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MEASUREMENT RELATED TO HUMAN PERCEPTION AND INTERPRETATION – STATE OF THE ART AND CHALLENGES

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Abstract − Measurement of characteristics related to human perception and interpretation is discussed. After a review of the historical framework current research activities are surveyed, on the basis of the authors' experience in European projects and coordination actions. Then future research needs and challenges are addressed.

Keywords : measurement science, measurement related to perception, measurability.

1. INTRODUCTION

The measurement of characteristics related to human perception deserves great attention for both scientific and practical reasons. From the scientific standpoint, they are essential for the understanding of human perception, which in turn is basic for the study of attentional, cognitive and emotional functions. From the practical side, such measurements are inherently appealing, since they are customer oriented, highly informative and provide direct information on the perceived quality of products, devices, services, and the environment. Progress in this area requires an interdisciplinary approach, embracing scientific methods in physics, biology, sociology, and psychology. It is necessary to reach some agreement on basic concepts and terms, to find a common language and, possibly, to develop a unified general theory of measurement.

In this paper the historical development of the subject is briefly reviewed [1-11], then current research activities are reviewed [12-22], on the basis also of the authors' experience in European research projects and coordination actions. Lastly, future research needs and challenges are addressed [23-29].

2. HISTORICAL FRAMEWORK

2.1. The schism of the 1930s

Is the quantitative estimation of sensory events possible? In the early 1930s, this key question was posed explicitly to a Committee, appointed by the British Association for the Advancement of Science (BAAS), consisting of physicists and psychologists [2, 7]. During six years of discussion, they did not reach any agreed upon conclusion. Basically, the scientists in psychology claimed that the result of a psychophysical experiment cannot be expressed in purely physical terms, because it is based on perceived equalities and inequalities of sensations. Conversely, physicists argued that the measurement of the intensity of a sensation is not well founded since it is based on assuming that a psychophysical law is valid (at that time Fechner's law). But such a law cannot be proved unless it is possible to measure sensations directly, and, in their view, sensations are not directly measurable because they are not additive. Thus the final report, published in 1939, concluded that it was impossible to reconcile the two parts [2]. This cleaved the scientific community with consequences up to the present day. At present, there are good chances to become reconciled. But before discussing this, it is necessary to review some of the main achievements in this area during The 20th Century.

2.2. Twentieth century achievements

After the BAAS Report, measurement had essentially a parallel development in the two communities of physics/engineering and psychology, with noteworthy achievements in both of them, but little interactive communication. We will briefly discuss three main topics, namely,

1. the evolution of measurement in psychology,
2. the interest in physical metrology of "physiological quantities" and
3. the formulation of the representational theory of measurement.

In psychology, a new school of measurement was born, which was most properly named psychometrics. Whilst in psychophysics, traditionally, characteristics of an object are investigated, as perceived by a "standard observer", in psychometrics, the focus is rather on characteristics (traits or states) of individuals, measured as responses to standard test items [5].

Concerning psychophysics, the contributions of S.S. Stevens must be particularly mentioned, since he provided replies to the arguments that were raised in the BAAS Committee against the measurability of sensory events. It was argued that sensations were not directly measurable and he developed the method of *magnitude estimation*, in which subjects directly scale by free-number assignments according to a rule, the intensity of their sensations (or rather perceptions) as evoked by physical stimuli [4]. In the

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Committee, it was also argued that addition of physical quantities was a necessary requirement for measurement, and Stevens responded by proposing his famous fourfold classification scheme of measurement scales [3], in which nominal and ordinal scales representing non-additive quantities are also included. With these contributions, the psychophysics of The 20th Century proved to be able to overcome the reservations raised in the BAAS Committee.

As regards physical measurement, it is most important, for our purposes, to recall that in 1960 luminous intensity was included among the base quantities of the International System of Units (SI). Since this quantity measures the physiological response to a physical stimulus, we may say that the idea of explicitly accounting for persons' responses was accepted officially [11]. Moreover, the interest in the so called "physiological quantities" is now growing [28], as we will discuss at a later stage.

