Modularized Applications with Smartphones and Smartpads in Shape, Color and Spectral Measurements for Industry, Biology, Medicine, Science, Education and Training

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Abstract. Aim of the paper is the demonstration of a paradigm shift in shape, color and spectral measurements in industry, biology and medicine as well as in measurement science, education and training. Laboratory applications will be supplemented and replaced by innovative in-field and point-of-care applications. Innovative functional modules are smartphones and/or smartpads supplemented by additional hardware apps and software apps. Specific examples are given for numerous practical applications concerning optodigital methods. The methodological classification distinguishes between different levels for combinations of hardware apps (hwapps) and software apps (swapps) with smartphones and/or smartpads. These methods are fundamental enablers for the transformation from conventional stationary working places in industry, biology, medicine, science, education and training towards innovative mobile working places with in-field and point-of-care characteristics. The innovative approach opens so far untapped enormous markets for measurements in industry, biology and medicine as well as in science, education and training. These working conditions will be very common due to their convenience, reliability and affordability. The fundamental enablers are smartphones and/or smartpads. A highly visible advantage of smartphones and/or smartpads is the huge number of their distribution, their worldwide connectivity via cloud services and the experienced capabilities of their users for practical operations. Young people are becoming the pioneers.

1. Mobilization of Computers
The computer market is changing. Miniaturization and mass production are in progress. The special advantages of smartphones and/or smartpads are their mobility and their multitouch user interfaces. Market leaders are Apple with iOS operation system and Google with Android operation system. Microsoft with Windows 8 operation system is a late but powerful and experienced follower (Fig. 1-01). Windows 8 smartphones and/or smartpads combine the typical Windows working style with the leisure look and feel of iOS and Android life style (Fig. 1-02). The innovative computers are equipped with consumerized interfaces for wired and/or wireless communications (Fig. 1-03). Smartphones and/or smartpads are additional equipped with powerful internal hardware apps for image acquisitions that are light sources, cameras, camcorders and scanners and with software apps for image processings.
Smartphones and smartpads are mobile because they are light weight and battery powered. In addition, the number, quality and diversity of external hardware apps for smartphones and/or smartpads are increasing. In the next chapters selected examples will be given for optodigital hardware apps and digital software apps which are already on the market. They are applicable for industrial, biological and medical diagnostics as well as for scientific investigations or mobile education and training purposes.

The Ozcan Group at the University of California, Los Angeles (UCLA) is working since years successfully on this topic. The research results were recently summarized in a very informative overview [1]. A fundamental purpose of the present paper is to show that many innovative mobile smart solutions can be designed with already existing functional modules according to the LEGO principle. Due to standardized operation systems (see Fig. 1-01 and Fig 1-02) and standardized interfaces (see Fig 1-03) the existing hardware modules and software modules must not be modified in their original structure and functionality [2]-[4]. The disadvantage of multi-hybrid solutions can sometimes be that they are more complex and also more complicated in its structures and in its functions as specialized solutions. But the advantage of these multi-hybrid solutions is that they are available quickly, because they are composed of commercially available components.

2. Mobile Smart Optodigital Hardware and Software Apps for Shape Measurements
Shape measurements are the analysis of geometric shapes in 1, 2, 2.5 and 3 dimensions. Typical optodigital hardware apps are cameras and microscopes preferably with USB-interfaces (Fig. 2-01). Very numerous software packages for image processing [5] are considered software apps. Normally the real objects are compared with fundamental master objects in algorithms or data bases. Most commonly the boundary representations are used. Once the objects are represented by extracting the shapes from images of the object, the data clouds have to be simplified before a comparison with standardized masters can be achieved. The simplified representation is often called a shape descriptor (or fingerprint, or signature) of the real object. The simplified representations try to carry most of the important information, while being easier to handle, to store and to compare than the shapes directly [6].
3. Mobile Smart Optodigital Hardware and Software Apps for Color Measurements

Color measurements are the analysis of light and body colors near to the human color perception. Typical optodigital hardware apps are color sensors preferably with USB interfaces (Fig 3-01). With colorimeters an unknown color is evaluated in terms of known colors near to a standardized human color perception. Color measurements are of great importance for the analysis of raw materials and finished products in industry. Color measurements are also critical in biology and medicine. For color measurements the quantification of colors is based on the three-component theory of true color vision. It states that the human eye possesses receptors for three primary colors red, green and blue. All colors are seen by human as mixtures of these primaries. In colorimetry, these components are referred to as X-Y-Z coordinates. Colorimeters, based on this theory of color perception, employ three optosensors as receptors to see colors in much the same way as the human eyes (Fig 3-01) [7].

