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COMPUTATIONAL METHOD TO DETERMINE THE ON BOARD AVAILABLE ELECTRICAL CAPACITY/ENERGY OF LEAD - ACID STARTING BATTERIES, OF AUTOMOTIVE VEHICLES

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Abstract: *A suitable sizing of electrical energy amount necessary to be stored on board is one of the most important conditions to assure the optimal operational environment of modern automotive vehicles.*
The paper presents a short synthesis of an original method to determine the available energy (capacity) or state of charge (SOC) of the on board lead- acid starting battery of land automotive vehicles, developed by SC INAR SA Brasov, as partner in the project "Energy Optimized Electrical Systems for Land Transport, Using Batteries and Supercapacitors. TRANS SUPERCAP" in partnership with „Transilvania University of Brasov", as project leader.
The mathematical model is a result of processing data picked up in the starting cycle of IC engines. The algorithm and software developed in the study could be a real help for design engineers , service technicians, as well as for vehicle drivers, to estimate the on board electrical energy reserve in the engine starting cycle, at different states of charge (SOC) of the battery in use. The paper revealed the main data necesary to be processed, to indicate the present state of charge (SOC) of a given battery: ambient temperature , battery terminal voltage, and discharging battery current.The study concluded with a valuable method to indicate the available electrical energy (the on board energy reserve), to maintain the battery state of charge „ready to start".
The momentary battery specific data are continually measured,analysed and compared with the external caracteristics(curves) of a given type, and size of starting battery in use in the starting cycle of IC engines. The computing model is approaching the battery´s energy(capacity) availability with starting power requirements of automotive vehicle engine,.and could be displayed on the dash board numerically[%] as a ratio between the present capacity and the rated capacity of the battery at rated temperature [+23 +/- 5˚C].
Keywords: *Battery state of charge(SOC) indicator, mathematical model.*

1. INTRODUCTION

The reliable and quick starting of I.C engines is the primary phase to put in operation the land automotive vehicles.The proper features of engine's starting electrical machines are intrinsicaly estabilished by the characteristics and state of charge (SOC) of starting storage batteries. The diagnostic of state of charge of the on board storage batteries reveals the momentary starting potential of the automotive vehicle engine.
Following the inquiries of various methods and embodiments to determine the available capacity/stored energy of starting type batteries, the paper is approaching an original non-invasve method as external analysis of electrical parameters of starting batteries.
The external characteristics of starting storage batteries represents the relationship between the elecrical parameters, at the battery terminals, treated in the state as electrical supply source.
In present paper we try to develop a computational method to determine the state of charge of starting batteries analysing there external characteristics, in discharging state of batteries in startig cycle of the engine. In figure 1 is presented the equivalent electrical circuit of a starting storage battery and its external receiver, which in this particular case is represented by the starting electrical machine of the engine.
Regarding this equivalent electrical circuit the analytical relationship is:

$$U_b=U_0-R_i I_d \quad \textbf{(1)}$$

This equation represents, so called, external characteristic of the starting storage batteries, and its graph is shown in figure 2.

