DATA FUSION IN COLOR CONDUCTION

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Abstract

Data fusion is an upcoming concept in the mathematical and industrial fields. It provides for fusion of information stemming from many and different types of sensors in a way which makes description and control of a given process possible in more efficient, productive manner.
In gravure printing, color conduction has resulted in higher quality through optimisation of many important single parameters (viscosity, concentration, ESA, ink temperature, ink blending, etc.).
In offset printing, similar as well as more complicated parameters (dot-size, ink-tack, water balance, etc.), have been measured and controlled.
The issue offered by data fusion is based on the collection of such and further data, even if they are limited in accuracy and temporal occurrence. Through processing, modeling and estimating , improved quality, easier color management and user-friendly operation can be achieved.

1. Introduction

Data fusion means, shortly said, the combination of information originated from many sensor.
The concept is simple but its implementation is generally complex and costly. Most of today's industrial technology bases on single-sensors and over the years big efforts have been made to improve their accuracy, precision, dynamic range, response time, temperature independence, etc. This approach has proved highly successful but was undertaken almost exclusively in the deterministic domain.

In the last years speed and complexity of modern data processing allow to think at multiple-sensors with subsequent data fusion in the statistical domain, a procedure needless to say, marvelously implemented ever since, in human beings.

It should be noted, that the multisensors concept does not need to be restricted to their number i.e. to the spatial domain. It can be applied to the temporal and spectral domains too. Important is only that the description of a state, of a behaviour or of a process is performed by means of many and (in general) different sets of data.

Examples of this evolution are already existing in the field of geodesy, where technology has shifted from the higher instrumental precision to the use of many (not necessarily highly precise) measuring instruments.
Also in the military field single-detection of targets is being replaced by multi sensors technology, which allows better management of the environmental variations occurring in a battlefield.

2. Tools

Deterministic mathematical tools are of course important everywhere but typical for data fusion is the use of statistical tools. e.g.

- single signal description (average, peak-to-peak, sigma, autocorrelation, etc.)
- multiple signal descriptions (cross-correlation, covariance, etc.) and of time-frequency transforms (Fourier transform).

3. Advantages

The advantages offered by data fusion are (Fig. 8):

- increased reliability (single sensors might measure wrong or not at all or not at the desired time)
- compensation of performance degrations due to aging of sensors or change of the environment
- use of less precise detectors (example Fig.1)
- noise analysis (Fig. 2)
- prediction tracking (knowing what the system is going to do it is possible to perform the measurement at the most favourable moment) (Fig. 3)
- context adaptive data association (data might be important only in a certain context)
- deeper process analysis (a single sensor might not allow to reconstruct the way the signal or its variations are generated)
- sub-optimum control (today's systems always relay on optimum-striving control techniques. With multiple sensors fusion this

approach is hardly possible and suboptimum-striving mathematical tools have to the created)

- "less thinking but having statistics do the job"
- state of the art procedure (management of large quantities of data is today more popular than improvement of hardware accuracy)

4. Applications to color conduction

It is well known that color printing is a multidimensional process. Color conduction in gravure and offset have strong structural similarities although they differ in the physical way of inking an in its transversal control (none in gravure, zonal in offset).
These situations are indicated in Fig.4 and 5 with following comments:

- some of the entries are of parametric type (indicated with OF) i.e they are determined off-line (paper, tack, doctor blade, cylinder pressure) and are invariable at least for a job.
- most of the entries are (or should be) of variable type (indicted by ON) i.e. they are determined continuously (at selectable internals) during the run. For many of them, suitable sensors are available (viscosity, temperature, speed, register). For others, sensors have been proposed (concentration, ink-film thickness, water-film thickness).
- estimation of the printed result is performed in the colorimetric domain (for visual estimation) and in the area/density domain (for technical estimation). A blend of both is then used to control the process.
- the fusion of sensor's data is performed with algorithms [A] and [B] which in the case of small variation around preset values have the character of linear matrices. Their inversion [A-1] [B-1] for control purposes might not be simple and requires that the correspondent determinants $|A|, |B|$ are different from zero. Instead of matrix inversion, solutions using iteration are possible but the problem of loop stability might be difficult to solve.

