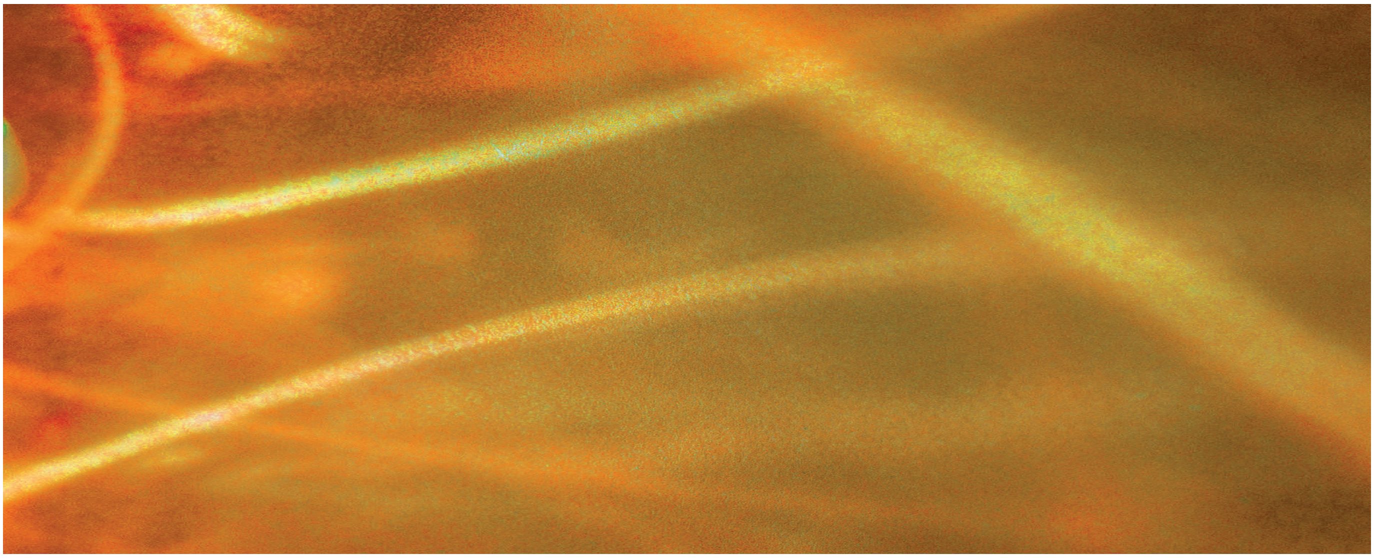

Measurement with Persons: A European Network

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Abstract: The European 'Measuring the Impossible' Network MINET promotes new research activities in measurement dependent on human perception and/or interpretation. This includes the perceived attributes of products and services, such as quality or desirability, and societal parameters such as security and well-being. Work has aimed at consensus about four 'generic' metrological issues: (1) Measurement Concepts & Terminology; (2) Measurement Techniques: (3) Measurement Uncertainty; and (4) Decision-making & Impact Assessment, and how these can be applied specifically to the 'Measurement of Persons' in terms of 'Man as a Measurement Instrument' and 'Measuring Man.' Some of the main achievements of MINET include a research repository with glossary; training course; book; series of workshops; think tanks and study visits, which have brought together a unique constellation of researchers from physics, metrology, physiology, psychophysics, psychology and sociology. Metrology (quality-assured measurement) in this area is relatively underdeveloped, despite great potential for innovation, and extends beyond traditional physiological metrology in that it also deals with measurement with all human senses as well as mental and behavioral processes. This is particularly relevant in applications where humans are an important component of critical systems, where for instance health and safety are at stake.

1. Introduction

In the area 'Measurement with Persons,' man enters into the measurement system in two, radically different ways:

- Measuring Man: A human is the measurement object itself
- Man as a Measurement Instrument: Instead of equipment, the human senses are used for measuring objects

Man normally appears in traditional engineering measurement merely as the operator of the measurement system. 'Human' aspects in that case are mostly limited to the skill in handling instruments, performing the measurements and interpreting results of measurement, for example in determining measurement uncertainty associated with limited measurement knowledge on behalf of the operator.

The objectivity required when measurement results are to provide the basis on which important deductions and decisions of compliance, is traditionally ensured by using instruments which are considered more adept at interrogating a measurement object than relying on the "five senses" of a human being. This applies be it scientific observation to increase our understanding of the Universe and/or when decisions of conformity of object characteristics to specifications need to be made, for instance in regulation aimed at ensuring health & safety.

When "Measuring the Impossible" (MtI) [1], however, man is no longer a passive operator of a measurement system but becomes a primary focus of interest.

This paper presents the results of three years of discussion amongst physicists, metrologists, physiologists, psychophysicists, psychologists and sociologists aimed at gaining a more insightful and wider understanding of “hard’ (i.e., classical chemical and physical measurements) and ’soft’ measurements (i.e., measurements mediated by human perception and interpretation).

Some objectives, as studied in the MINET project [2], are:

- Harmonizing basic measurement and metrological concepts (terminology, nomenclature) and techniques in ’new’ areas of *Measuring with Persons*, such as sensations of taste, smell, light, alertness, etc.
- Promoting quality-assured measurement (metrological traceability, measurement uncertainty) when *Measuring with Persons*, for use in decision making and risk/impact assessment.
- Particularly relevant in applications where humans are an important component of critical systems.
- This MtI approach is quite underdeveloped, despite great potential for innovation.

