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SMARTPHONES – SMART EATING?

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Abstract: *Currently, all around us, smartphones have become ubiquitous. One obvious question is if and how such devices could help us get healthier eating habits? The answer, based on novel technologies (e.g., advanced sensing and signal processing), is that smartphones or tablets can very easily help us check not only food quantity intake, but also food quality (e.g., freshness, chemical compounds, etc.). In this paper we will briefly survey various techniques allowing us to analyse food quality using these devices. We will start by firstly enumerating the main components of mobile cameras and sensors. Afterwards, we will briefly review nutrition analysis software. Towards the end, we will stress the importance high-performance image recognition techniques play for reaching a compelling answer to our question if we are eating smart or not yet?*

Keywords: Smartphones, Food analysis, Nutrition applications.

INTRODUCTION

Clearly, food is an absolutely essential element for life, while lately people have started to pay special attention not only to quantity (how many calories are we supposed to eat daily to have and maintain a healthy weight/diet), but also quality (new and various food storage and processing methods raise questions pertaining to their advantages and disadvantages for our health).

Today, technologies play a key role in our everyday lives as we are relying on plenty of new and smart devices. It was estimated in 2020 that worldwide there are around 3.5 billion smartphones and 1.6 billion tablets, and that these numbers are only going to follow an increasing trend [Home page of BankMyCell].

An informal definition is that a smartphone is *"a mobile phone with highly advanced features."* The main characteristics of a smartphone are: high-resolution touch screen display, WiFi connectivity, web browsing capabilities, and the ability to run sophisticated applications. The majority of applications can run on different mobile operating systems (OS) like: Android, Symbian, iOS, BlackBerry and/or Windows [Home page of Technopedia].

One aspect of interest is that researchers have already determined various ways through which food compounds could be identified by using smartphones [Kawano et al. 2015; Akpa et al. 2017; Hernandez et al. 2017]. Lately, two approaches have gained traction (see Fig. 1):

- directly imaging a food plate (Fig. 1, right), using either ambient or the flash camera light [Gordon et al. 2019];
- relying on an external dedicated device (Fig. 1, left) [Home Page of SCIO Consumer Physics, Home page of Spectral Engines].

In this paper we will first of all focus on camera lenses and the associated electronics. Afterwards, we will discuss different food analyses applications. In the end we will review the major advantages and limitations offered by smart devices for food analysis.

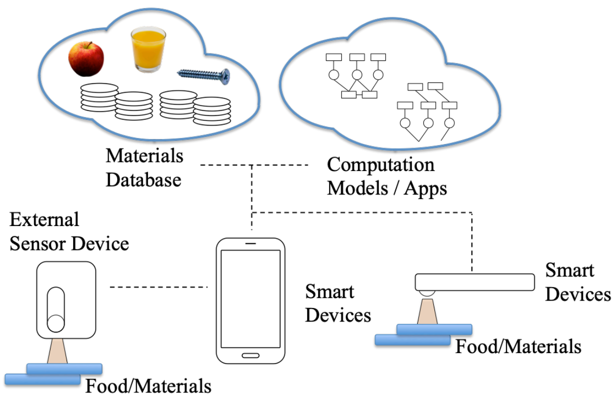

Fig. 1. Two general imaging schemes using smart phones for acquisition and data processing.

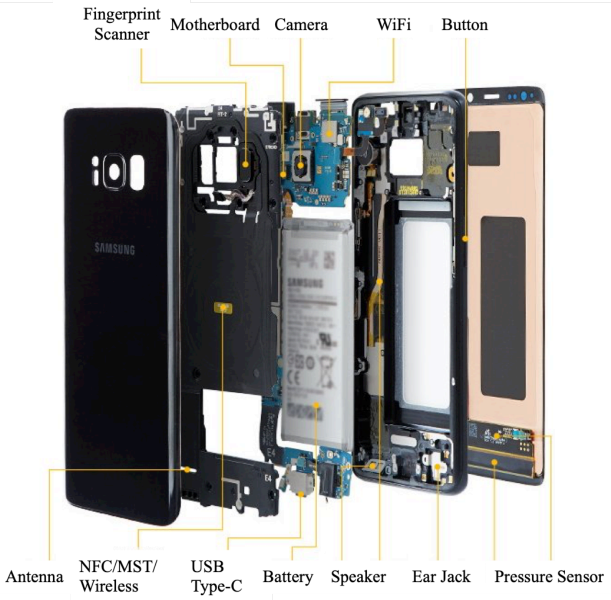

Fig. 2. Samsung Galaxy main components [Home page of Samsung]