5. Implementation

5.1 Hardware architecture (Fig.6)

Because difficult to modify and to expand, the hardware of a data fusion system for color conduction needs careful design:

- a distributed architecture is mandatory

- at sensor-level, galvanic separation (including explosion-proof barriers if needed) is mandatory
- at BUS-level, selection of the type and of the interface standards for the sensors is probably the most important and difficult task (there are many busses available, but which will be the ones - if any- who will survive in the future?).
  In any case a bi-directional, complementary BUS is mandatory.
- the other levels are of less important choice because they are limited in cost and upwards compatibility is mostly respected by computers producers.

5.2 Software architecture (Fig.7)

Software is (at least basically) easy to adapt and to expand if some structural decision are respected:

- distributed architecture is, in our opinion, mandatory.
- sensor analysis has to condense and filter single-sensor data prior to send them to crosscorrelation (and further).
- linguistic levels have to take care of incomplete, inconsistent and wrong-timed information.
- modeling and templating need to be updatable in a semiautomatic way. They can advantageously include algorithms based on known physical behaviors.
- at the decision level further fusion with heuristic and human data is unavoidable.

6. Conclusions (Fig.9)

Time is mature to have multisensor technology and data fusion applied to color conduction. To this purpose input sensors are already available and their implantation should be foreseen when installing new presses.
Output sensors i.e. optoelectronic inspectors of the final print (delivering data having colorimetric accuracy) are available and are already introduced in sheet-fed offset but not in web printing. It is to hope that, in view of the new possibilities offered by data fusion, this obstacle (mainly of financial nature) can be overcome. It is a challenge that both manufacturers and printers have to face in next years to come: the target being the "press independent" production of high color quality.

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1.1 Process with no memory (stochastic)

1.2 Signal and noise

↳	signal	=	N events
↳	noise	=	$\sqrt{N}$
↳	s/n	=	$\sqrt{N}$

1.3 Example

	signal	noise	s/n
1 Sensor (good)	100	10	10
	25	5	5
4 Sensors	25	5	5
(bad)	25	5	5
	25	5	5
Sum	100	10*	10

(*noise = $\sqrt{5^2 + 5^2 + 5^2 + 5^2} = 10$)

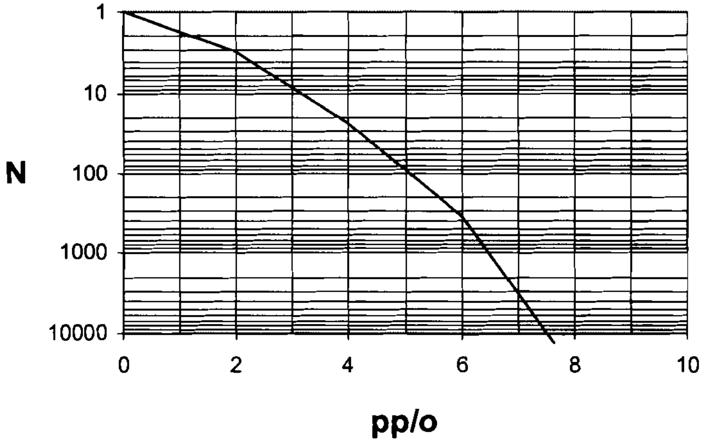
1.4 Conclusions

With 4 sensors having each 50% accuracy it is possible to have at least the same accuracy as with 1 sensor having accuracy 100%.

Fig.1 *Markov Process*

2.1 Peak-to-peak / sigma for N measurements

2.2 For stochastic noise



- curve H of maximum "disorder"
  (decorrelated signal)
- deviation from curve H indicate "order"
  i.e. correlation is present

2.3 Decorrelation

- through Fourier transform and filtering

2.4 Determination of the noise origin

- through cross-correlation analysis

Fig.2 Noise analysis

3.1 Process with memory

3.2 Joint probability

$$p\,(x,y) = p(x), p(y/x) \quad (1)$$
$$= p(y)\,.\,p(x/y)$$

➢ **no memory (=stochastic)**

$$p\,(y/x) = p(y)$$

i.e.

