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DELIVERABLE

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Deliverable Leader:	Susanne Hintschich (IPMS)
Contributors:	Optics: Jens Knobbe (IPMS), Peter Reinig (IPMS), Hans-Georg Dallmann (IPMS), Tino Pügner (IPMS), Mario Grafe (IPMS), Annamaria Gerardino (CNR), Francesca Bertani (CNR) Electronics: Paraskevas Bourgos (WINGS), Konstantinos Tsoumanis (WINGS), Panagiotis Vlacheas (WINGS), Orestis Liakopoulos (WINGS), Ioannis Stenos (WINGS), Nelly Giannopoulou (WINGS), Kostas Tsagkaris (WINGS), Vera Stavroulaki (WINGS), Dimitris Kelaidonis (WINGS), Konstantinos Petsas (WINGS)
Reviewers:	E. Martinelli (UTOV), G. Nychas (AUA)
Approved by:	P. Bourgos (WINGS), A. Gerardino (CNR), G. Koutalieris (INTRA)

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Executive Summary

Within the PhasmaFOOD project, a comprehensive sensing system will be created. This sensing system comprises the actual sensors and light sources, the electronics with which they are controlled, the mechanical housing for the aforementioned components, a mobile phone with functionalities for data processing and user interaction, as well as a cloud based database. The specifications of these system parts are laid down in Deliverable Report D1.2 (1). They were derived mainly from the requirements set out in Deliverable Report D1.1 (2), which states the Use Cases against which the system shall be tested in subsequent Work Packages.

This Deliverable Report D2.2 documents the design process of the sensing components of the PhasmaFOOD system and the progress on Tasks T2.1 and T2.3. These tasks implement the specifications of the subsystems of the PhasmaFOOD smart sensing system as laid out in Deliverable Report D1.2: A) The sensing subsystem comprising optical components, light sources and raw sensors and B) the electronical subsystem comprising electronic cards as well as electronic interfaces to the sensing subsystem and to the mobile user device. Beyond that, further system components consist mainly in the form of software, which is to run on a smart phone and on a cloud-based infrastructure. These are described elsewhere: The recent Deliverable Report D2.1 (3) elaborates on the specifications for software to control the sensors, interact with users and analyse data. In close collaboration with these activities, the system design of the sensing subsystem and electronics subsystem has progressed.

Within Task T2.1, based on the system specifications of D1.2, we evaluated and selected the three sensors, namely the UV-vis spectrometer, the NIR spectrometer and the board-level vis camera. Next, appropriate light sources for all three sensors were identified and a common lighting and sensing concept was derived for the integrated sensing system. Several versions of this concept were discussed with respect to their stability of measurement, light throughput, size and further parameters, which were previously specified in Deliverable Report D1.2. All of these versions make use of the optical transflection geometry as laid out in D1.2. The concept we finally selected consists of interchangeable modules held in a single housing. This approach has the benefit of a maximal light throughput, which is decisive for the realization of Use Case 1. Furthermore, it will allow design variations on the shortest possible time scale during the second design iteration in Year 2 of the PhasmaFOOD project. This modular optics concept was then translated into an optical design of the sensing frontend of the PhasmaFOOD system.

With the help of the optics design software ZEMAX (4), we first implemented the optical parameters of the required light sources and the selected sensors on a component-wise basis before integrating them into a unified design. The details and drawings of the design are given here in Annex I, which is confidential. ZEMAX designs can easily be exported to any CAD software in order to produce the mechanical design of the hardware inside which the sensors and light sources will be mounted. While this mechanical design will be documented in

Deliverable Report D2.3 and D2.4, we considered issues of manufacturability already during optics design. Particular attention was paid to the very compact size of the integrated system, which poses challenges to the system assembly as this must be done manually. Also, the interface between the sensing frontend and the sample (food) was investigated and several variants are proposed how to organize this interface in order to cater for the sensing needs of all three Use Cases and, additionally, for instrument referencing. As with the optical design, we selected a modular approach where the sample interface can be interchanged. That way, we are best prepared for the requirements of the three Use Cases.