MOBILE PHONE DEVICES

The components of a generic smartphone are: motherboard, display, camera, sensors, as well as battery (Fig. 2). The camera is a module for taking images/frames using a photographic objective. There are three main types of photographic objective: fixed focus, autofocus (AF), and optical zoom. Fig. 3 shows the most important parts of a camera: AF motor, optical system, and image sensor.

All optical systems have aberrations [Steinich et al. 2012; Chen et al. 2016], which can be classified into:

- monochromatic (e.g., spherical, coma, astigmatism, field curvature);
- chromatic – spherical and coma aberrations (as light of different wavelengths generates different focal points).

By carefully crafting optical systems (and the associated image processing software packages)

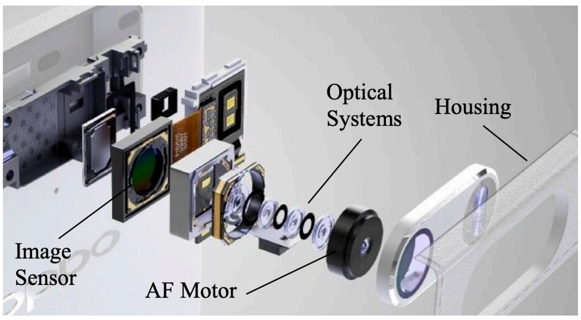

Fig. 3. OppoN3 camera main components [Home page of Oppo-N3]

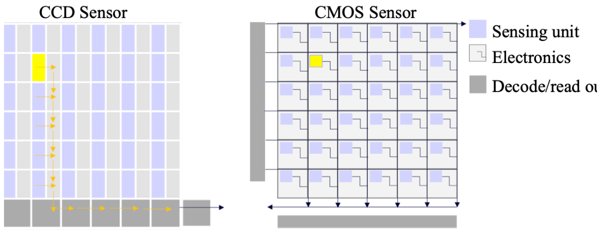

Fig. 4. Comparison of the photo sensing area sizes for a CCD vs. CMOS sensor.

designers can reduce, or even eliminate, some of these aberrations [Liu et al. 2017; Zhao et al. 2019]. In fact, over the years, the lens designs have evolved starting from the simple double Gauss lens to multiple aspheric lens elements. The latest versions of smartphone cameras customary incorporate plenty of aberration corrections needed for (ultra) high quality images [Peltoketo et al. 2016; Gordon et al. 2019], as well as software for compressing and transferring them for further post-processing.

IMAGE SENSOR

Another very important component of a camera is the image sensor (Fig. 4). There are two types:

- charge-coupled device (CCD); and
- complementary metal-oxide semiconductor (CMOS) [A Konika Company, 2019].

From Fig. 4 it can be seen that the sensing area is larger for CCD than for CMOS sensors. As a consequence (see comparison in Table 1) the power consumption is quite different: a CCD sensor consumes as much as 100 × more than a CMOS one [Cevik et al. 2015].

Obviously, people are mainly interested by image resolution (total number of pixels). As can be seen from Fig. 5, the number of pixels has been exponentially growing over the years. This aspect is of major importance from the image analysis point of view, as more pixels (more information) lead to much sharper understandings, but are computationally demanding. By incorporating additional light sources (like, e.g., IR and/or UV) [Wilkes et al.