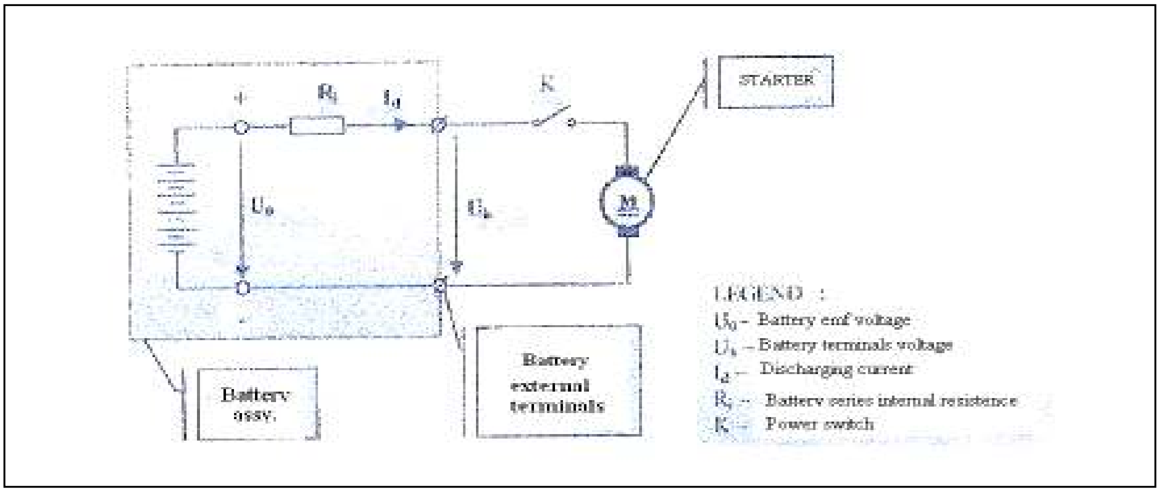

Figure 1: Equivalent circuit of a starting storage battery, connected to an external receiver

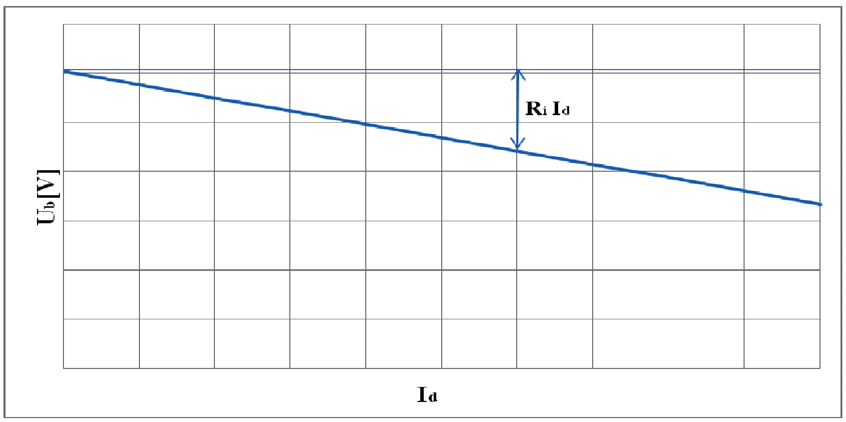

Figure 2: External characteristic graph of starting storage batteries

The external characteristics (graphs) of starting storage batteries are not a manufactures catalog data, but these could be offered to interested users or could be plotted in testing laboratoris for each rated capacity.

Starting with a given external battery characteristics, for each type of starting storage batteries, it may be stand out tair state of charge following the meassurement of ambient temperature, as parameter, the discharging current simultaniosly with the battery terminal voltage in the driving cycle of starting electrical machine of IC engine.

The acquisition, and processing of measured discharging current, the battery terminals voltage, and ambient temperature represent sufficent primary information to compute and display the momentary available capacity/energy of starting storage batteries which we try to synthesize in present paper.

2. MATHEMATICAL MODEL AND ALGORITHM FOR DETERMINING THE AVAILABLE CAPACITY/ENERGY THE ON BOARD LEAD-ACID STARTING BATTERIES, OF AUTOMOTIVE VEHICLES.

2.1. Voltage value at the terminals of a starting batteries "Ub", at a certain current “Id” (discharging current), is determined directly by the battery state of charge (SOC).

Assessment of the state of a battery charge(SOC) is based on information provided by its external characteristic, that is: $U_b = f(I_d)$.

Analytically it is described by linear relationship:

$$U_b = U_{b1} - R_i \cdot I_d \quad \textbf{(2)}$$

where:

U_b - voltage at the battery terminals;

U_{b1} - terminal voltage at the load(discharging) current "I_d";

$I_d \cong 0$ (open circuit discharging current);

R_i - internal resistance of battery(strictly dependent by momentary battery capacity and electrolyte temperature):

$$R_i = \frac{U_{b1} - U_d}{I_d} \cdot f_\theta \cdot f_d; \quad \textbf{(3)}$$

where:

U_{b1} - open circuit voltage(OCV);

U_d - terminal voltage at the discharging current „I_d";

I_d - discharging current;

f_θ - temperature correction factor;

f_d - correction factor dependent by the battery discharging level(c_d);

Dependency $f_\theta(f(t))$ and $f_d = f(c_d)$ will be developed in the study.

To build the mathematical model and the algorithm of diagnosis should be established a relationship between the nominal capacity „C_n 100%" and momentary capacity „C_n X%" with increasing battery internal resistance with each percentage of capacity „C_n".