Metrology has traditionally tackled measurement in physiology, that is, the study of the mechanical, physical and biochemical functions of living organisms, by examining how different external influence quantities, such as physical, chemical, and biological, affect these functions from ‘outside’ the organism. This could be for diagnosis, therapy or treatment of patients, for instance. But physiology lies at the interface to the psychophysical[1], mental and behavioral functions ‘within’ the organism and it is increasingly recognised that there can be significant interplay across this interface. Psychophysical, mental and behavioral processes are known to affect significantly the human response to various stimuli – take pain as an example. This makes it necessary to complement traditional physiological metrology in several ways, including an adequate account of the resultant variability in human response (so-called ‘action spectra’ for various quantities in photometry, acoustical metrology, etc.) in some cases. [3]

In an increasing number of regulatory fields, traditional physiologically-based regulations are now adding human factors such as cognitive ability, reflecting the fact that human responses need also to account for psychophysical, mental and behavioral processes in critical applications. For instance, the UK’s Health & Safety Executive [4] in tackling hazardous installations in the onshore and offshore industries, takes a specifically “Human Centered” approach. Decisions about whether a human is performing reliably as an ‘instrument’ (e.g., as part of a control room) or whether she is in good health need to be based on quantification of these physiological and psychophysical effects in an objective and comparable manner.

To obtain this, it is necessary first to define properly suitable measurands and then provide, where possible, their traceability to appropriate SI units. Guidance on the evaluation of measurement uncertainty also needs to be developed in some cases, for instance where physiological measurands are referred

[1] Subdiscipline of psychology dealing with relationship between physical stimuli and their subjective correlates, or precepts

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to diverse measurement scales such as the ordinal or where measurements are qualitative and/or multivariate. The present paper will conclude with a list of challenges for the future of this important, new area of metrology.

2. MINET Activities and Results

As a crucial starting point of any measurement task, even human-based measurements, it has to be recognised that the quality of measurement needs to be assured at *every* step in the task:

- Initial specification of the task in terms of the metrological requirements of the customer;
- In a dialogue between customer & metrologist, measurement specifications are matched to product (or entity) specifications;
- Selection and use of a measurement method, personnel, equipment with a metrological performance appropriate for the task;
- Correct expression of the measurement results (including statements about construct validity, metrological traceability, and measurement uncertainty); and
- Through to use of the measurement results by the customer, for instance for product conformity assessment. [5]

Reflecting this, MINET has been investigating how the four 'generic' metrological issues, (1) Measurement concepts & terminology, (2) Measurement techniques, (3) Measurement uncertainty, and (4) Decision-making & impact assessment, can be applied specifically to 'Measurement of Persons' in terms of 'Man as a Measurement Instrument' and 'Measuring Man' as discussed and debated in a European forum which attempts to unite physicists, metrologists, physiologists, psychophysicists, psychologists and sociologists.

2.1 MtI and MINET Activities

The MINET project consortium has 22 core members across the European Union, each bringing different but complementary expertise and experience to the network. [2] The consortium represents a broad spectrum of researchers with a common interest in developing an improved understanding of human perception and cognition and how these are related to the physical attributes of materials, objects and environments. Participants' fields of expertise include such diverse topics as physical and chemical metrology, media psychology, brain imaging, genetics, computer graphics, statistics, software modeling and cognitive neuroscience. In addition to the networking project, a total of 15 Measuring the Impossible projects (MtI EU NEST [1]) have been active and are summarized in Tables 2, 3, and 4.

The MINET Consortium is coordinated by Prof. Birgitta Berglund and her colleagues at the Gösta Ekman Laboratory, Stockholm University and the Karolinska Institute, Stockholm, Sweden.

Activities within MINET have addressed these topics as follows:

- Workshops
- Training Course and Book
- Study-visit Programme
- Think Tank Events
- On-line Internet Repository of current literature and Glossary

2.1.1 MINET Workshops

As is the overall aim of the MINET project, a series of workshops intends to gain a more insightful and wider understanding of "hard' (i.e., classical chemical and physical measurements) and 'soft' measurements (i.e., measurements mediated by human perception and interpretation). The MINET workshops achieve this through lectures by renowned speakers, combined with presentations of selected projects within the Measuring the Impossible program, and followed by general discussions.

- *1st Workshop, Portorož SLO* September 26th, 2007: "Measuring the Impossible: What can metrologists and psychophysicists learn from each other?"
- *Workshop 2, Rome IT* October 8th - 9th, 2008: "Awareness, Perception, and Interpretation: Measurements vis-à-vis the complexity of life"
- *Workshop 3, Wageningen NL* May 14th - 15th, 2009.
- *Workshop 4, London UK* November 10th - 12th, 2009: "Measurement, Sensation and Cognition"

MINET has also arranged sessions at conferences. This has included so far:

- Session Measuring the Impossible at the 16th International Electrotechnical and Computer Science Conference, Portoroz, Slovenia, September 2007.
- Session Measuring the Impossible at Measuring Behavior, Maastricht, the Netherlands, August 26-28, 2008.

MINET made four presentations at the IMEKO conference in Annecy (FR) in September 2008, which at the instigation of people of MINET was also devoted more to human measurements. See also the third newsletter for details: http://minet.files.wordpress.com/2008/09/minet-newsletter3.pdf

2.1.2 MINET Training Course 2008

This course was aimed at senior scientists with an interest in understanding and measuring human perceptual responses and behaviors. In the first part, generic theoretical and methodological issues were explored, including:

- The conceptual basis of measurement and approaches to experimentation in the various fields involved.
- The development of formal, representational and probabilistic, theories, and theories and methods for multidimensional problems.

In the second part of the course, several application areas were presented, including sound, visual, touch and smell perception, brain imaging, body language and emotions, and, finally, the use of measurements in decision making.

The course was very successful with about 80 attendees, far above our expectations, coming from 14 countries from all over Europe and USA (see Fig. 1). About half of the audience was involved in Measuring the Impossible projects, and nine

Figure 1. MINET Training Course "Theory and methods of measurements with persons," Palazzo del Principe, Genoa, Italy 9-11 June 2008.

different projects were represented. The course programme was divided into a general theoretical and methodological part and a successive presentation of selected applications.

The 19 lectures were given by scientists who are well known and of high standing in their respective research fields. Three lecturers were from United States research institutions.