Table 1. CCD vs CMOS sensors

	CCD	CMOS
Noise	Low	High
Light sensitivity	High	Low
Power consumption	High	Low
Price	Expensive	Cheap

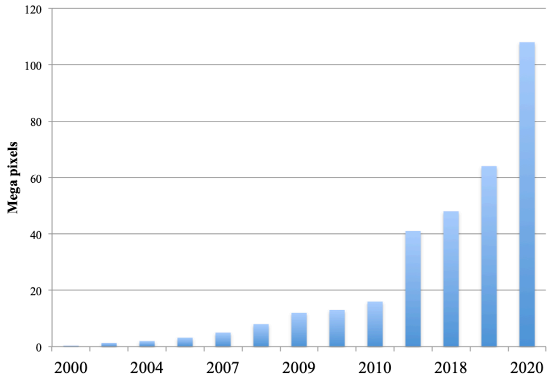

Fig. 5. Number of pixels on phone image sensors.

2016; Kheireddine et al. 2019], or by connecting to external dedicated devices [Home page of SCIO, Home page of Spectral Engines] and specific apps, a smartphone could eventually behave like a lab-on-a-chip. Relying on a high quality image (of the food under test), not only optically but also properly processed digitally, one could not only store the information, but also analyse it through various software [Yetisen et al. 2014; Zhang et al. 2015; Stanco et al. 2016; Min et al. 2019] for obtaining nutrient information.

NUTRIENT ANALYSIS

A wide range of nutrition applications were developed over the last decade aiming to enable the user to describe a meal and assess its content. The majority of such applications rely on *a nutrient database* for generating *a nutrient analysis report*, and compare this to the users' nutritional particular needs and special requirements. Also, most of the nutrition applications can be tailored to different needs and goals (of the end-user) providing:

- diet assessment;
- meal plans, recipe creation/selection;
- progress tracking;
- prenatal, paediatric nutrition;
- sports nutrition, etc.

The diversity and complexity of such nutrition applications expands further, with custom versions dedicated to:

- food producers and suppliers;
- food service providers;
- academics and researchers.

Such custom versions have evolved into interdisciplinary tools for product cost analysis, food labelling, recipe analysis and reformulation, new product development, instant food diary import, and goal and task management, which have to adapt to changing requirements of legislations and more. Such diversity speaks for itself for the advantages nutrient applications provide for both individual users and food related businesses (see Table 2).

Table 2. Types of nutrition software applications

Online & offline applications	**Dietary analysis services**
Aliment Plus http://alimentplus.com/	Nutmeg Nutrition Consultancy http://www.nutmeg.com
Nutrition Systems Diet Sure www.dietsure.com	KelicompCRISp www.kelicomp.co.uk
Nutrition Systems CompEat Pro http://www.compeat.co.uk/	Nutricalc http://www.nutricalc.co.uk/
Nutrition Data www.nutritiondata.com	Catering for Schools www.catering4schools.com
Nutritics www.nutritics.com	Saffron https://fdhospitality.com/advice/business-challenge-nutritional-analysis/

Depending on the complexity, the accuracy, the quality of its data and customer service, and the degree of user-friendliness and intuitiveness, nutrition applications vary greatly in terms of costs (from freely downloadable for individual usage, to subscription based for professionals and businesses).

All of these nutrient applications can be downloaded and run on smart phones. For example, the nutrition tool MUSE Food is explained in [Gao et al. 2019]. This application can identify contours of food shapes by an improved image segmentation algorithm. In that paper, the following steps for gaining information about the food one is interested to evaluate/test are suggested:

- *sensing* by taking several images;
- *aggregation of data* which merges those images through several databases;
- *echo ranging* for estimating the food depth; and
- *segmenting* all the information gathered (using fully convolutional networks).

