MEASUREMENT SCIENCE AS A BASIC RESEARCH AND DEVELOPMENT DISCIPLINE OF SCIENTIFIC RESEARCH.

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Introduction

By contemplation about the „*Measurement Science*" definition we can find some classical definitions of measurement and we find that measurement belongs to the oldest activities of the mankind described in ancient historical documents.

When we need to utter and aggrandise the expression "*measurement*", we always hesitate for a while. Naturally questions are being raised and we have to realise that measurement, as a human activity is as old as mankind itself. When we speak about measurement, do we only understand measurement as a question of the highest attribute of science and a tool for scientific research? Are we able to find the subtle border of this expression used in the category of ethics and ordinary human life?

In The Roget`s College Thesaurus we can find equivalents for *measurement* as: measure, admeasurement, mensuration, survey, valuation, appraisement, appraisal, metage, assessment, determination, assize, estimate, estimation, dead reckoning, reckoning, gauging and more than hundred other cross references.

The world classical literature introduces a lot of examples of the noun *measure* e.g.: *"The union of ... fervour with measure, passion with correctness, this surely is the ideal"* (William James). *"I gave them an account ... of the situation as far as I could measure it"* (Winston S. Churchill). *"We must measure twenty miles today"* (Shakespeare).

Naturally many questions relating to measurement science arose during the historical development of this discipline. One fact is unambiguous: That *Measurement Science* now with new modern dimensions is the basic research and development discipline of many other scientific domains.

It is not the intention to answer all the questions relating to measurement in this short study. We are trying only to find some particular answers to some questions and also to find an appropriate role of the Institute of Measurement Science in elucidation of these questions and enrichment of the *Measurement Science* with new modern dimensions.

Basic questions on Measurement Science

The concept of the measurement is twined with the term of *observation*. What can be observed either directly or indirectly is a set of traits of some concrete system. If observation is to be precise it must be quantitative because concrete systems have quantitative properties, if only because they exist in determinate amounts and in space-time.

Thus we can define measurement as a *quantitative observation*. Whenever numbers are assigned to certain phenomena on the basis of observation, measurements are being taken. There are as many kinds of measurement as kinds of properties and measurement techniques. Essentially we can count, compare, or measure in a strict sense. In order to decide what kind of measurement is to be done, an analysis of the concept denoting the corresponding property must be performed. Accordingly the nature of *quantification* must be analysed before the features of measurement can be understood.

At least three questions of a philosophical interest are raised in relation with quantification:

I. Why do we value quantification, whether quantification underlies measurement and vice-versa.

II. Relation of numerical quantification to measurement. Measurement is the foundation of quantification or, quantitative properties appear upon measurement, and measurement generates quantitative concepts.

III. The third philosophical question is associated with Galileo Galilei, (1564 - 1642*)*, who stated: *Measure the measurable and try to render measurable what is not yet.*

Accepting the measurement philosophy the modern science is more oriented to measurement techniques. They depend on the nature of *mensurandum* (property of the concrete system we wish to measure), on the knowledge at hand, on the accuracy requirements, and on the operator's ingenuity and dexterity. It is clear that measurement techniques should depend primarily on the nature of the mensurandum in its relation to human observers.

When we analyse the scientific approach and the role of measurement as a process of science as a style of thinking and discovering with all human creations, we should distinguish in science the research activities from its end product: *knowledge.*

Scientific research needs to start with the recognition that the available account of knowledge is inadequate to handle certain tasks. It does not begin from draft because research deals with problems and no question can be asked, let alone answered, outside some range of knowledge: only those who are prepared to see can see that something is different.

Fraction of the basic knowledge from which every research starts is hypothesis, i.e. nonspecialized knowledge, and a fraction of it can be rechecked, enriched, and ultimately replaced by the same method. As research proceeds it corrects or even discards parts of the account of commonplace knowledge. Thereby the latter is enriched with the results of science: part of today's commonsense is yesterday's results of scientific research. We can conclude that scientific research expands from common knowledge and outgrows it. The scientific research begins at the point where ordinary knowledge and idea fail to solve tasks.

Measurement is an unavoidable part of scientific research sequence: Scientific problem, hypothesis, physical law, theory, explanation, prediction, observation (experiment), measurement, evaluation and conclusion.

Measurements are accomplished in order to check certain statements, not to determine significance. When we say „Pressure is what barometer measure", we add a dimension of human experience to the objectively meaningful sign `P` incorporated in physics (which is indifferent with pressure measurements) and obtain consequently a fuller understanding of its meaning, but that does not constitute a definition of „pressure".

What can be observed and measured either directly or indirectly is given by a set of properties of some physical system. If observation is to be precise it must be quantitative because concrete systems have quantitative properties, if only because they exist in determinate amounts and in spacetime. *Quantitative observation is measurement*. Whenever numbers are assigned to certain characteristic on the basis of observation, measurements are being performed. We know that there are many kinds of properties and measurement procedures. Basically we can calculate, evaluate, or measure in a challenging signification. In order to make a decision what kind of measurement is to be done, a testing of the concept denoting the corresponding property must be performed. For that reason the nature of quantification must be tested before the characteristics of measurement can be recognized.