Lastly, we have to note that in the second half of The 20th Century a noteworthy systematisation of the theory of measurement was achieved in the name of representational measurement [6]. In this framework, the notion of measurement scale is central, and it encompasses what makes a measurement possible and meaningful. Indeed scales are characterised both by the empirical relations or operations that they are able to represent and by the class of admissible transformations that they may safely undergo. As an example, a ratio scale, which applies to most of the quantities in the SI, for example mass or length, represents both empirical relation of order and empirical operation of addition, and it may undergo similarity-transformations, i.e., multiplication by a positive constant. Such a transformation occurs when we change the conventional unit.

Although developed mainly in the area of behavioural sciences, this theory is now quite popular also among physicists and engineers, mainly thanks to the contribution of Finkelstein [8]. He proposed a well-known definition of measurement, that is, "a process of empirical, objective assignment of symbols to attribute of objects and events of the real world, in such a way as to represent them or to describe them". In this definition the term "to represent" clearly points at the representational approach.

We would like to conclude that during The 20th Century many important achievements have been made in the area of measurement. This should lead to a reconsideration of the conclusions of the BAAS report and to a new, multi- or interdisciplinary approach to measurements related to human perception and interpretation. In this regard, a new favourable scientific environment has emerged.

3. THE "MEASURING THE IMPOSSIBLE" ENVIRONMENT

"Measuring the Impossible" is the impressive title of a European Call for research projects recently issued, concerning the measurement of quantities and qualities related to human perception and interpretation [20]. This Call is important not only as a privileged funding opportunity, but also because it stimulates sound motivations for promoting research in this area. They include *scientific arguments*, "many phenomena of significant interest to contemporary science are intrinsically multidimensional and multi-disciplinary, with strong cross-over between physical, biological and social sciences", *economic aspects*, "products and services appeal to consumers according to parameters of quality, beauty, comfort, which are mediated by human perception" and *social reasons*, "public authorities, and quasi-public bodies such as hospitals, provide citizens with support and services whose performance is measured according to parameters of life quality, security or wellbeing". A few examples of projects funded may be helpful for getting a feel of what is going on.

The project MONAT, "Measurement of naturalness", coordinated by the National Physical Laboratory (NPL, United Kingdom), aims at measuring the naturalness of materials, such as fabrics, as the result of visual appearance and touch [26]. The former is influenced by factors such as colour, texture, gloss and white-light reflectance, the latter by thermal conductivity, hardness, surface topography and friction coefficient. This requires the measurement of physical and psychophysical qualities, and their combination in order to account for multi-sensory perception and interpretation.

The project SYSPAQ, "Innovative sensor system for measuring perceived air quality", coordinated by the Technical University of Berlin, aims at linking chemical measurements to odour perceptions through the development of an electronic-nose device customized for improving and monitoring indoor air quality.

CLOSED, "Closing the loop of sound evaluation and design", coordinated by the Institut de Recherche et de Coordination Acoustique/Musique (IRCAM, France), aims at improving products by including perceived sound-quality information on products-in-use already at the design stage.

Moreover, though these projects are interesting in themselves, they are not isolated research activities, but have rather cooperated and interacted with each other mainly thanks to the Coordination Action environment, named MINET–*Measuring the Impossible Network* [21]. MINET is coordinated by the Stockholm University, and it promotes discussion, cooperation and synergy among the researchers operating in this field. This includes the implementation of an interactive website, a database on the available expertise, the organisation of workshops and "think tank" events.

In this framework, an *International Training Course* has been held in Genova, Italy, on "Theory and methods of measurement with persons" [22]. The major challenge is to make experts from different disciplines work together, seeking a common language, and to develop a coherent understanding and development for such a multifaceted subject. It is planned to prepare a book, based on the lectures given in the Course. It will probably be the first one dealing with this measurement topic in such a multidisciplinary fashion. Some of the main research challenges arising in this broad area will now be discussed.

4. RESEARCH ISSUES AND CHALLENGES

4.1. Instrumentation and methods

It is now time for figuring out some of the main research issues that are central to this area and to point out some of the main challenges involved [20].

Generally we may group these issues in three main categories,

- instrumentation and methods,
- foundation and theory,
- implementation areas and applications.

