuit. This harmonic disturbance forms disturbing series mode voltage U_{SM} and common mode voltage near$_{CM}$.Influences of differences of earth current rises another disturbing harmonics tension , which adds to conformable voltage U_{CM}. On input device there are disturbing voltage superposed on voltage measuring signal $U_{land.}$

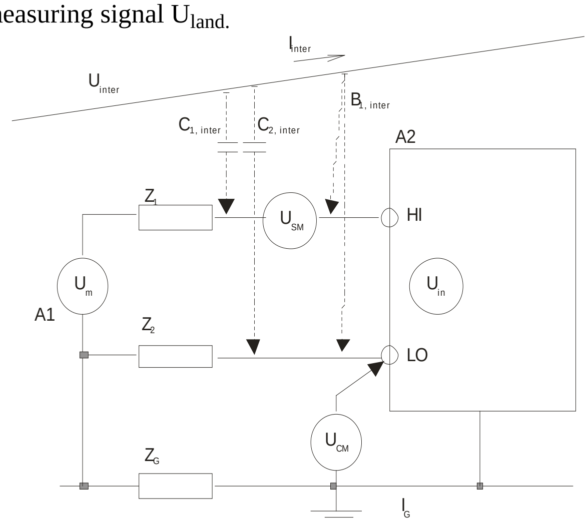

Fig.8 Influence of interference voltage to measured signal

Very important aspect at composition of technical means there is electric parameters of binding periphery it is output and input of following element. At those structures correct voltage level, kind of voltage, correct output and input impedance of interconnected periphery and frequency characteristic have be realized.

C. *Remove and limitation influence of electric interference*

Distance of lead with data from cables AC of limitation of influence of disturbance of EMI is possible achieve: of distance of data cables from radius of power cables AC, of using the high - quality signal and data cables with twisting pairs for elimination of frequency of 50Hz, of shielding of cables against a strong electric field and of galvanic separation.

The galvanic separation is possibility to isolate mainly the earthy currents. There has been tested a module. The linear optocoupler IL300 was used in the same schematic as in the datasheet for IL300. The scheme in “Fig.9 Circuit with the optocoupler IL300” shows the tested connection and the results of tests confirmed the circuit. The output is strictly linear.

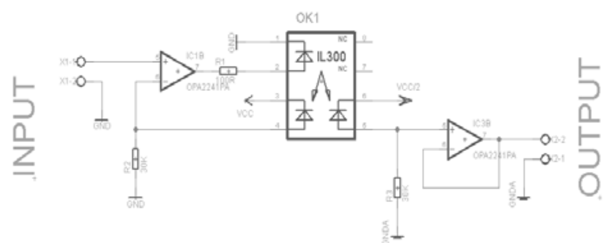

Fig.9 Circuit with the optocoupler IL300

D. *Remove and limitation influence of electric interference*

Analog continuous signal from sensors on entrance have to be converted in technical circuits on binary number. The conversion runs in two phases. At first there is will performed sampling of signal and then quantitation follows quantization. This operations are very important during the processes of signal condition.

The error of sampling can able indeed yet very worse. If namely in original analog signal is occurred frequency higher than is half of sampling rate (given a name also Nyquist frequency), will get accordance with Shannon theorem to total and irrevocable distortion signal thanks effect aliasing. The aliasing can be prevented only so - called anti - aliasing filter, which is low-pass filter registered before converter. The low-pass filter will forbid to input frequencies higher than is Nyquist frequency into the AD converter.

Because digital signal as a rule is processed on equipment working in binary numeric system, there are the numbers of quantized levels of A/D converters as a rule equal with N the power of number 2, and the quantized signal can be imply in N bits.

If would give up the sizes of errors of particular samples into chart, it would come into being random signal, which is named quantized noise. The size of noise is emitted as index number in decibels, namely as a relation of useful signal to noise. Because number in denominator of fragment - quantitated error is near of all linear converters the same (interval +1/2 up to 1/2 quantified levels), it depends size of quantified noise only on numerator of fragment, it is on the size of useful signal, which is maximum number of quantified levels of existent converter.