There is many items which argue to be interpreted in connection with measurement, e.g.: empirical *interpretability* of scientific terms, in order to ensure the empirical *testability* of scientific hypotheses, formation of *exact hypotheses and theories*, scales and units, relation of *numerical quantification* to measurement, (is it possible to quantify every phenomenon ?, or is it desirable to attempt the quantification of what is still qualitative?), measurement techniques, uncertainity estimation, data evaluation, resultant data visualisation, and more.

Institute of Measurement Science, its role and position.

To find an appropriate role of the Institute of Measurement Science in clarification of these questions and development of the Measurement Science is limited by three factors: number of researches, their qualification dimension and financial support.

The origin of the *Institute of Measurement Science, Slovak Academy of Sciences* goes back to the *Laboratory for Research and Design of Measuring and Physical Devices*. This Laboratory was founded in 1953 as one of the first laboratories or institutes of the newly constituted *Slovak Academy of Sciences*. The initial goal of the Laboratory was to design, produce and implement original devices dedicated to experimental research within the Slovak Academy of Sciences. During the sixties and seventies significant results were achieved at the Institute in the development of measurement theory and mathematical-statistical methods for the processing and evaluation of measurement data. Simultaneously with the activities in this field the problems of selected physical quantity measurement have been also pursued. The Institute has developed several original measuring devices for use in the field of medicine.

RESEARCH SCOPE

At present the Institute is a scientific institution whose activities encompass two basic domains of fundamental and applied research:

1. Development of measurement theory and mathematical-statistical methods for processing experimental results, and design of experimental systems for measuring selected physical quantities,
   SCIENTIFIC LABORATORIES: Theoretical methods, Interferometry, Applied measurements, and Sensors.
2. Mathematical and computer modelling of biologic structures and processes, processing of biosignals and medical images, and development of measuring systems for biomedicine.
   SCIENTIFIC LABORATORIES: Biomeasurements, Magnetometry, Neural Networks, Tomographic Methods, Image Processing, and Pneumometry.

To explain in more detail, the research at the Institute is characterised by the following activities:

- Theory of measurement is oriented to development of linear and non-linear statistical procedures for estimating and testing hypotheses on various parameters of statistical models.
- Development of interference methods for automated measurement of deviations of optical surface shape,
- Position deviation measurement for large-scale objects using pendametry and hydrostatic levelling,

- Development of measuring methods for selected geometrical quantities in precision machinery, and development of transducers for measurement of non-electrical quantities.
- Measurement of dynamic phenomena in selected biological subsystems (e.g. the heart or brain), which manifest themselves through electric and magnetic fields. Research of measuring methods and devices for biology and medicine. Methods for biosignal processing are solved and specifically oriented measuring systems are developed. Using computer simulations, new model-based and multichannel measurement approaches are studied and possibilities of non-invasive determination of the state and characteristics of selected biological objects are investigated.
- Multichannel measurement of the cardiac electric field, non-invasive determination of the electrical and physiological state of the heart and diagnostic and therapeutic utilization of the obtained information. The electrical activity of the heart is studied using models of the cardiac activation, cardiac electric generator and realistic inhomogeneous torso volume conductor. The applicability of different models for forward ECG simulations and for inverse identification of such as phenomena as arrhythmogenic cardiac tissue or ischemic lesion is tested and sensitivity of the models to errors in real measured data is evaluated.
- Development of methods for weak magnetic field measurement in biological objects using the Josephson effect. Application of macroscopic quantum effects, especially macroscopic quantum interference in superconductors with low and high values of Tc, in the field of measurement of extremely weak magnetic fields or physical quantities whose changes can be transformed to changes of magnetic flux. The research is concentrated on Josephson junctions, RF and DC SQUIDs, superconducting quantum magnetometers (SQM), gradiometric antenna systems and their applications in systems for measurement of beam intensity in accelerators, biomagnetic and geomagnetic fields.
- Design of measuring transducers and imaging methods based on Nuclear Magnetic Resonance (NMR). New measurement and imaging methods from the point of view special sensors for the whole-body imaging and micro imaging. Method of gradient magnetic fields design, method of correcting the inhomogeneity of the spin density and flow imaging, measurement of gradient fields, method of the magnetic susceptibility and flow measurement by NMR imaging, magnetic field time-instability improvement, signal/noise and spatial resolution problems. Planar radiofrequency transducers for thin layer imaging based on nuclear magnetic resonance as a part of the whole body tomograph. The transducers can be used for biological and non-biological samples measurement and imaging with higher resolution. Functional magnetic resonance imaging of human brain. Magnetic resonance micro-imaging and spectroscopic imaging.
- NMR micro-flow imaging by higher magnetic fields, diffusion and perfusion measurement. The original results are expected in research of the blood microcirculation and transport in the smallest vessels and capillaries. The results of the research are to be applied mainly in medicine and biology, for diagnostics of adults, children and newborn, for intra-somatic diagnostics, for porous materials defectoscopy, in NMR microscopy and for flow measurement.
- Exploration of mathematical and computer methods of non-linear image processing and development of fast algorithms for 3D visualization of medical data.
- Study of invariant signal recognition using the methods of artificial neural networks. Analysis and construction of flexible neural networks for time-series prediction; Application of radial-basis function neural networks for time-series prediction, non-linear adaptive filtration and signal classification; Dynamical modification of self- organising maps based on growing cell structures approach for signal classification; Study of bio-feedback on the basis of EEG; Self organised criticality and percolation problems.