Instrumentation-oriented research concerns both the measurement of physical events (the stimuli) that give rise to a sensory response and the physiological (or behavioural) responses to internal/external stimuli. It would also include perception and interpretation processes and the development of sensors that mimic, to some extent, human perception. Since the time of the "schism" the progress in these areas has been enormous, and in itself this would be a good reason for reconsidering things. Concerning, for example, the measurement of sound, we now have highly accurate measurement microphones and binaural recording devices, that make it possible to measure the acoustic stimuli as they appear at the input to the auditory system. We also have sophisticated binaural reproduction devices with processors and algorithms for the required signal processing. In the case of sight, we can measure not only luminous intensity and colour, but also parameters of the interaction between light and matter, as well as properties of surfaces, such as texture that also involves sophisticated signal processing. Similar considerations apply for the other senses too.

Concerning the measurement of physiological responses, novel techniques are available, especially in the field of brain imaging [12]. Roughly, there are two main approaches based either on the electromagnetic characteristic of the neural activity of the brain, including electroencephalography (EEG) and magneto-encephalography (MEG), or on the emodynamic paradigm, that is effects related to the blood flux associated with brain activity, comprising functional magnetic resonance imaging (fMRI) and positron emission tomography (PET). These techniques developed rapidly because of their great value in neurophysiology/neuroscience. From our standpoint, several metrological issues are of interest, including spatial and time resolution, level of measurement (i.e., interpretation of which kind of measurement scale is valid for instrumental output), calibration issues and, most importantly, how these scales are associated with participants' perception and interpretation.

As we have mentioned, there is an increasing interest in exploring the physiological quantities, that is quantities causing a physiological response in the human body, and their compatibility with the international system of metrology. A workshop on this very topic is foreseen in November 2009, organised by the Bureau International des Poids et Mesures (BIPM). It will deal with optical radiation, radio waves and microwaves, ionizing radiation, acoustics, magnetic fields and other international standard measures and units applied in documents by the World Health Organization. Here the focus is mainly on adverse health effects, yet it is important, in our opinion, that the two approaches, health on the one hand, perception, interpretation and behaviour, on the other, will establish a dialogue and explore potential synergies.

In a broader vision of human response, we may include behavioural aspects also. In this regard, image-based measurements play a key role: they are essential, for example, for studying emotions or body language. Emotional responses may also be assessed by physiological-oriented measurements with instruments. Galvanic skin response, for example, measures detectable changes in skin conductance, induced by the sympathetic nervous system due to stress and/or emotions. Although often replaced by brain imaging, this relatively old method is still profitably used, because of its simplicity and low cost. Another approach to emotion is to measure the activation of critical facial muscles by electromyography [9]. Moreover, highly valuable information on the complex mechanism of visual perception may be gained by the tracking of saccadic eye movements: current advances in this area have revealed space-time gaps that seem to be interpretable via relativistic-like principles [20].

Sensors that mimic human perception include, for example, the electronic nose. In current research aiming at sensing directly the quality of indoor air, such a device has been built according to a perceptual odour space determined empirically for materials emissions. It is multidimensional and the interdistances between odour qualities were calibrated with the aid of a set of odour references that fulfils reliability requirements. Other examples are tactile sensors, that have an increasing ability of "perceiving" surface texture, or the visual sensors called artificial retina. Advanced robotics and clinical applications are expected for these sensors. One example is the blind being able to appreciate the aesthetics of sculptures.

In fact, as we have explicitly noted for the electronic nose, all these instrumentation-related possibilities should not make us forget that the screening and testing of participants as measuring instruments are absolutely necessary for reliable and valid psychological measurement. Many reliable *methods of measurement* are available, ranging from the traditional methods of psychophysics (the method of limits, of average error and of constant stimuli, which were developed by G. T. Fechner for determining absolute thresholds of detection and just noticeable differences or, in general, equalities or inequalities among sensations) through the basic methods of direct scaling introduced by S.S. Stevens (magnitude or ratio estimation and production), to the more advanced approaches, such as the master scaling [17]. In the latter, individual scales of magnitude estimation are calibrated by the use of a set of reference stimuli that provides a common experimental context. In general, methods of psychophysics have benefited from developments in experimental design and statistics. Statistics has also contributed to psychometrics, which is another school of psychological measurement using standardized tests for collecting data, i.e. in the form of questionnaires, interviews or performance tasks [5]. Thurstonian scaling [1] is somewhat intermediate between psychophysics and psychometrics and is sometimes called "indirect scaling" as opposed to Stevens's direct scaling. From a psychophysical perspective, this approach is based on the assumption that a single value of an external stimulus will evoke perceptions that are mapped on an inner psychological continuum, giving rise to a probability distribution, usually assumed to be Gaussian. So it is possible to establish a precise relation between distances on such a continuum and the probability of order relations. Accordingly, it is possible to infer, from a pair-comparison test, a metric scaling. Actually, these inner representations are not necessarily related to an external stimulus and this is why this approach may be used in psychometrics also: indeed, it was first proposed for measuring attitude. A remarkable model for psychometric tests is provided by the item response theory [5], in which the probability of the correct response to a test item is a function of person and item parameters.