4. Mobile Smart Optodigital Hardware and Software Apps for Spectral Measurements

Spectral measurements are the analysis of unknown spectra in comparison with evaluated terms of known spectra. Typical optodigital hardware apps are spectrometers preferably with USB interfaces (Fig. 4-01). With spectrometers an unknown spectrum is evaluated in terms of known spectra concerning its wavelengths and amplitudes. Spectral diagnostics is of great importance in chemical industry as well as in biology and medicine. Real objects are becoming visible by emitting or reflecting photons. The wavelengths of these photons depend on the object's composition, along with other attributes such as temperature. The human eyes perceive the presence and absence of photons with different wavelengths as different colors. For example, photons with a wavelength of 620 to 750 nanometers are perceived as red. An object that primarily emits or reflects photons in that range looks red [8].
5. Modularized Mobile Smart Applications for Shape, Color and Spectral Diagnostics

Modularized mobile smart applications are realizable by the combination of the contents of chapter 1, 2, 3 and 4 (Fig 5-01, Fig 5-02 and Fig 5-03). It is of great methodical importance that modularized mobile smart solutions are harmonizing the present barriers between industry, biology and medicine.

6. An example application for mobile smart biomedical diagnostics

The actual challenges for biomedical diagnostics lie primarily in creating miniaturized systems in which the presence of low concentrations of target biomarkers can be reliably detected in small volumes of biological samples. The multi hybrid combination of common mobile smart instruments like smartphones and smartpads with microfluidic analytical chips will lead to a new class of in-field or point-of-care diagnostic systems. The availability and advantages of diagnostic instruments with commercial smart phones and/or smartpads combined with commercial microscopic hardware and software apps and combined with commercial miniaturized microfluidic chips generate awareness on the public market for mobile smart POC systems [9], [10]. An example application for this combination was developed for different immunological assays like Francisella tularensis as pathogen detection example and Borrelia burgdorferi as diagnostic example [11]. The setup of the analytical diagnostic
instrument contains three components: A smartphone iPhone 4S from Apple, a microscope adapter with software from FotoFinder Systems (see Fig. 2-01) and a microfluidic chip from microfluidic ChipShop (Fig. 6-01). The microscope adapter developed by FotoFinder Systems is a hardware app which uses an optical lens setup to realize a 20x focusing of the already integrated camera inside the smartphone combined with a software app for image analysis and processing. Around this setup another hardware setting was realized to introduce the microfluidic chip aligned to the optical setup (Fig. 6-02).

![Fig. 6-01 Smartphone with modular adapter and a microfluidic chip](image1)

![Fig. 6-02 Colorimetric immunological diagnostics](image2)

7. **An example application for mobile smart education and training materials**

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![Fig. 7-01 Imaging & Vision Handbook - front cover](image3)

![Fig. 7-02 Imaging & Vision Handbook - back cover](image4)

ISBN 978-3-00-039674.8

An optodigital version of the handbook is available via www.stemmer-imaging.de
8. Conclusions
Smartphones and Smartpads became global mass products with great convenience, high reliability and affordable prices. These market developments enable a paradigm shift in industrial, biological and medical measurements and diagnostics. With modular hardware apps and software apps new classes of hybrid instruments can be created. Modular hardware apps and software apps are reducing development time, cost & risk. Smartphones & smartpads are revolutionary game changers in lifestyle and workstyle. Miniaturization & consumerization inspire each other with increasing speed. Field instrumentations will be based on re-invented laboratory instrumentations. First steps on innovative routes are already gone successfully. An interesting convergence of measurements and diagnostics in industry, biology and medicine can be expected.

9. Sources
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