A special issue discussed within PhasmaFOOD is the measurement of packaged food. Here in principle, the coupling of light into and out from packaged food is possible with the chosen optics design version (as well as with any other) as long as the package is reasonably transparent at the wavelength of interest. It will be a matter of testing samples and analyzing measured data in order to determine whether such measurements produce meaningful data and can be integrated into robust calibrations. This is one aspect of the test and validation work planned for the subsequent Work Packages 3 and 5. In summary, Task T2.1 produced an optics design of the sensing frontend, which can be directly used for the mechanics design of the system housing in Task T2.4.

Within Task T2.3, the electronics subsystem is being developed, based on the requirements of the components of the sensing subsystem, the functional requirements of the overall PhasmaFOOD system as laid out in D1.2, and the detailed software specifications recently fixed in Deliverable Report D2.1. We will present here the current status of the ongoing work, which will receive its final documentation in Deliverable Report D2.3. The first important decision was to separate electronics components into sensor-near electronics, used to drive the components of the sensing subsystem, and an electronics main board, to unite data streams, do a first pre-processing and communicate with the mobile application. The former remain close to the sensors and light sources in order to minimize noise during sensor readout and reduce interactions between sensors. Therefore, they will be mechanically integrated into the sensing subsystem. The characteristics of the individual boards and their interfaces to the main board are described here. The main electronics board is currently under development, in order to implement the specifications of D2.1. Therefore, we will only provide a brief overview here and instead refer to the full documentation, which will be part of Deliverable Report D2.3.

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Definitions, Acronyms and Abbreviations

Acronym	Title
AES	Advanced Encryption Standard
AF	aflatoxin
API	Application Programming Interface
CMOS	complementary metal-oxide semiconductor
CO	Confidential, only for members of the consortium (including Commission Services)
D	Demonstrator
DB	Database
DL	Deliverable Leader
DON	deoxynivalenol
Dx.x	Deliverable (where x defines the deliverable identification number e.g. D1.1.1)
EU	European Union
LOD	Limit of Detection
MEMS	Micro-Electromechanical Systems
MRL	maximum residue limit
NIR	Near Infrared
PU	Public
R	Report
SW	Software
URI	Uniform Resource Identifier
UV	Ultraviolet
VIS	Visible
WP	Work Package

1 Overview

The PhasmaFOOD smart sensing system consists of four major sub-systems, as described in Deliverable Report D1.2 (1):

I. The PhasmaFOOD sensing sub-unit comprising a UV-VIS and a NIR spectrometer as well as a CMOS camera, light sources, electronic boards to drive these sensors and light sources, an electronic interface to read out sensor data to the electronics sub-unit.

II. An electronics sub-unit, equipped with electronic interfaces (hardware connectors and embedded software) suitable to read sensor data from the sensing sub-unit and to send/receive data from a mobile user application (smart phone), as well as a power supply and further components as detailed in D1.2.

III. PhasmaFOOD cloud platform with database, data analysis and machine learning algorithms, dashboard for system calibration and set of APIs for interfacing with the mobile apps, portable sensing device and 3rd party services.

IV. IV. PhasmaFOOD mobile applications (iOS and Android) to be used as the main interface towards the end user and provide a communication channel between the portable sensing device and the cloud platform.