We present in figure 3 the graphics of external characteristic $U_b = f(I_d)$ of a type of battery with nominal capacity „C_n".

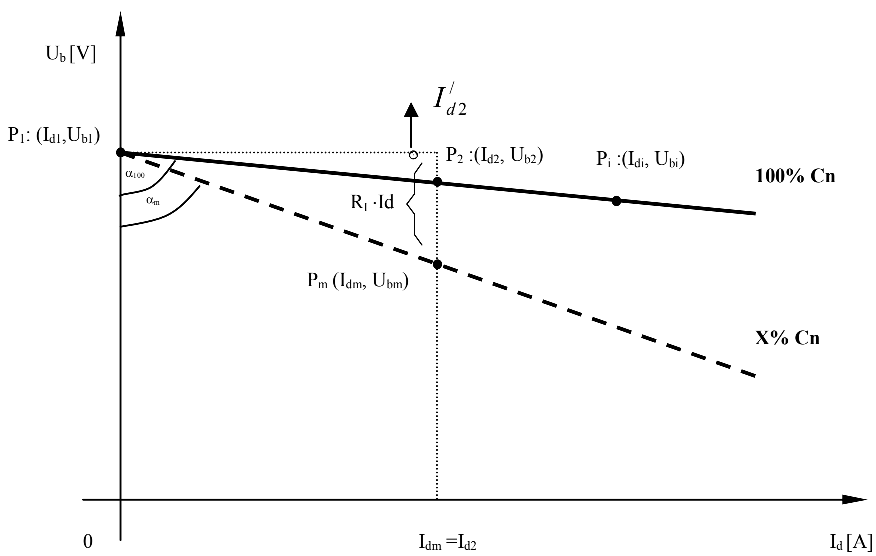

Figure 3: The graphics of external characteristic

a) In the right triangle $\Delta_{d_r^{/}} \quad P_1 P_2 I^{/}_{d2}$ we can write:

$$tg\alpha_{100} = \frac{I_{d2} - I_{d1}}{U_{b1} - U_{b2}}, \quad \textbf{(4)}$$

and for any point "P_i„ on the external characteristic at „100% C_n" we can write:

$$tg\alpha_{100} = \frac{I_{di} - I_{d1}}{U_{b1} - U_{bi}}. \quad \textbf{(5)}$$

- Open circuit terminal voltage „U_{b1}"can be approximate at the value 12,2V. [2], [3].

- Discharging current at" OCV" „$I_{d1} \cong 0$", so

$$tg\alpha_{100} = \frac{I_{d2}}{12{,}2 - U_{b2}}$$, or for any point " P_i " $$tg\alpha_{100} = \frac{I_{di}}{12{,}2 - U_{bi}}.$$ **(6)**

b) In the $\Delta d_r \quad P_1 P_m I'_{d2}$ we can write:
:

$$tg\alpha_m = \frac{I_{dm} - I_{d1}}{U_{b1} - U_{bm}}, \text{ or } tg\alpha_i = \frac{I_{di} - I_{d1}}{U_{b1} - U_{bi}}, \quad \textbf{(7)}$$

$$\text{or } tg\alpha_i = \frac{I_{di} - I_{di}}{12{,}2 - U_{bi}}. \quad \textbf{(8)}$$

The ratio „ $\frac{tg\alpha_i}{tg\alpha_{100}}$ " indicates synthetically the degree of battery discharge, which is the percentage:

$$X\% = \frac{\dfrac{I_{di}}{12{,}2 - U_{bi}}}{\dfrac{I_{dm}}{12{,}2 - U_{bm}}} \cdot 100\%. \quad \textbf{(9)}$$

Simultaneous measurement of the discharging current, and the voltage at the battery terminals at the current „ I_{dm} " (at a certain temperature), and solving this ratio simply, we can reveal the degree of discharge of the battery or the energy reserve, left at a time. By evaluating the energy consumed in a starting cycle, we can display the number of attempts to start, which can be done at a given state of charge level.
The numerator of the "X%" relationship personalizes each type of battery (ie for each nominal capacity), and less by the manufacturer.

" $\frac{I_{di}}{12{,}2 - U_{bi}}$ "

According to EN 50 342 standard, external characteristics, and cold cranking discharging currents „ I_{cc} " differ not more with ± 5%, at the same nominal capacity „ C_n ", for most world wide starting battery manufacturers.