E. Sampling and quantizing

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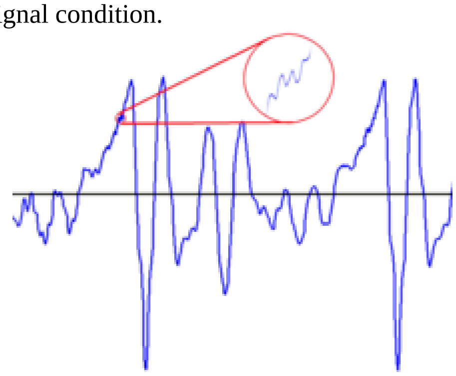

Fig. 10 Scheme of real analog signal with enlarged detail

The section of analog signal can be though over and over again magnified and observed up to his infinitely small details, but for reasons of final capacities of memory and of narrow - minded of rate transmissions the real sampling is kept down only on perforce necessary quantity of samples for next processing on picture is about 15 ms of sound signal of corresponding of a small section of speech sound **„ A"**.

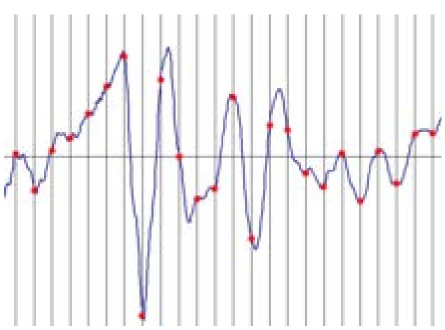

Fig. 11 Scheme of sampling of analog signal of speech sound **„ A"**

The sampling is will performed to even sections of time axes and out of everybody's section is took off one sample of one's value of amplitude (red points). From original signal there is lots of much details, because instead continuous line is got only a family of discreet points in interval corresponding to used strobe frequency.

The error of sampling can able indeed yet very worse. If namely in original analog signal is occurred frequency higher than is half of sampling rate (given a name also Nyquist frequency), will get accordance with Shannon theorem to total and irrevocable distortion signal thanks effect aliasing. The aliasing can be prevented only so - called anti - aliasing filter, which is low-pass filter registered before converter. The low-pass filter will forbid to input frequencies higher than is Nyquistova frequency into the AD converter.

For example a record of music on CD uses the sampling rate of 44,1 kHz, so that on CD can be written frequency about to the 22 kHz. Because the range of frequency of audible in human's ear has the range from 20 up to 16 kHz, be as on CD possible write down audible spectrum in all of breadth.

In telecommunication fields there is used the sampling of 8 kHz (standard telephone band is from 0,3 to the 3,4 kHz), so that the highest transferred is frequency of 4 kHz, and that's adequate for voice transport .

Because, the computer and other devices can imply a digital signal as a number only with narrow accuracy, there is requirement the sampled values adjust according to amplitude . The value of sample gives expressing only up definite quantum; this phase is named as a A/D conversion of quantization.

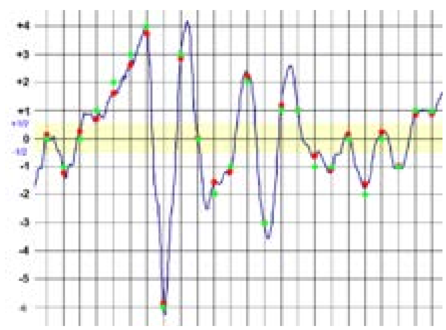

Fig.12 Scheme of quantification of signal samples

In fig. 12 there is able to have the amplitude on axis "y" only **integer** values. To be possible to determine, which values have after quantization put on definite sample, it is necessary divide space about separate values on tolerant zones (one such zone is schematic showed around value 0). The all samples, which will fall to the given to tolerant zone, is associated at quantization assigned value. Quantized values are in figure schematic showed as green points. How is seen, quantized values at most cases are added of real sampled values. Size of quantified error is a distance between quantized and original sampled points, in the picture there are mined longitude of imaginary stroke between red and green points. Size those errors is in interval +1/2 up to -1/2 quantized level.