To summarize, many methods are available for gathering information from the real world, whether outer or inner, and we must focus on how to best use such information. This is where measurement theory comes to play.

4.2. Foundations and theory

Several foundational and theoretical issues are, in our opinion, of prime interest in this area, including

- the language,
- the concepts of measurement scale and of measuring system (or instrument),
- the logic (deterministic, probabilistic, fuzzy…),
- the issue of measurability,
- multidimensionality and mathematical modelling.

Language has been a main issue in the scientific and philosophical debate of The 20th Century. In the metrology community, a noteworthy revision of linguistic terms has been undertaken, starting with the publication of the international vocabulary of basic and general terms in metrology (1984), now in 3rd edition [24]. It is interesting to note the evolution of such editions, since the trend has been to include further disciplinary areas. It may be envisaged that in a near future measurements with persons may play a role there. Moreover, in the workshops and think tank events organized by MINET, the issue of language/vocabulary soon emerged. It is natural that this will be a challenge in any multidisciplinary environment. Yet, in any revision of terms, a revision of concepts and theories must also be considered, that indeed will be beneficial for the entire world of measurement [29].

Any theory of measurement should deal, at least, with two main topics, the *measurement scale* and the *measurement process*. As we have seen, the notion of scale is central to representational theory [13], and it should be given more consideration in physical measurement too. Although nowadays we know much about scales, further research is still needed for ensuring that this concept is really common to measurement in physical, psychological and social sciences. This include, for example, a probabilistic formulation [19], a better understanding of the notion of scale in the case of derived quantities, and a better systematization of the foundations for various psychological methods of measurement.

The concept of *measurement process* has a strange history. It is closely related to the notion of *measuring system*, or instrument. Although, since the time of Galileo, scientific instruments have been the key to developing modern science, it is interesting to realize that instruments were ignored in the research on the foundation of measurement; however see [18]. Only recently was the theoretical role of the measuring system outlined. In particular, it is important to consider whether this is important only for physical measurements or for psychological measurement, too.

The question of the *logic* is transversal to all the above. If uncertainty is recognised as an essential aspect in measurement, a probabilistic or a fuzzy logic may be best suited [27]. Systematic studies in these latter perspectives are still in their infancy.

Measurability has recently been discussed and proposals, mainly based on the representational approach, have been presented [16, 23, 25]. This is clearly a key point requiring careful discussion together with *mise en pratique* issues.

As outlined in the "Measuring the Impossible" Call, *multidimensionality* is often involved in the processes of human perception and interpretation. A shift from unidimensional to multidimensional measurements will result in significant changes. In a unidimensional scale, the key property is order, whereas in a multidimensional space, the key property is distance. Moreover, in the latter case the problem of dimensionality reduction becomes most important. In future work, it would be beneficial to proceed with foundational search in parallel with mathematical and numerical developments of models and methods [14].

Human perception and interpretation of, say, the living or working environment, may be understood through the mediation of *modelling*. Modelling of complex perceptual environments requires a combination of physical and perceptual measures. It would therefore be highly desirable that all quantities involved refer to the same international system. Thus, a fruitful future problem is to investigate *whether or not* and *to what extent physical and perceptual characteristics may be part of the same system*.

4.3. Implementation areas and applications

Measurements related to human perception and interpretation have a wide range of actual and potential applications [15, 20]. Here we briefly mention the areas of perceived quality (of products and services), environment, ergonomics, safety, security and clinics.