$$p\,(x,y) = p(x)\,.\,p(y) \quad (2)$$

➢ **posterior probabiliy**

$$p\,(y/x) = p(x,y)\,/\,p(x) \quad (3)$$

➢ **anterior probability**

$$p\,(x) = p(x,y)\,/\,p(y/x) \quad (4)$$

= inverse probability

= learning through experience

Fig.3 *Bayesian process*

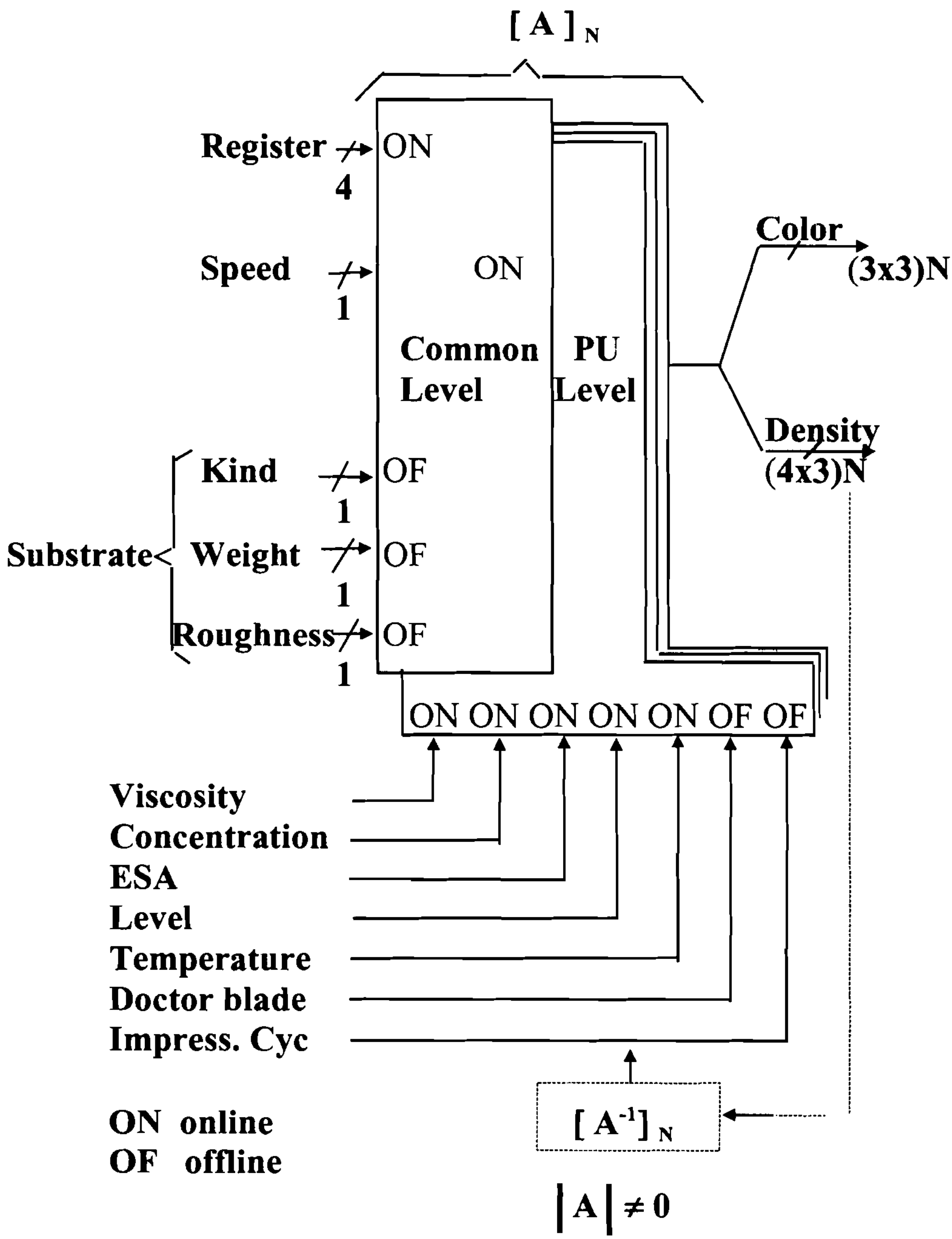


Fig.4 Gravure Matrix

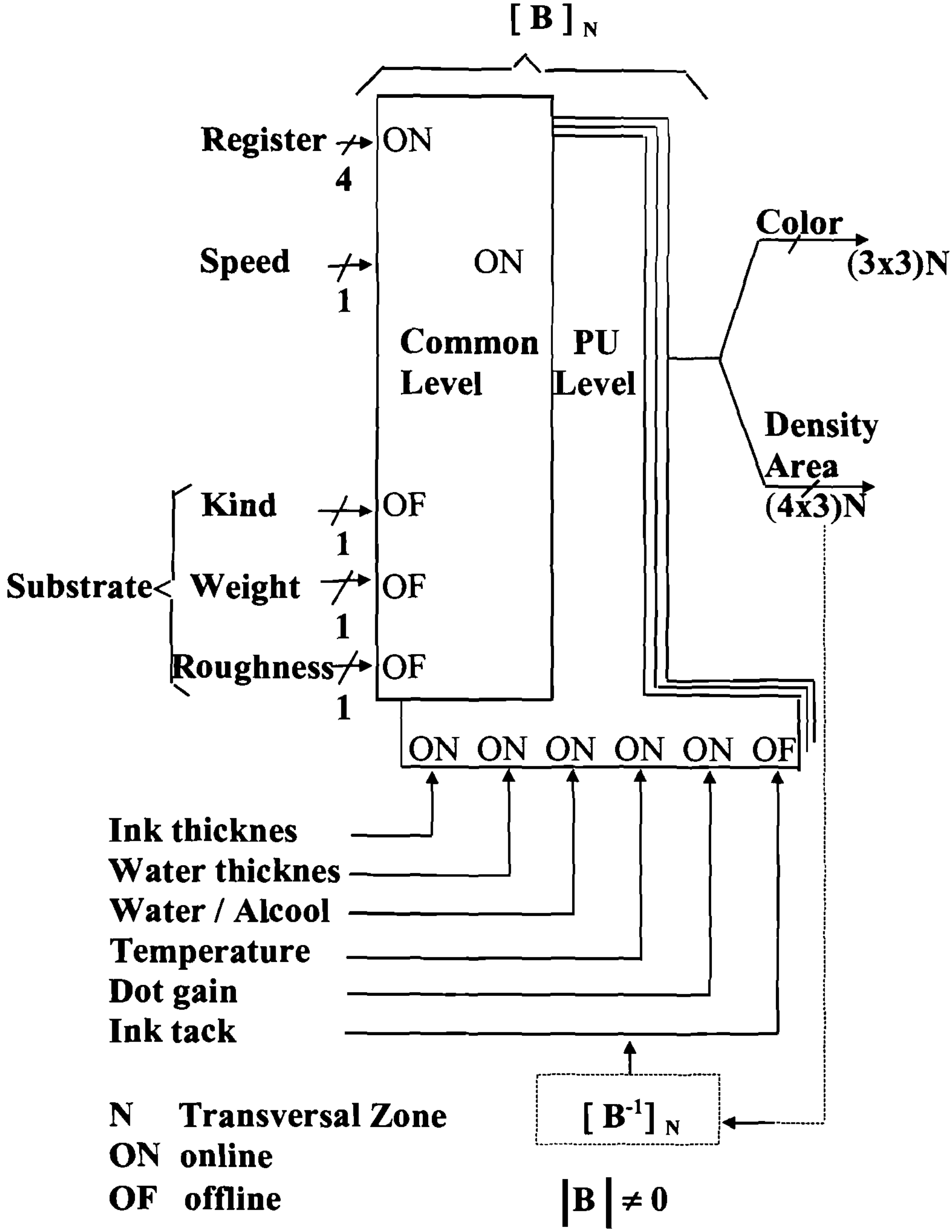


Fig.5 Offset Matrix