In addition to theoretical lectures, attendees had also the possibility during the course of some practical experience with a demonstration set up by researchers from the FUGA "Fun of Gaming" MtI project.

The background level of the attendees was rather high with only 21 % having less than 1 year and 40 % more than 5 years research experience. 61 % of them had research positions in public or private institutions, while the others were Ph.D. students. The interdisciplinary character of the course is well reflected by the attendees' background that was mainly focused on engineering (57 %) but with representatives from psychology, psychophysics and biology.

In general the audience was satisfied with their scientific expectations (95 %) and with lecture quality (74 %). They found useful the course contents in present (43 %) or planned (27 %) research activities. The location was at Palazzo del Principe, a XVI century palace in Genoa.

A MINET book *"Measurements with Persons: Theory, Methods and Implementation Areas"* is now in preparation [6], broadly based on the lectures presented at the Training Course.

2.1.3 MINET Study Visit Programme, Repository and Think Tanks

The EU MINET - Measuring the Impossible Network aiming at achieving a long-term integration and advancement of interdisciplinary research and novel investigative methods in Europe has encouraged study visits for the exchange of advanced knowledge on MtI methods. Four consecutive sub-programs of study visits have been arranged during the MINET project and reports from the various visits, about 15 visits so far reported, are available. [7]

A repository established during the MINET project contains a wealth of information about current literature; schools; approaches; and methodologies used in Measuring the Impossible activities and is freely available on the Internet. Several hundred references are made to major research work about measurement dependent on human perception and/or interpretation. The Repository has been accessed over 2000 times since its creation at the end of 2007. New references to the MINET Repository are sought publicly on a continuous basis, and you are welcome to submit your suggestions. [8]

The four MINET Think Tanks [9], dedicated to the four metrological issues (a) through (d) listed in Section 4.4, are open for participation and debate about measurement dependent on human perception and/or interpretation. Each Think Tank is intended, at least on a voluntary basis, to continue to work even beyond the official end of the MINET project.

The main results of these MINET activities are given below.

2.2 Measurement Concepts & Terminology

Much work has been done over the years internationally in establishing a vocabulary in metrology [10] which aims to define key, generic concepts in any measurement: measurement, measurement object, uncertainty etc. Initially dominated by physics, the vocabulary has progressively moved to include increasingly measurements in chemistry, biology, etc.

As part of the MINET Repository, a glossary of metrological terminology [11] has been developed, with an emphasis on the terms and concepts in measurement dependent on human perception and/or interpretation. The Glossary contents are ordered according to the following categories:

- Entities, Quantities and Units
- Measurement
- Devices for Measurement
- Properties of Measuring Devices
- Measurement in Conformity Assessment

It has about 60 fully-clickable terms, from Accidence, Calibration to Validity and Verification, and with many references not only to the *International Vocabulary of Metrology* (VIM) [10] but also other sources of terminology, including some definitions formulated during the MINET project.

The MINET Think Tank A [9] is dedicated to the topic of Measurement concepts & terminology and held its inaugural meeting in Berlin (DE) April 13th, 2007. The event debated the question:

> *"Is different formulation of concepts & terminology in the different MtI fields hindering this development and how can we improve the situation?"*

The MINET Think Tank event A included an introductory educational lecture: "Cross disciplinary terminology for properties of systems" (Dr. R. Dybkaer, Frederiksberg Hospital, DK). Dr. Dybkaer recalled the divisions of "property" by mathematical characteristics: different 'scales,' progressing from the most basic, nominal and ordinal, to the 'rational' scales. This division in scale had been developed after the second world war in response to the need to extend measurement into the social and behavioral sciences.

Breakout discussions dealt with the following four questions:

(I) What are the necessary basic concepts and terminology?
(II) Are there different concepts & terminology in the various fields?
(III) Is it important to harmonize?
(IV) How can we encourage harmonization and/or innovation?

Apart from stimulating subsequent work on the MINET Glossary, these discussions concluded that it was particularly important to consider how to encourage harmonization [question (IV)] in order to increase awareness/appreciation for the differences between the various MtI fields and the difficulties in understanding these differences as well as foster openness and respect.

Concept[1]	Definition	Notes
Measurement	process of experimentally obtaining one or more **quantity values** that can reasonably be attributed to a **quantity** (2.1 VIM)	(VIM): NOTE 1 Measurement does not apply to **nominal properties**.
Measurement	Process of associating numbers, in an empirical and objective way, to characteristics of objects and events of the real world in a way so as to describe them	[Finkelstein 1984]

Table 1. Extract from MINET WP3 Repository: Glossary. [11]

An example of differences in terminology, here for 'Measurement,' is given in Table 1. In the MINET project, interdisciplinary discussions have at least agreed to disagree, recognizing there are still differences of opinion about terminology amongst the different disciplines.

2.2.1 Concepts & Terminology: Man as Measurement Instrument

When focusing on metrological concepts and terminology where a human replaces the measurement instrument in a system as shown in Fig. 2, the following are of particular interest:

- Human state, performance and reliability <u>understood</u> in terms of human perception.
- Five senses: see, hear, smell, taste and feel.
- Perceived comfort, naturalness, quality, feelings, etc. or human awareness.

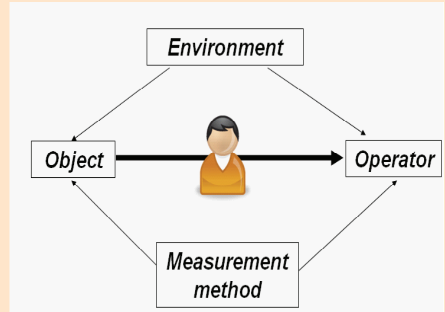

Figure 2. Man as a measurement instrument.