In the first part of the last century, the impact of mass production was so high that qualitative aspects of goods were somewhat neglected. Today, the shortage of energy sources and the concern for pollution may cause an increasing request for durable, high quality goods. Thus, *perceived quality*, which results from perception and interpretation of sensory input, may play a key role in industrial competition. Example of products include food, materials, simple and complex devices. A good cup of coffee, for example, is appreciated on the basis of a combination of taste, smell, sight and touch. Common materials of daily use include fabric, paper, wood and stone. For these, the feeling of naturalness is important: in this regard, as already mentioned, research is ongoing, for relating naturalness with a combination of visual and tactile inputs [26]. Domestic electric appliances are appreciated not just on the basis of their performance, but also, perhaps mainly, because of the sound quality they produce as well as their visual appearance. Colour photocopiers seem to be evaluated mainly on the basis of pleasantness instead of fidelity; in the case of single colours, pleasantness seems mainly to depend on hue, lightness and chroma, whilst for combinations of colours predictions are more difficult. Next generation of touch screens on mobile devices may provide some touch feedback, that is, simulating texture by varying friction factor through controlled ultrasonic oscillation. Lastly, for many years, car producers have been aware of how interior car noise, door closure sound and even interior smell will affect consumers' decision to buy a new car. The last example is particular significant because in the last, say, twenty years, perceived quality has been the main (or even the only) motivation for supporting research in the product development area, at least at the European Community level. Yet, we think that even if this remains an important application area, as we have claimed, there are other emerging areas, perhaps even more valuable in a strategic perspective.

Outdoor and indoor *environments* are going to be of major concern in the years to come. Outdoors, visual, olfactory and auditory perception provide the basis for quality evaluation. Research projects concerned with the characterisation of landscapes and of soundscapes (that is, a combination of sounds that results from an immersive environment) may be mentioned, as well as measurement campaigns for reducing loudness or odour intensity of fertilisers in the surroundings of industrial plants. This study area, called "environmental psychophysics", faces challenges of characterising exposures in a multisensory way, varying over time and often obscured by background conditions, that requires carefully designed and controlled measurement procedures [10]. Indoor environment is also of great importance, because people spend about 90% of their time indoors, either at work, at home or when commuting between work and home. The quality of indoor environment depends upon the quality of its subsystems, i.e., air quality, soundscapes, visual-tactual surfaces, and their integration. Perceptual studies and measurements must thus be combined with sophisticated modelling of complex systems.

The indoor environment provides an immediate link to *ergonomics*. Although originally intended to deal with work systems only, ergonomics has now a new definition by the International Ergonomics Association: "The scientific discipline concerned with the understanding of the interactions among human and other elements of a system, and the profession that applies theory, principles data and methods to design in order to optimize human well-being and overall system performance". It is now concerned with human activities in general, including work, study, recreation or rest. The relationship between human beings and their environment, including machines and devices, are experienced through the senses and their perceptual measurements are key ways for obtaining valuable scientific and professional data. A typical ergonomic concern is the measurement of comfort. In systems of transportation, discomfort is often associated with noise and vibration exposures in which case perception plays a central role. Epidemiological or quasi-experimental studies in their various forms rely on measurement with persons as their main tool.

Ergonomics aims at ensuring, on the one hand, a good quality of life for operators, on the other, a best performance of the concerned system. Consider the case of a driver: ensuring that he/she is working in optimal conditions is possibly the best mean for guaranteeing the *safety* of people carried. Consider also the case of a watchman: here his/her performance affects *security*.

Security is another important application area. The case of face recognition for the identification of suspected persons may be briefly considered. So far, several approaches have been implemented for the automation of this task: comparing a picture of a suspect with a data base of criminals may be a too heavy task for a human being. At present, approaches related to the psychology of face recognition seem to be promising. They are related to multidimensional measurements and to perceptual models. Forensic science is a closely related field: a major problem there is the reliability of eyewitness testimony, due not to the wish of lying, but to failures in memory. There are ongoing studies in perception and memory formation that may result in practical methods for assessing the reliability of eyewitnesses.

Clinical applications are also important. The measurement of the intensity of pain may help to optimise treatments [17]; changes in sensorial sensitivity may be used in diagnostics (e.g., decrease of smell sensitivity as an early warning symptom for the Alzheimer disease) or for the monitoring of rehabilitation processes. Lastly, humanoid robotics aims at developing machines that resemble, to some extent, some aspect of human behaviour. They must be equipped with sophisticated sensor interfaces that mimic some aspect of human perception and may be used in rehabilitation and special assistance programmes.

5. FINAL REMARKS

The measurement of characteristic related to human perception and interpretation has been discussed. First, the historical framework was sketched. Then, the state of the art was presented, based mainly on the examination of current research projects. Finally, challenges and future research needs were addressed.

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