2.2. For example the ratio " $\frac{I_{di}}{12{,}2 - U_{bi}}$ ", for the batteries with nominal capacity 88 Ah, 100% charged ,at the discharging current I_d =350A is: $\frac{350}{12{,}2 - U_{b350A}} = K_{88Ah}$ (see external characteristic of 88 Ah battery capacity, 100% charged).

2.3. The ratio " $\frac{I_{di}}{12{,}2 - U_{bi}}$ ", for battery capacity 110 Ah, 100% charged, is represented by the value „ K_{110Ah} ", and so on.

2.4 We can remark that to display the momentary status of charge of a starting battery(the battery capacity) it must be rated (normed) with the battery electrolyte temperature.
According to the theory of lead-acid batteries used for starting an internal combustion engine(IC) is given the dependence(relationship) of the battery nominal capacity "C_n " by the electrolyte temperature, that is:

$$C_n = \frac{C_t}{1 + 0{,}01(t - 25^0 C)} \quad \textbf{(10)}$$

where:

C_n - rated (normed) capacity

C_t - actual capacity at a given temperature „t".

This relationship reveals that every degree difference in temperature from 25^0C, the rated capacity differes with one percent (1%), compared to actual capacity at ambient temperatures.
Returning to the relationship, where is presented the relative value of capacity "X%" at the reference temperature of 25^0C, it must be rectified with the value of capacity dependence of normed (rated) capacity at 25^0C temperature, versus to reference capacity which differs to temperature of 25^0C. So we can write:

$$X\% = \frac{K_i}{\dfrac{I_{dm}}{12{,}2 - U_{dm}}} \cdot \frac{1}{1 + 0{,}01(t - 25^0 C)} \cdot 100\%, \quad \textbf{(11)}$$

$$X\% = \frac{(12{,}2 - U_{dm}) \cdot K_i}{I_{dm}\left[1 + 0{,}01\left(t - 25^0 C\right)\right]} \cdot 100\% \cdot \quad \textbf{(12)}$$

2.5. It can be concluded that the input data necessary for displaying the currently available capacity of starting batteries are:

a) the type and rated(normed) battery with given" K_i" values;

b) battery electrolyte temperature (ambient temperature) „t" ⇒ [^{0}C]; and

c) measured data (acquired):

➢ current "I_{dm}" at the moment when is triggered the measuring cycle; "I_{dm}" value will be saved, and insert into the algorithm for calculation and displayed on display;

➢ voltage at the battery terminals „U_{bm}", at the moment when the measurement cycle is triggered,with the delay in ending the measurement of current "I_{dm}", value which will be saved.

3. GENERAL ALGORITHM AND PROGRAM ARCHITECTURE

As results of the mathematical model accomplished in the previous chapter, there is a wide range of operations that require different implementations (from analog to digital conversion and up to managing the database). Their sequence is represented as a general algorithm presented in figure 4.

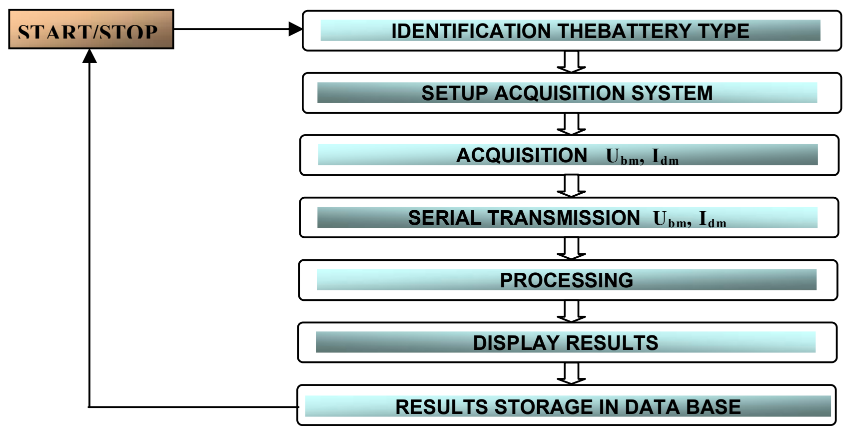

Figure 4: A general algorithm

With the development of the general algorithm is possible to determine the program architecture (figure 5). This highlight the program elements and data flow between them, and can establish principles of implementation. A key feature of the architecture adopted is that it is built for Windows operation system software, requirements being handled in this way, such as portability, flexibility etc. Operating algorithm, and the architectural element levels are strongly dependent on specific implementations of operation environments.