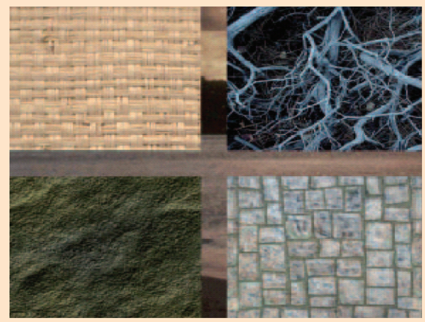

Figure 3. Artificial tactile surfaces from MtI project Syntex. [1]

- Creating and maintaining correct mental model of the system.
- Psychophysics.

The five human senses can be used to measure quantities or kinds of property which can be considered as new to traditional metrology: olfactory 'odor,' tactile 'roughness,' etc. Further properties are associated with psychophysical, mental and behavioral measurements, for example, aesthetic properties of perceived quality of objects, expressed in terms of naturalness, authenticity, artificialness, elegance and more generally qualia[2]. Perceived color of illumination in buildings, perhaps with novel, environmentally-friendly light sources, can be an essential factor in reducing energy consumption and increasing human comfort, alongside more engineering-based considerations. [12]

As in certain, more established areas of metrology, reference materials can be developed to act as 'local' references for traceable measurement even in this emerging area, as studied for example in the MtI project Syntex [1] (see Fig. 3) where such materials with specific perceived qualities were artificially produced and measured perceptually: a development with interesting applications in the rapidly growing area of 'smart' textiles, for instance.

The full range of measurement scales, from nominal to ratio, needs to be employed to tackle measurement in this broad area. [13] For instance, measurement of perceived naturalness in the MtI project MONAT (see Table 2) [1] has invoked the use of a combination of different psychophysical scaling methods. [14]

[2] Qualia is defined as the quality of sensory experience as perceived mentally.

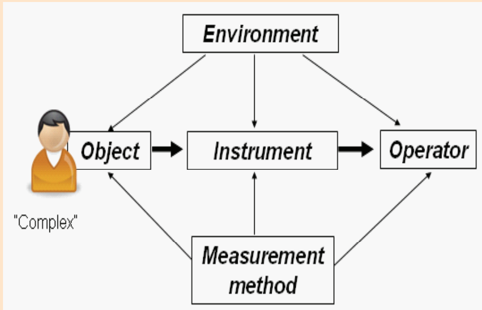

Figure 4. Measuring man.

Figure 5. Measuring an unknown odor from project SysPAQ. [1]

2.2.2 Concepts & Terminology: Measuring Man

In measurement systems (Fig. 4) where a human is the object of measurement:

- Measures of human body language and consciousness.
- Physiology, Psychology, Psychometrics, Psychophysics, Sociology.
- Important factors in assessing human condition, performance and reliability.
  - Human alertness, stress and health.

As mentioned in the Introduction, metrology needs to extend beyond physiological measurement of humans, increasingly to include the psychophysical, mental and behavioral functions 'within' the organism and their interplay. Such processes invoke new quantities to describe states of mind and consciousness. Other measures when measuring man are empathy and efficiency in different situations.

Metrology is still in its infancy in this area, but there is an urgency in the need to develop in this area since, as we will see below, technology is moving rapidly into this [2, 3] and indeed essential and critical decisions of compliance are already being made. [2, 4]

2.3 Measurement Systems & Techniques

The field of engineering and physical instrumentation for measurement is of course vast, well-established but continually under development. Exploitation of new technologies (e.g., nanotechnology, biotechnology etc) is enabling metrology to continue to meet increasing demands for efficient measurement in terms of accuracy, complexity and diversity.

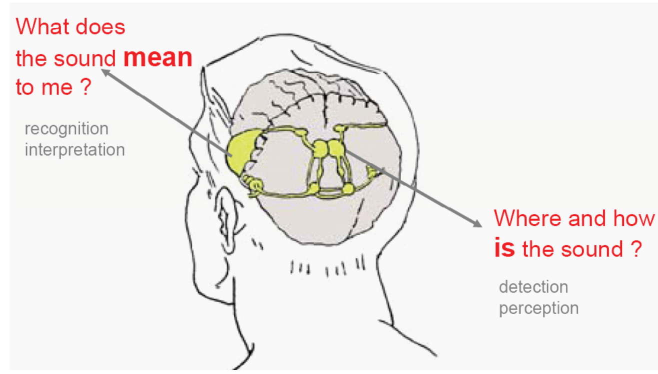

Figure 6. Perceived sound: more than physiology (from Jens Blauert Institut für Kommunikationsakustik Ruhr-Universität Bochum, D-Bochum, Germany). [16]

2.3.1 Measurement Techniques: Man as Measurement Instrument

Many of the measurement concepts regularly employed in characterizing the metrological performance (accuracy, range, resolution etc) of traditional measurement instrumentation and methods [15] can also be applied when characterizing human beings as 'instruments' (see Fig. 5).

Care has to be exercised in such studies and an overall aim is to *bridge the gap* between:

- Engineering tradition criticized for a far too instrumental view of operators.
- Humanistic and behavioral science tradition all too preoccupied with issues centered on human operators.

One has to consider a full range of measurement techniques when regarding a 'human' instrument, including Physics, Physiology, Psychophysics, and Psychology, which go beyond traditional physiological measurement (e.g., acoustics and photometry) in recognizing significant and important 'signal processing' of the human brain.

For instance, regular acoustic limits on exposure to certain levels of sound need not only to account for risk of physical damage to the ear drum but also the perceived level of acoustic disturbance. Court cases dealing with environmental acoustics often place more weight on evidence that sound causes human disturbance (e.g., impaired learning in school classes) than purely physiological effects. [17]

Another example is visual perception: A purely physical optics description of the human eye cannot completely explain effects such as (i) image inversion: the image on the retina is not perceived in vision as upside down; (ii) sight in the elderly is perceived to be 'better' than it is; and (iii) patients with artificial retina can see clear images even with a limited array of detectors. [18]

Quantities such as 'pain' interestingly span the full range of perceptive measurement, from for example, a mechanical force applied physically, through a series of physiological, neural, psychophysical, mental and behavioral responses.