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quantitated error is near of all linear converters the same (interval +1/2 up to 1/2 quantified levels), it depends size of quantified noise only on numerator of fragment, it is on the size of useful signal, which is maximum number of quantified levels of existent converter:

$$SNR_{A/D} = 20 \cdot \log 2^N \approx 6{,}02 \cdot N \text{ [dB]} \quad ()$$

For example at 16 bit quantizing used at record of music on CD there is signal-to-noise ratio 16 * 6,02 = 96,32 DB.

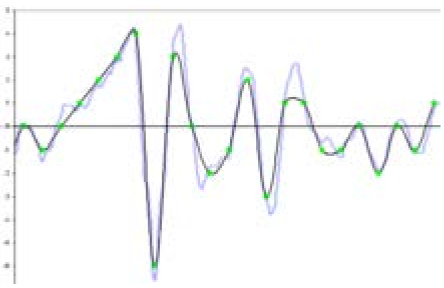

Fig 13 Reconstruction of analog signal from digital data.

Thanks converting original analog signal in two axis cannot mostly signal retroactively converted from digital form answer to original signal. Black line in the figure 13 represents via backward D/A transfer reconstructed analog signal, while blue line is original analog signal, from which was by A/D converter obtained digital signal (green points).

Kind and type of AD conversion affects for size of quantified noise. It can help to remove another negative influence from disturbance. Now there is used this kind of ADC:

Comparing principle of parallel function, it has a high speed, the conversion is in a moment, it has net simple scheme

Comparing principle and stepwise, it is simple solving, very high speed of conversion.

Compensational integrating principle or observation or approximation kind, they are simple and speed is sufficient

Converter with simple and double integration, it keeps down disturbing voltage of high frequency.

Sigma delta converter, reaches high resolution, big immunity against interference from 50up to60Hz, conversion rate is lower. E.g . the type of AD7194 from Analog Devices.

Integrated circuit of AD7194 is a precision **Σ-Δ** ADC with configurable filtering adds Flexibility to Industrial

Measurement System Designs Engineers designing industrial measurement systems must take into account the need to reject 50 Hz and 60 Hz power line frequencies in sensitive signal chains. Some system

modules need a high level of power line rejection and must sacrifice conversion speed

to meet these requirements, while other system modules must provide faster conversion

speeds but still maintain some reduced level of power line rejection.

The AD7194 contains a regular sink filter, which gives excellent rejection of 50 Hz and 60 Hz line frequencies. However, the device also offers a fast settling filter option, which allows customers to achieve nearly four times the conversion speed, while maintaining around 40 dB of line frequency rejection. With this flexibility in application, system designers can utilize one Σ-Δ ADC IC for multiple industrial measurement system requirements, saving time to market and R&D costs. Decreasing for 50 Hz is up to -120dB of power voltage.

III. Software Methods

Software means can affect significantly processes signal condition. There are in the main operations computation of measured values to equivalent physical quantity, checking errors and uncertainties in measurement, calculations of indirect measurement, statistical balancing.

Recomputation of measured values to data and values of physical quantity after AD conversion are first software operation together with rounding. Recalculation uses statistic transform function the general formula is:

$$y = f(x) + \sum_{j=1}^{n} g_j(v_1, v_2, ..v_p) \quad (1)$$

where is y output of function, f(x) transform function with measured value x, g function of disturbing from influences v_1 up to v_p.

A. Uncertainty and errors in measurement

Process of measurement is process of stochastic system. It is impressed with rising random, systematic eventually rude errors.

Random errors have reasons in stochastic actions. Absolute value and mark of these errors is described according to law of probability. These errors it is impossible except. At their determination there is necessary to evaluate repeated measurement behind same conditions by the help of statistic methods. Evaluation of result of measurement employs calculations:

The arithmetical average:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (2)$$

where is x_i value measured in step i, n number of repetition of measurement.