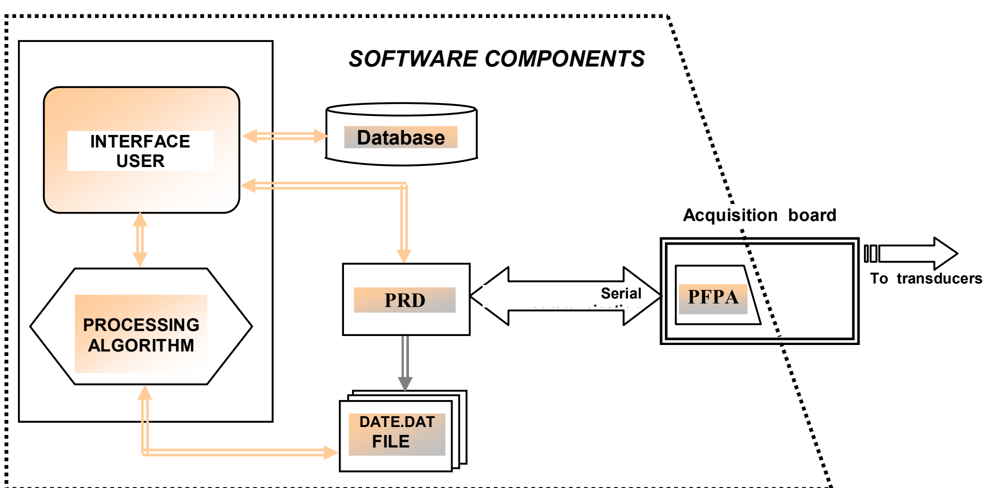

Figure 5: Program architecture

4. THE PROGRAM DESIGN AND IMPLEMENTATION DETAILS

4.1. Acquisition card operation program (PFPA)

The design of this program is the cornerstone of software components, which determines directly the accuracy of the results, measuring manner, and acquisition the values of "U_{bm}" and "I_{dm}" how it performs, acquisition the values of "U_{bm}" and" I_{dm}".
Algorithm of this program is presented in figure 6, and impelmentation was performed in assembler language, using specific instruction set for "80C51" microcontroller family.
Development and testing program requires the use of specific instruments like development board, assembler, and monitor programs, etc.

4.2. Receiving data programs (PRD)

Program "PRD" provide initialization of serial available port "COM", read in loop the data transmitted across the serial bus from serial acquisition board (program PFPA).
The data is written into a buffer file, "DATE.DAT" in the following convention:

- For each data set (U_{bm}, I_{dm}) opens a new file.
- Data are recorded in sequence:

- terminal voltage" U_{bm} ";
- delimiter ",";
- discharging current "I_{dm}";

Implementation is done in languages C++ and ASM.
Algorithm of this program is presented in figure 7.

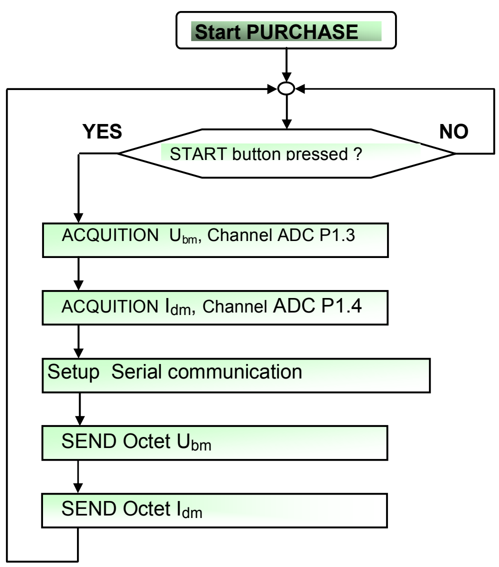

Figure 6: Algorithm of program (PFPA)