MtI projects in the MINET network and several projects related to the EU NEST Pathfinder Initiative "Measuring the

BRAINTUNING
- Applying innovative neuroscience to investigate how music and music-induced emotions are processed in the brain.
- Examine the multifaceted relationship between the structure of music and how it affects our emotions.

CLOSED
- Develop innovative tools for tailoring sonic signatures for optimal customer satisfaction.
- Develop models to account for emotional and cognitive responses to the functional and aesthetic aspects of a product.

MEMORY
- Explore the complex mechanism of the short-lived perceptual distortions of space and time involved in the brain interpretation of the world around us.
- Understand the neuronal mechanisms, leading to the development of possible aids for diseases related to misperception of external space.
- Define an integrated environment that combines real-life perceptual information with the cyberworld, leading to innovative communication protocols for more human-like machines and robots.

MONAT
- Help manufacturers create artificial materials that are more like "the real thing," making luxury more affordable and saving precious natural resources.
- Studying the sensory chain of the brain's interpretation of sensory information and the raw information transmitted by the nerve cells in our eyes and skin to learn the secrets of what makes materials seem natural.
- Design synthetic materials that closely mimic their natural counterparts and develop mathematical models that link the physical properties of a material with its perceived naturalness.

PERCEPT
- Map information into a quantifiable and comprehensive form that could provide a basis for clearer communication and more effective education.
- Analyze subjective interpretation with an objective measurement system.

SOMAPS
- Study how complex stimulation patterns on the skin are processed by the central nervous system and how memories and emotions can affect the resulting perceptions.
- Develop models on how to link the corners of the triangle that links physical stimulus, brain activation and subjective experience.
- Predict properties of the subjective experience directly from the applied stimulus.

SYNTEX
- Study how texture provides us with emotional qualities and expectations and knowing how to measure and control these.
- Develop a new investigative method to assess human interpretation of textures.

SYSPAQ
- Develop a fully integrated electronic system able to determine human acceptability of air quality.
- Combine perception psychology and expertise in sensor and related technologies, to link chemical measurement directly to sensory perception.
- Develop perception methods and software tools for modeling human response and creating a system capable of measuring and monitor indoor air quality as we perceive it.

Table 2. MtI projects: Perception. [1]

Impossible" [1] dealing with Man as a Measuring Instrument: Perception are summarized in Table 2.

Examples of measurements with man as the measurement instrument are the measuring of perceived intensity of touch, cold and warmth. [20] In this type of work one difficulty is the calibration of the perceived intensity. Examples of how sound affects humans include measurements for understanding of how and why music affects us (see Fig. 6). [21] Soundscape and illumination can be important in control room activities or when a customer is shopping. The study of how persons, particularly when disabled, negotiate transportation systems and how these can be optimized to facilitate travel covers every step in a journey, ranging from interpreting various signs and instructions to tackling a variety of hinders along the way. Other examples are measurements of human performance response time. One such example is the signaler's intervention in a rail incident in the UK [19] as shown in Fig. 7.

2.3.2 Measurement Techniques: Measuring Man

A wide range of measurement techniques has been developed in recent years: Electroencephalography (EEG), Electrocardiography (ECG), Electromyography (EMG), Magnetoencephalography (MEG), functional Magnetic Resonance Imaging (fMRI), electrodermal activity, respiration, eye movement tracking, pattern recognition, computer vision, thermograph, etc.

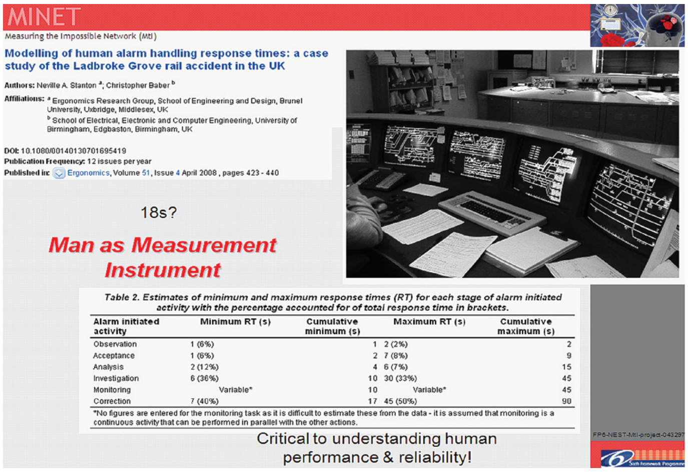

Figure 7. Human reliability as Measurement Instrument critical in some applications. [19]

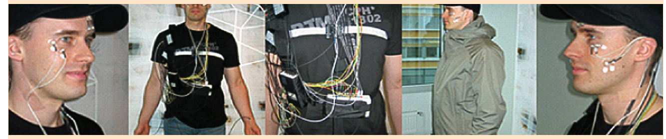

Figure 8. Emotionally adaptive computer game from project FUGA. [1]

EYEWITNEM

- Reduce injustice by bringing a more scientific approach to evaluating eyewitness testimony.
- Develop a practical toolkit that significantly improves our ability to assess the reliability of individual eyewitnesses.

FUGA

- Focusing on creating novel measurements techniques to quantify the complex and dynamic experience of enjoyment derived from computer games.
- Establish innovative comprehensive measurement methods to help designers and media psychologists to improve computer and video gaming.
- Improve the understanding on how addiction to gaming arises and how it can be prevented or treated. (See Fig. 8)

MINDBRIDGE

- Explore the causes and mechanisms of consciousness, and answer the question how the human brain transcend its physical structure to create conscious experiences and a sense of self-awareness.
- Develop a toolbox for studying different levels of consciousness, as well as the relationships between conscious and unconscious processing in the brain.
- To produce an empirical theory of consciousness to supplement existing theories, which are based largely on philosophical reasoning about how consciousness ought to work.