- Digital processing of medical (especially CT and MR) images. Image preparation and segmentation, 3D image smoothing and visualization, computer modelling of MR-imaging based on diffusion-weighted measurement. Research objectives: Increasing signal-to-noise-ratio in multivariate MR image data via the anisotropic diffusion smoothing and image segmentation based on geometry-driven diffusion preprocessing of input MRI data; Automated segmentation of 2D and 3D MR images using interactive (X--Windows), functional, and statistical methods; Development of quantitative evaluation procedures (design of figures of merit) of the performance of image processing algorithms; Subvoxel precision surface detection; Fast voxel traversal algorithms;
- Development of methods for dynamic parameter measurement in pneumometry. The activity of the laboratory is concentrated on the solution of the problems for dynamic analog and discrete measurement of volume, flow, gas concentration and diffusion, parameters of respiratory mechanic and the problems of signal processing in breathing process.

At present the research of the individual laboratories is involved in 17 research projects supported by grant of the S.G.A. (Scientific Grant Agency). Some of these projects are supported also from abroad.

EDUCATION

Since 1962 the *Institute of Measurement Science* has been a supervising body of postgraduate studies and the seat of the Commission for the PhD degree award in the scientific discipline of *Measurement Science*. In 1985 the Institute gained the privilege of conducting PhD studies also in *Bionics and Biomechanics*. The scientists and researchers of the Institute contribute significantly to graduate and postgraduate studies at other universities in Slovakia. In particular, our institute has signed official agreements of co-operation with three faculties:

- The Faculty of Electrical Engineering and Information Science, Slovak Technical University, Bratislava,
- The Faculty of Machine Engineering, Slovak Technical University, Bratislava, and
- The Faculty of Mathematics and Physics, Comenius University, Bratislava.

The main activities carried out within this co-operation are as follows: lecturing in graduate and postgraduate courses, supervising the diploma theses for the MSc and PhD degrees (in Slovak and also in English for foreign students).

CO-OPERATION

Several university departments are directly involved in conducting common research with the individual laboratories of our Institute, e.g. the Department of Optics, Faculty of Mathematics and Physics - Comenius University, or the Department of Geodesy, Faculty of Civil Engineering - Slovak Technical University. The fellows of our Institute are being received at foreign universities and research institutions as visiting professors (USA), senior researchers (USA, Sweden, Germany, Austria) or visiting scientists within the framework of common research projects (Austria, Denmark, Germany, Russia, France, Belgium, Italy).

SCIENTIFIC MEETINGS

In the course of the 47-year history of the *Institute of Measurement Science* the fellows of the Institute have organised a number of scientific international seminars and conferences: PROBASTAT (Probability Theory and Mathematical Statistics), EMISCON (Measurement

Theory and Practical Applications), MEASUREMENT, MODEL BASE BIOMEASUREMENTS, etc.

Conclusion

As expected, numerous questions relating to measurement science arose during the long chronological expansion of this discipline. We replicate the fact that is unambiguous: The *Measurement Science* now with new modern technology remain considered to be the fundamental research and development discipline of many other scientific domains.

It was not the intention to answer all questions relating to measurement science aspects in this study. We were trying only to find some selected answers and also to find an appropriate position of the Institute of Measurement Science in explanation of these questions in the course of enhancement of the *Measurement Science* with new modern proportions.

The Institute of Measurement Science of Slovak Academy of Sciences with all its activities (research, education, co-operations and as an organizer of international workshops and conferences) remains the substantive link of the research institutes in the world engaged to the *measurement science* corresponding with international organisations as IMEKO, IEEE, EMBS, IFAC, TEMPERE and URSI.

References:

FINKELSTEIN, L.: From Measurement to Knowledge and Thought. Measurement for a Sustainable Future. Proc. 3rd Biennial Conference of Metrology Society of Australia. 3-7, 1999.

BUNGE, M.: Scientific Research, Berlin-Heidelberg-New York: Springer-Verlag, 1967.

ADAMS, E.W.: Elements of a theory of inexact measurement. Phil. Sci. 32, 205, 1965.

FROLLO, I.: Biomedical Engineering Research at the Institute of Measurement Science. 2nd International Workshop: Applied Informatics In Biomedicine And Medical Engineering, Žilina and Bratislava, Slovak Republic, August 22 - 28, 1998.

BAJCSY, J.: Scientific Education in Measurement in Slovakia. Journal of Electrical Engineering, 9-10, 276-279, 1998.