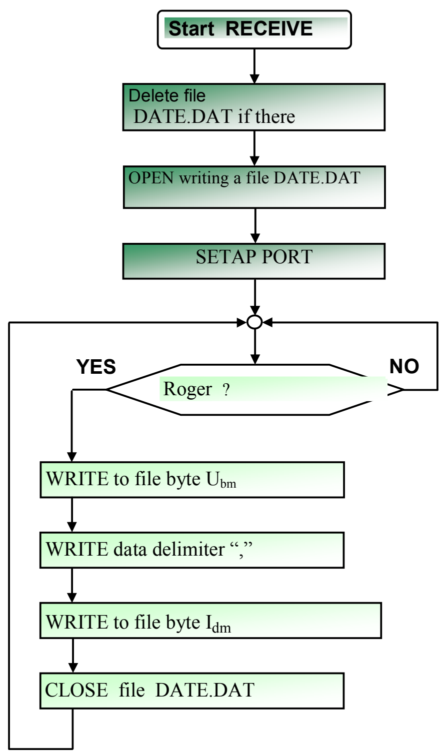

Figure 7: Algorithm of program (PRD)

4.3. User graphical interface

By following the standards of Windows programs, it was designed an interface "users - friendly", to ensure with specific elements (menus, control switches, dialog boxes, etc.), the way of access to all system functions as well a fast, and efficient exchange information between PC and user. In figure 8 is presented this dialog screen frame.

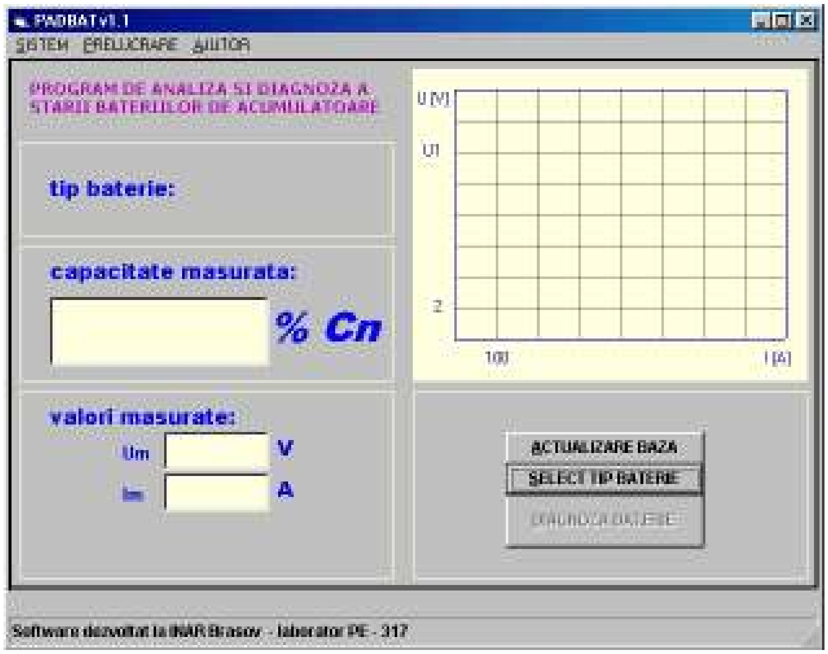

Figure 8: Dialog screen frame

4.4. Acquisition and Diagnosis

The entry into service of acquisition board is notified by a screen frame as in figure 9.

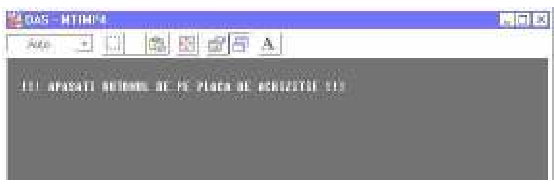

Figure 9: Entry into service

Pushing the acquisition switch the programs will immediately display the result as shown in Fig. 4.5.

Figure 10: Display the result

5. CONCLUSIONS

The long time, and implicitly high cost of conventional methods for testing the state of charge of starting batteries are not always done with good results, accuracy, and objectivity required by the regulations on allowable limits for good operation of the starting batteries of IC engines. Diagnosis method based on the equipment designed and implemented in the study, presents a solution which benefits by the advantages of modern technologies in microelectronics (microcontrollers), and information technology (IT).

It is noted that in addition to performing as: processing speed, accuracy etc., a key benefit is the flexibility of the system. Thus it is possible to optimize and extend with new functionality including here the possibility of communication with other systems, without hardware changes in the structure of the equipment.

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