Table 3. MtI projects: Cognition. [1]

COBOL

- Develop a new theory for measuring the components of body language to form a basis of more reliable tools for detecting criminals, deterring terrorists and studying degenerative diseases.
- Measuring and evaluating complex or ambiguous actions and sequences to provide a more detailed analysis of the individual components of emotional body language that are critical for eliciting emotional response.

FEEL EUROPE

- Stimulate interdisciplinary research to identify investigative methods that will underpin advances in measurement techniques for future application.
- Define and develop novel kinds of technical cognitive systems, with the ability to understand human behavior and provide a basis for the development of improved human-machine interfaces.

BIOEMERGENCES

- Establishing strategies and tools to measure variations between healthy individuals, between those with the same genetic defect and between those receiving specific therapies.
- Focusing on determining how to measure the individual differences in living beings at all levels.

Table 4. MtI projects: Emotion. [1]

Modern measurement techniques such as fMRI are probing deep into the human brain *in vivo*. These complement traditional physiological methods used in both healthcare and the treatment of patients. At the same time, recent research in intelligent instrumentation is leading to devices, employing neural networks, for example, which possess several sensory abilities resembling human sensing. [22] So there is a clear convergence at the human/machine interface and metrology needs to adapt and extend its scope to meet these challenges.

MtI projects in the MINET network as part of the EU NEST Pathfinder Initiative "Measuring the Impossible" [1] dealing with Measuring Man: Cognition and Emotion, respectively, are summarized in Tables 3 and 4.

A second MINET Think Tank [9] addresses Measurement Systems & Techniques in the various Measuring the Impossible fields and held an event at Portoroz (SLO) September 27th, 2007. The event debated the question: "What are the limitations of different measurement systems and techniques and can there be synergies between them?"

The MINET Think Tank event B included an Introductory educational lecture: "Measurement Techniques in Communication and Media Psychology," by Prof. Gary Bente, University of Cologne, Germany.

Breakout discussions mainly focused on the scope of measurement in terms of the following questions:

- Generalizability of results and limits of different techniques.
- Can different techniques be combined?
- Examples of research questions that would benefit from a multi- or interdisciplinary approach.

Subsequent work of the Think Tank B has included populating the MINET On-line Repository (see Fig. 9) with references to current literature about Measurement Systems & Techniques.

Man as Measurement Instrument: Control rooms. Panel/jury, Papers

BAE 2002 "Human factors integration: Implementation in the onshore and offshore industries", *BAE Systems Defence Consultancy prepared for the Health and Safety Executive* 2002, http://www.hse.gov.uk/research/rrpdf/rr001.pdf

Rossi G.B., Crenna F., Panero M. [Univ Genova] 2005 "Panel or jury testing methods in a metrological perspective" *Metrologia*, 2005, 42, n°2, 97-109 [on-line]

El Sadik A, Rahman A S M M and Hossain M A 2008 "Suitability of searching and representing multimedia learning resources in a 3-D virtual gaming environment", *IEEE Trans Instrum Meas* **57**, 1830 – 9 DOI http://dx.doi.org/10.1109/TIM.2008.919867

Figure 9. Extract from MINET WP3 Repository: Measurement Techniques. [8]

2.4 Measurement Traceability and Uncertainty

It is equally important in measuring with persons as in traditional measurement to ensure that any measurement results are founded on sound metrological concepts, particularly metrological traceability and measurement uncertainty. These provide quality-assured measurement results which are, respectively, comparable with other measurements and have declared measurement quality.

2.4.1 Measurement Uncertainty: Man as Measurement Instrument

When man is the measurement instrument, we have exchanged the traditional measurement instrument, which often is perceived as objective with a "subjective" human. Typically, the 'instrument' might be highly variable with time and hence it is sometimes difficult to repeat such measurements under similar conditions.

With measurement techniques so diverse in this field, ranging from objective to more subjective judgments based on self-reporting, perceptive measurements cover a large variety of classes.

In order to treat these measurements correctly there are a variety of scales: ordinal, interval, ratio and nominal. [13, 14] For the different scales there are different permissible operations and different appropriate statistics.

Measurement uncertainty will often be a dominant factor, as an essential factor for quantifying the quality of the measurements, reflecting limitations in measurement knowledge, and in making decisions of conformity. Table 5 summarizes different categories of measurement uncertainty in Measurements with Persons. [23]

2.4.2 Measurement Uncertainty: Measuring Man

In making measurements on man himself, for instance when attempting to assess the performance of an individual in a control room, a wide range of measurement techniques can be employed - from physiological to psychological and from functional Magnetic Resonance Imaging of brain activity to self-reporting from the human measurement object himself. Here, we have a situation where the measurement object may react differently each time the measurement is made. Hence, as in the case with man as a measurement instrument (see below), the measurement situation may be difficult to repeat.

For example, fatigue which is highly relevant for operators is a parameter measured when measuring man. Figure 10 shows an example of current research where two different measurement methods: 'self-rating' by the driver and analysis of eye blinking, produce similar trends in tiredness during about two hours of driving. It is however difficult to state whether the difference in measurement results is significant without further analysis and declaration of measurement uncertainty with each method and some risk assessment. This is an area of current research interest. [24]

A third MINET Think Tank C [9] aims to tackle the subject of uncertainty in measurement dependent on human perception and/or interpretation and organized an event in Rome, Italy, October 9th - 10th, 2008, under the title: "How is measurement uncertainty evaluated in the different Measuring the Impossible fields?"

The MINET Think Tank event C included introductory educational lectures: "Uncertainty Sources" by Prof. G. B. Rossi, University of Genoa (IT) and "Uncertain Measures?