The selection variance of repeated measuring:

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2 \quad (3)$$

which determines deviation of random error for explicit probability

The selection variance of the arithmetical average:

$$s_{\bar{x}}^2 = \frac{s^2}{n}. \quad (4)$$

Systematic errors have some reasons at suggestion and implementation of measurement system. They exist then, when at suggestion there are not detected their causes, there are not compressed their influence and not performed necessary correction. Not detected systematic errors are assessed at determination of uncertainties in measurement.

Uncertainties in measurement define values as parameter of measurement accordance with real conditions. Perfect knowledge requires obtaining relevant information in the process of measurement. To primary resources of uncertainties in measurement there are placed e.g . Incomplete definition of metered quantity, non-representative range of samples of measurement, unknown conditions of measurement, errors of human factor at hand data collection, incorrectly intended accuracy of instrument, inaccurate values of constants for evaluation of signals and other.

Uncertainty in measurement for concrete metering is determined uncertainties of type A of date according to statistic methods and uncertainties of type B, which are non - measurable and which are expertly estimated.

Uncertainty of type A equals with standard deviation of arithmetic average of sample of measurement at n>10 number of measurement and has the formula:

$$u_{A,x} = s_{\bar{x}} = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{5}$$

Uncertainties of type B is estimated for every source of uncertainties accordance with range of possible changes of deviation from nominal value +/ - $z_{and,max}$. Concrete calculation uncertainties of type B are:

$$u_{B,z_i} = \frac{z_{j,\max}}{k}, \tag{6}$$

where is k value for selected approximation of probability distribution, for normal (Gauss) partition (N) is k= 3, for equable rectangular partition (C) is $k=3^{-0,5}$, for triangular partition (S) them to= 2,45, for bimodal partition (U) is k= 1.

Total uncertainty of measurement is according to formula:

$$u_x = \sqrt{u_{A,x}^2 + u_{B,x}^2}\ . \tag{7}$$

On entry of system there is come signal of dynamic changing and rise other errors. Problem of dynamics is given according with inertia of system. The base of description is dynamic characteristics, which takes in consideration all dynamic influences. Description is via form of differential equation, image or frequency transmission, and logarithmic frequency characteristics.

B. Indirect measurement

In practice there is offered indirect measurement for one and more quantities. Indirect measurement means, that from values of measurement quantity x_i accordance with mathematical model is calculated values other quantity $y= fc(x_j)$ for j=1 up to n. All rules for measurement is valid at solution of indirect measurement, acquisition and evaluation of accuracy and of uncertainties.

A example can be e.g . a indirect flow measurement accordance with measurement of differential pressure in cross - sectional device for one metered quantity or indirect measurement of heat consumption accordance with metered flow, temperature entrance and temperature exit from exchanger.

C. Statistic balancing of measurement

Statistical balancing of measured data (data reconciliation - DR) is effective method for total improvement of file of measured data. Make use of mathematical models and natural laws. [5,6]

Models of measurement is come - out from static characteristics of dependence of exit/entrance. There is able to partly model of polynomial relation (reduction of measured temperature at sensor Pt100) or model of exponential relation at evaluation of sensor NTC or about common matrix model.

Statistical balancing of data was developed in effective and extensive method of complex elaboration of measured data, there is utilized all information included in information. The DR method (obtaining of consistent data) is also base to data validation (exclusion of rude and systematic errors of measurement). The method DR is possible apply only in cases of redundant measurement.

The basic idea of DR is repair (balance) measured values so, that date has to bring near mostly to (unknown) correct values of measured quantity. Well - balanced values x_{and}' are obtained from relation:

$$x_i' = x_i^+ + v_i \tag{8}$$

where to measured values are added so - called corrections v_{iand}. In ideal case the corrections would have to be equal with in the negative taken errors; these however aren't known. If is if but I know a mathematical model, to which correct values agree with, there is the best possible solving its, which is based in method of maximum credibility.

Well - balanced values conform to two basic conditions:

1. Balanced values of metered quantities are agreed with physical laws, so they are consistent with them, whereas this condition is possible write down in form

$$F(x', y', c) = 0 \tag{9}$$

where is F a vector of formulas according to mathematical model of technological process, x' vector directly plumbed quantities, y' vector of indirectly of metered (derived) quantities, c vector of exactly known constants.