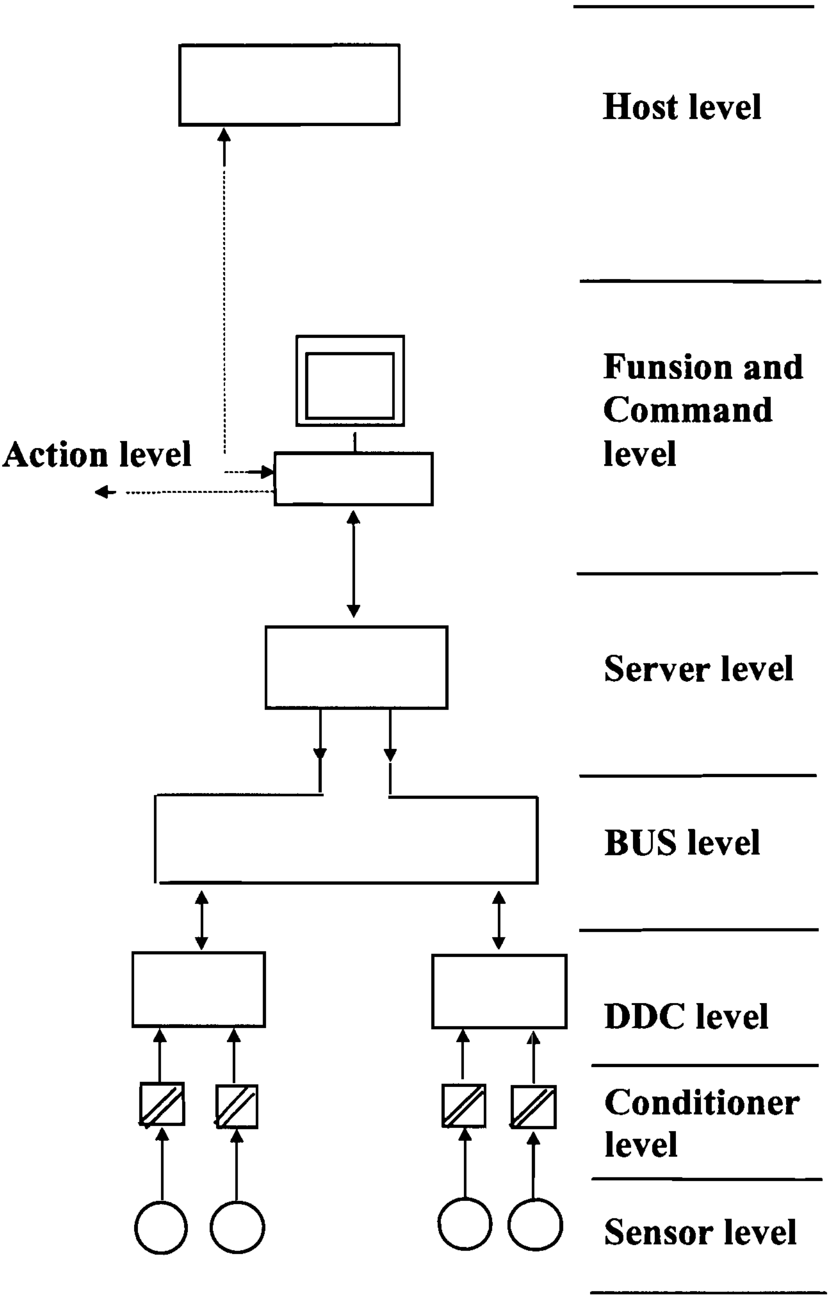


Fig. 6 Hardware Architecture

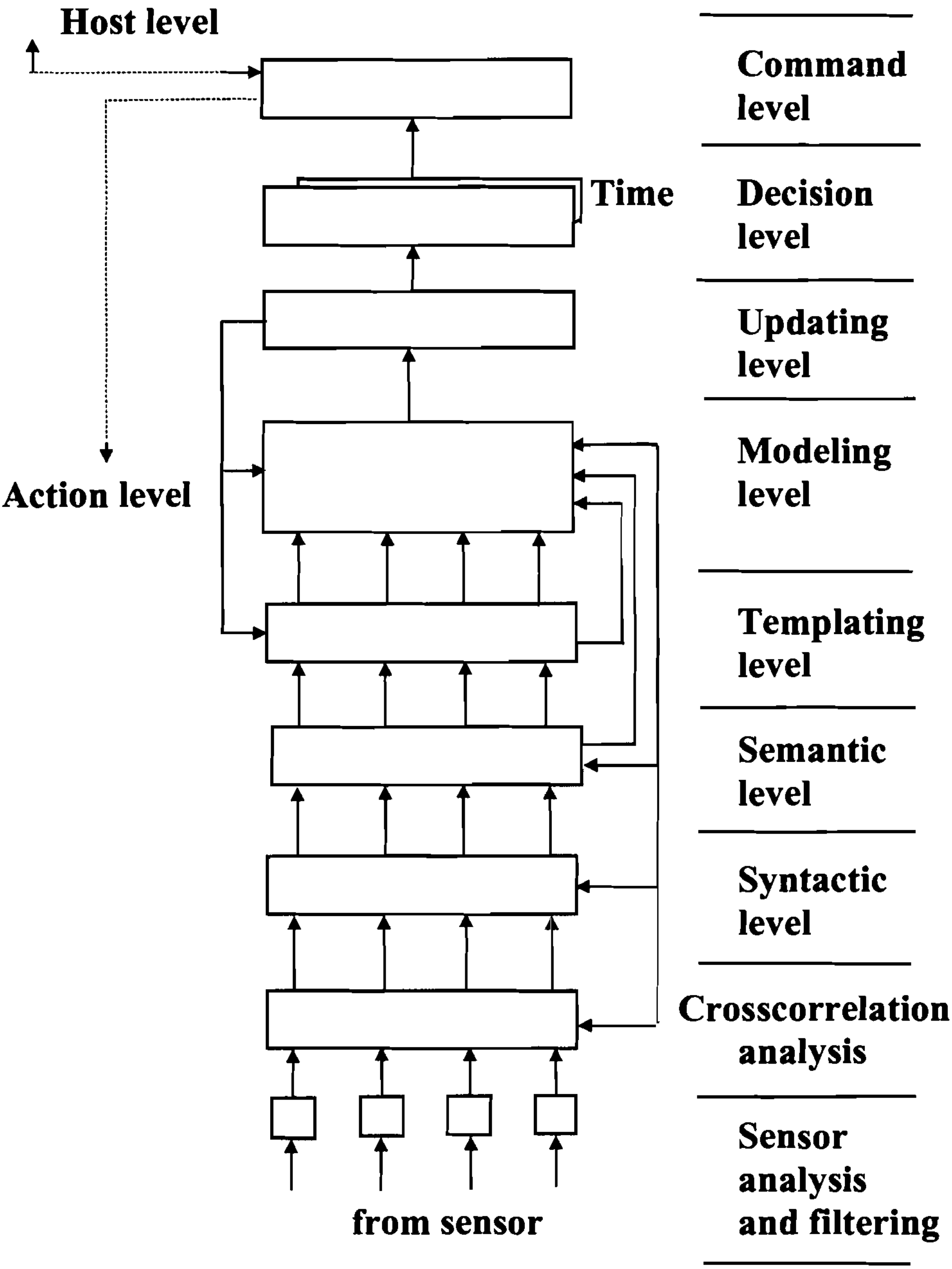


Fig. 7 Software Architecture

① **increased reliability**

② **compensation of performance degradation**

③ **use of less precise sensors**

④ **noise analysis**

⑤ **predetection tracking**

⑥ **context adaptive data association**

⑦ **deeper process analysis**

⑧ **suboptimum data processing**

⑨ **less thinking and having statistics do the job**

⑩ **state of the art procedure**

Fig.8 ***Advantages of data fusion***

1. **Time has come to introduce multisensors statistical technology**

2. **Implementation (stepwise)**

   2.1 **Choose hardware architecture**
   •BUS
   •normalize interfaces

   2.2 **Built in the (new) presses as many sensors as possible**

   2.3 **Make prevision for future sensors (documented)**

   2.4 **Provide for easy entrance of fixed parameters for run and for press**

   2.5 **Provide for on-line quality assessment**

3. **Software**

   3.1 **Start fusion of data differentially (linear matrix)**

   3.2 **Have skilled people to analyze and fuse collected data**

Fig.9 *Conclusions*