Element	Person	Uncertainty	Information	Communication
Object	Measuring Man	Hazard and Exposure	"Ambiguity:" non-specific, one-to-many relation, variety, generality, diversity and divergence	Act of measurement (or more generally of transmitting a message) will reduce our ignorance or uncertainty.
Instrument	Man as Instrument	Measurement	"Vagueness:" fuzziness, unclearness, indistinctness, etc.	Uncertainty reflects certain loss of information when communicating message from transmitter to receiver.
Operator	Man as Operator	Measurement	Lack of knowledge or skill	Act of measurement will reduce our ignorance or uncertainty – Bayes theorem.

Table 5. Measurement uncertainty in human aspects. [23]

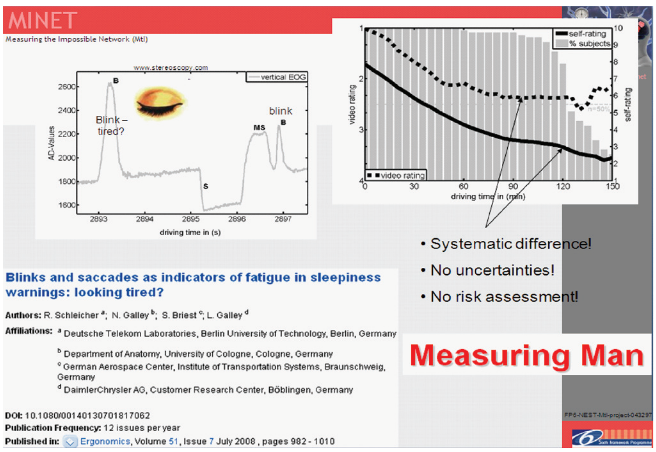

Figure 10. Measuring fatigue with different methods. [24]

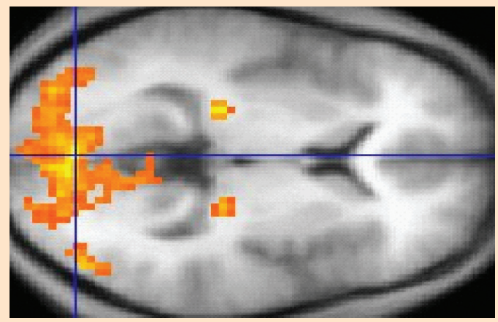

Figure 11. fMRI scan of the human brain. [31]

Comparison between Causal and Systemic Sciences from Viewpoint of an Applied Methodologist" by Prof. L. Cannavò, University "La Sapienza," Rome, Italy.

This was followed by breakout discussions considering the following questions:

(I) Evaluation: Typology of uncertainty sources?
(II) Concepts: Relation uncertainty ↔ liability & validity?
(III) Evaluation: Unknown laws – how to calculate U?
(IV) Evaluation: Alternative, non-numerical estimates of U?

In debating concepts, specifically (II) the relation between uncertainty and validity, the MINET Think Tank C observed that researchers from the various MtI fields had more similarities than differences in their interpretation of these terms. This has stimulated subsequent work on the MINET Glossary, including consideration of terms such as Validity.

The evaluation of measurement uncertainty (III) when underlying laws are unknown, as is often the case in measurement dependent on human perception and/or interpretation, was considered to be a relatively difficult task. We have to deal often with multidimensional and correlated measurements demanding different techniques such as bootstrapping, as well as playing with data and exploiting familiarity. [25] There is also uncertainty in measurement models as well as measurement uncertainty.

2.5 Decision-making and Impact Assessment

Understanding the relevance, impact and consequences of measurement in wider contexts is leading to increased attention to the role of quality-assured measurement in decision-making, including guidance on translating measurement uncertainty into terms (impact, risk, costs) more readily appreciated by the decision-maker. [26]

Many important decisions when assessing human condition, performance and reliability (for instance, human alertness, stress and health) are based on the results of measurements of man. It is essential in this case that these results are quality-assured so that measurement results can be used for objective decision-making where risks of in-correct decision-making are at least estimated and perhaps minimized.

2.5.1 Decision-making: Man as Measurement Instrument

Having agreed on appropriate descriptors of human performance and reliability and how to measure them, a next step is to consider ways of improving these. An example of how the effects of training can be measured and improve human performance and reliability in control room situations is discussed in reference [27].

2.5.2 Decision-making: Measuring Man

Physiological metrology and standardization have received renewed attention in recent years in the context of the emergence of multimodal biometrics systems gathering data from different sensors and contexts, for instance in telebiometry [28, 29, 30] with applications in for instance regulation to protect health and safety in these areas.

Similarly, in healthcare, new measurement techniques in connection with diagnosis and treatment of patients present metrological challenges in terms of for instance controlling exposure levels with respect to specification limits close to fMRI instrumentation [3] or in brachytherapy studied in a European Association of National Metrology Institutes (EURAMET) European Metrology Research Programme (EMRP) project. [32] Scans, such as shown in Fig. 11, are even being attempted to be interpreted as measures of human perception and behavior, such as in lie detection. The importance of correct decisions of compliance in such cases is obvious.

A final MINET Think Tank D event [9] took place at Wageningen, Netherlands, 13th May 2009, under the title: "Decision-making & Impact Assessment" and debating the questions:

(I) "How can decisions be made based on Perceptual Measurements?"
(II) "What are the impacts?"

The event included breakout discussions amongst the participants, debating questions such as:

I. How does measurement uncertainty, according to the GUM [33] for example, enter into making decisions based on measurements? Is it possible to make decisions based on measurements that are not accompanied with uncertainty statements?

II. What role can a probabilistic approach play in decision making? For example, the probability that a certain smell is perceived as more annoying than another smell is 95 %.

III. Is there a way to make statements with a certain confidence based on measurements? For example, we are 99 % confident that a statement is valid and thus we can make a specific decision.

IV. Apart from percent probabilities, are there other measures (economic, impact, risk, etc.) of the significance and consequences of decisions based on measurement?

V. Can the expected impact of decisions be used together with measurement uncertainty in order to make "optimal" decisions?