2. Sum of all corrections of measured data is minimal, whereas corrections are defined so, in order to sum of squares of weighted corrections (weight oh) which has to be minimum, and pays

$$Q_{\min} = \sum \left(\frac{(x^+ - x_i)}{\delta} \right)^2 \Rightarrow \min \tag{10}$$

Sizes of corrections have to grant a inequality:

$$Q_{krit} > Q_{min} \tag{11}$$

where is Q_{krit} critical value χ^2 partition with v steps of freedom assessed accordance with Gauss theory of errors (value Q_{krit} for existents v is introduced in statistic tables).

If inequality (5) isn't fulfilled, it means, that the DR detected present of rough error in measurement. In such a case it is impossible balanced data further to use, although the agreement with physical laws, because isn't fulfilled the criterion of Gauss's error distribution.

Contributions of balancing data would be devalued practically to presence of rough errors of measurement. Algorithm balancing causes, that only a ruge errors intersperses between other quantity so will enlarge their error. Is therefore necessary the ruge errors from data bank eliminate. As well there are elaborated some effective methods, which can detect not only a present of crude errors in data sector, but also localize their causes.

Application DR in the area of continual production processes are applied most often for three main application areas:

- balance of substances and energy (y accounting),
- monitoring of technological process,
- utilization of DR at advanced control and optimization of production processes.

IV. Examples of DR method

Example is concerned to flow measurement in two pipes. See fig.14. There is flow input divided into two devices, 1 and 2. The flow through device 1 is 4,2 kg/s and device 2 2,0 kg/s.

Before the process of DR it is possible the mass balance with account uncertainties of flow measurement o sizes ±0,5 kg/s write down in form:

$$(6 \pm 0{,}5)\ \mathrm{kg{\cdot}s^{-1}} = (3 \pm 0{,}5)\ \mathrm{kg{\cdot}s^{-1}} + (3 \pm 0{,}5)\ \mathrm{kg{\cdot}s^{-1}} = (6 \pm 0{,}5)\ \mathrm{kg{\cdot}s^{-1}} \qquad (6)$$

After operation of DR using law of preservation masses and criteria of minimum corrections there are the measured data put more precisely like this

$$(6{,}2 \pm 0{,}316)\ \mathrm{kg{\cdot}s^{-1}} = (3{,}1 \pm 0{,}387)\ \mathrm{kg{\cdot}s^{-1}} + (3{,}1 \pm 0{,}387)\ \mathrm{kg{\cdot}s^{-1}} = (6{,}2 \pm 0{,}316)\ \mathrm{kg{\cdot}s^{-1}} \qquad (7)$$

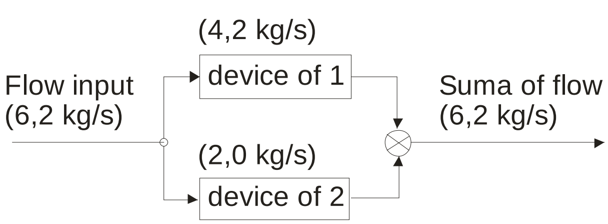

Fig.14 Pipe system with balanced flow date.

Measured data well - balanced introduced way are in accordance with law of preservation masses for displayed technological system and are from statistical aspects more accurate than real measured values (sizes of random errors fell down from 0,5 kg/s up to 0,316 kg/s, or. 0,387 kg/s). Introduced criterion for determination corrections also can detect incorrect measurement (measurement heavy - laden of rough error). Balance equations expressive law of preservation masses, which each other bind down metered quantity, is possible regard as other redundant measurement with zero error. Result is, that accuracy of measurement with DR will growth.

V. Conclusion

The paper deals with aspects of improving the operations of signal condition at inputs side of embedded system. There is the possibility via hardware means and software methods. In the software there is very important the statistical date reconciliation.[7]

Statistical reconciliation of measured data is the prospective method and leads practically to optimization of technological arrangement, reduce to operating costs, service costs, increases responsibility and safety factor of function system.

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