FOOD COMPOSITION AND ENERGY VALUE

In order to be able to make informed nutritional recommendations that quantitatively and qualitatively optimise the food intake, it is necessary to match the personal energy requirements to foods which could provide it. This correlation of energy requirements with energy intake depends intimately on detailed knowledge of the amounts of macronutrients (carbohydrates, lipids, proteins). There are multiple methods for analysing macronutrients. Once those are determined, food energy conversion factors can be used to analytically make accurate estimates. Most common methods are based on:

- *Protein analysis* – Kjeldahl method to determine nitrogen content, taking into account the average nitrogen content of proteins (of about 16%);
- *Crude fat s*tudy (includes phospholipids and wax esters) – gravimetric methods (AOAC approved);
- Total carbohydrate content estimated *indirectly* (all other constituents of food – protein, fat, water, alcohol, ash – are estimated individually, summed, and finally subtracted from the food total weight to determine the carbohydrate content);
- Total carbohydrate content estimated by *direct analysis* (weight measuring);
- The *total combustible energy content* of a food can be measured using bomb calorimeters.

For expressing energy of foods, both Joules (kJ) and calories (kcal) are used by most international food standards and energy values. Stakeholders (nutrition scientists, public health professionals, policymakers, regulators, consumers, and industry) accept and support harmonization of the different food standards [Home page of Codex Alimentarius, Home page of FAO Report]. Currently, there are several food composition databases associated to a specific market which include a large portion of food products (e.g., United States Department of Agriculture USDA database).

In general, any parameter under measurments is characterized by two values: a *measurement value* and its *standard deviation.* Regarding nutrients, most often, standard deviation is zero, which means that the measurement value was provided by the producer without any testing by a third party laboratory. For food produced on a large scale (bulk products), e.g., oils, sugar, biscuits, etc., measurement values are reasonably precise (see Table 3). For unprocessed foods, e.g., raw fruits and vegetables, nutrient values are highly variable, depending on variety, degree of ripeness, agro-technical conditions, etc. [Buisson, 2008].

Table 3. Nutrient database.

Database	Web addresses
McCance & Widdowson's Composition of Foods Integrated Dataset	http://www.fao.org/uploads/media/British_FCDB_cof_user_doc.pdf
USDA database	https://fdc.nal.usda.gov/
The Swiss Food Composition Database	https://naehrwertdaten.ch/en/

In general, a higher accuracy of the measurements of nutrients can be achieved by using methods, like, e.g., mass spectrometry, infrared spectroscopy, Raman spectroscopy, or spatially offset Raman spectroscopy [Odion et al. 2019; Pino 2019]. Such methods can obviously provide very precise information on nutrients and food components, but are time-consuming, and can be performed only in specialized laboratories.

CONCLUSIONS

One worrying issue revealed by the World Health Organization pertains to the fact that the overweight and obese population has *"tripled since 1975"* [Home page of World Health Organisation; Spinelli et al. 2019]. In support of this view, the World Obesity Federation has stated that *"obesity is a chronic, relapsing, progressive disease process and emphasises the need for intermediate action and the prevention and control of this global epidemic."* It becomes clear that we should check our weight regularly [Swinburn, 2011; Nyström et al. 2017; Baumann et al. 2019].

In this paper we briefly went over methods which would allow us to detect, estimate and analyse the nutrients found in our daily food intake, methods making use of apps running on smartphones. The interest on this topic is substantiated by:

- the development of novel sensing mechanisms [Rateni et al. 2017; Bobrinetskiy et al. 2018; Gao et al. 2019];
- an increasing number of papers being published on this topic [Ross et al. 2018; Ahn et al. 2019, Mandracchia et al. 2019];
- a larger number of companies developing software tools [Ferrara et al. 2019].

On one hand, such systems do have certain limitations: still incomplete food databases, dependence on cloud/internet, and, most importantly, low accuracy measurements of the compounds and nutrients densities [Ahn et al. 2019, Trijsburg et al. 2020].

On the other hand, latest discoveries in optics, electronics, and computer science, as well as the new IoT, should be used advantageously to improve lifestyles [Ellis et al. 2015; Ambrosini et al. 2018]. Besides making simple calls, video calls, messaging and surfing – hence using our smartphones as computers – it is compulsory that we understand and take advantage of the yet unearthed opportunities they allow, e.g., helping us adjust to smarter eating habits.

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