The MINET Think Tank D event also had introductory and case study lectures:

- "Science versus Justice: The case of Lucia de B" by Prof. Richard Gill, Mathematical Institute, Leiden University, Netherlands.
- "Probabilistic health impact assessment for decisions on food safety" by Hilko van der Voet, Wageningen UR, Netherlands.

3. MINET Newsletters and Databases

The official MINET project website [2] is intended not only to represent the MINET project, but also acts as a portal for all the EU NEST Measuring the Impossible projects [1], enabling visitors to access the individual projects websites from one website and thus providing a coherent presence and a virtual core for the MINET community. The website provides up-to-date information on all MINET events, activities and publications (e.g., workshops, think tanks and newsletters) and facilitates interactive discussions via a 'blog' resource. It also includes a private members' area for the extended MINET community (i.e., those who have registered on the e-MINET database – see below), providing exclusive access to additional information such as the presentations given at MINET events, including the training course.

Newsletters are published every six months and distributed electronically to all members of the MtI projects and the e-MINET community, as well as being available on the MINET website. The newsletters serve not only to introduce readers to the MINET project and the Measuring the Impossible research area, but also provide information and feedback on all MINET–coordinated events and activities. Researchers involved in MtI projects also have the opportunity to disseminate their project news in a dedicated section of the newsletter. The newsletters are therefore an important dissemination tool for the MINET project, enabling regular contact with all those interested in the Measuring the Impossible area.

cMINET is a database of core Measuring the Impossible (MtI) project partners, i.e., partners in EC funded research programs in the field of measurement of characteristics related to human perception and interpretation. It includes information on scientists and their institutions and the research field they are active or interested in. This database of contacts has been set up for the registration of interest by researchers, individuals from funding organisations, the European Commission and others.

eMINET is a second database for its part dedicated to a network which brings together people who have an interest in the Measuring the Impossible field. MtI researchers are from all fields that may have beneficial inputs to MtI research and includes researchers from many different scientific disciplines, ranging from psychology through metrology to social science. The aim of the database is to meet the needs of the broader public as well as help researchers searching for partners for future projects or experts in certain MtI fields. The benefits from joining the eMINET network include:

- Access to a network of contacts with an interest in developing the MtI field;
- Announcements of and participation in MINET network events such as workshops and think tanks, where cross-disciplinary discussions, sharing of expertise and development of best practice take place;
- Access to the "Members only" area of the MINET website, which contains presentations from previous MINET events and other useful information not available to

non-members and potential for developing new research projects falling outside of traditional disciplines and new cross-disciplinary collaborations.

The eMINET data base is designed as an on-line search engine of catalogue-type with a data input site. Coordinators grant new entries. Registration can be made at: www.measuringimpossible.net.

4. Conclusions and Future Work

On two occasions recently [3, 34], questions have been raised about the future of research and development in this field of Measuring with Persons. Here we give some responses to these questions as a way of summarizing this paper and the current MINET project.

4.1 Decision-making and Impact Assessment

What are the potential benefits of research in MtI, for society, business, industry, the scientific community, etc?

Are there, or will be there regulatory requirements? Are these requirements properly addressing the measurement issues?

Is the area sufficiently covered by standards or are standards in preparation?

- Decisions about health, safety, well-being and the environment are increasingly based on psychophysical, mental and behavioral processes in addition to traditional physiological measures. For example, aircraft noise is judged not merely on the decibel level but more importantly the disturbance level for school children.
- In an increasing number of regulatory fields, traditional physiologically-based regulations are now adding human factors such as cognitive ability
- International standardization includes psychology

What are the barriers to achievement of these benefits?

An interdisciplinary forum which attempts to unite physicists, metrologists, physiologists, psychophysicists, psychologists and sociologists needs to be maintained beyond the present project.

4.2 Measurement Traceability and Uncertainty

Can the measurands be quantified using a biological function and a SI unit, or what other approaches could provide traceability to the SI?

- The field is relatively underdeveloped metrologically, despite increasing needs in many critical areas of application, including health & safety.
- Development needed broadly of reference materials for tactile, visual, olfactory, etc., measurements based on physically existing standards, and/or 'kinds of property,' e.g., comfort, naturalness, etc.
- Measurands are referred to diverse measurement scales such as the ordinal or where measurements are qualitative and/or multivariate. Guidance beyond the existing GUM is needed about evaluation of measurement uncertainty.

4.3 Measurement Techniques

Are there validated methods of measurements available?

What specific developments in measurement instrumentation, techniques, protocols etc. are required in order to achieve these research objectives?

- The field is experiencing a rapid development of measurement technology (EEG, ECG, EMG, MEG, fMRI, electrodermal activity, respiration, eye movement tracking, pattern recognition, computer vision, thermography…).
- Recent research in intelligent instrumentation is leading to devices, employing neural networks, for example, which possess several sensory abilities resembling human sensing.
- Methods of metrologically validating measurement techniques and methods in this rapidly developing field remain in their infancy in many cases.

4.4 Measurement Concepts & Terminology

What are the quantities that need to be measured?

- Importance of psychophysical, mental and behavioral processes in determining physiological responses to all kinds of stimuli and all human senses.
- Psychophysical, mental and behavioral processes are known to affect significantly the human response to various stimuli, making purely physiological reactions highly variable in some cases.

Is there agreement on the definition of the measurands?

- Need to harmonize amongst physicists, medical staff, metrologists, physiologists, psychophysicists, psychologists and sociologists to achieve consensus about 'generic' metrological issues:
  - (a) Measurement Concepts & Terminology
  - (b) Measurement Techniques
  - (c) Measurement Uncertainty
  - (d) Decision-making & Impact Assessment

The unique mix in the EU network MINET of physicists, metrologists, medical scientists, neurologists, and scientists from psychology and sociology has achieved some consensus on fundamental aspects of metrology in the field of perceptive measurement. Now new research constellations and project proposals are being formulated for the future in this new area of metrology.

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