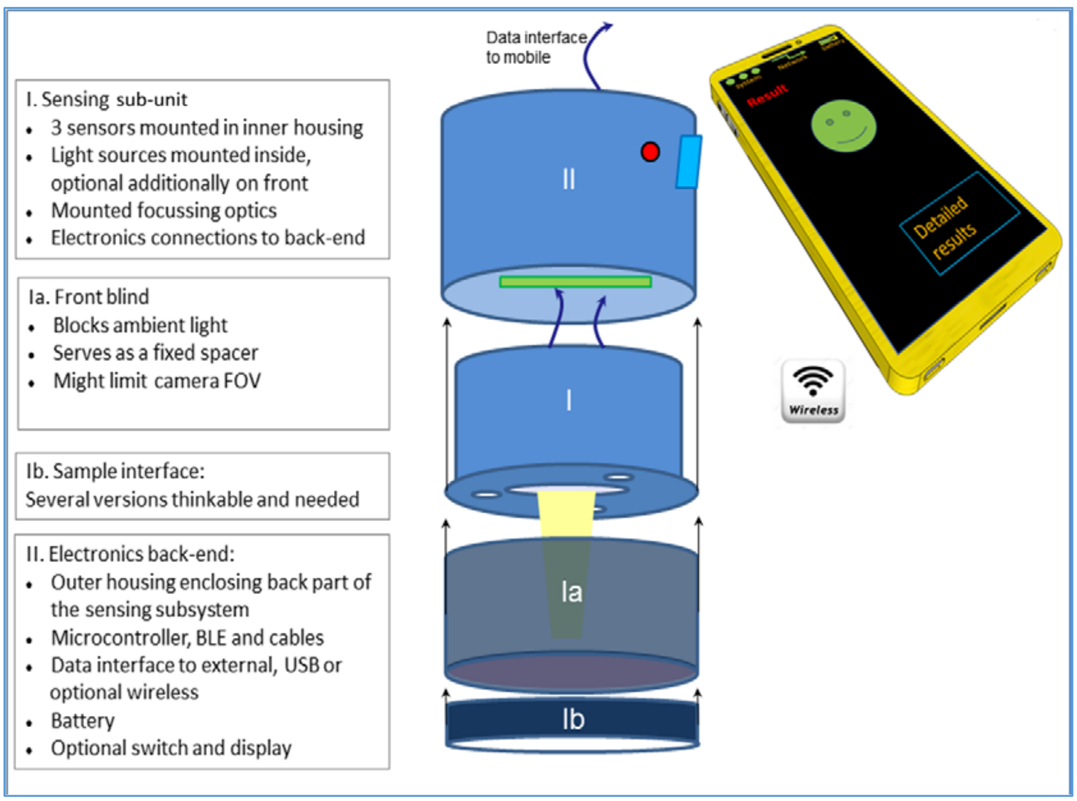


Figure 1 – Schematic of the sub-systems of the PhasmaFOOD smart sensing system, taken from D1.2 (1).

Figure 1 shows the status of the system development at the time of completion of the system specification. The sensing and electronics sub-units are depicted schematically. As mentioned above, the mobile application and cloud platform sub-units are mainly software-related components. Their design concepts and hardware specifications are described in Deliverable Report D2.1 (3) and will not be addressed here for the sake of avoiding duplicate documentation. The present report will instead focus on documenting the design of the actual sensing device, which is the result of Tasks T2.1 and T2.3 (5).

Within Work Package 2, the above schematic idea is developed into realizable plans and designs. Concerning the sensing sub-unit, this is a completed process. With respect to the electronics sub-unit, the development is currently in progress in order to implement the conceptual information of D2.1 into an electronics board design.

2 Design of the Sensing Sub-Unit

2.1 Design principles of the sensing sub-unit

The general principles of designing the sensing sub-unit have been agreed upon by the consortium in D1.2 (1). They primarily originate from the desired functionality of the system, which in turn is mainly based on the three Use Cases PhasmaFOOD intends to cover:

1. Mycotoxin detection
2. Spoilage detection
3. Fraud detection

In PhasmaFOOD, three sensing methods shall be used in order to facilitate the above detection scenarios for various foods. In particular, the sensors shall be used in conjunction such as to allow a meaningful fusion of data from a single sample:

A) VIS spectroscopy over the entire visible spectral range
B) NIR spectroscopy over the range from 1000 to 1900 nm
C) Imaging sensitive to the visible spectral range

The overall goal of the PhasmaFOOD project is the development of a portable device, which implies a compact optomechanical design and the use of miniature sensing components. Naturally, the sensitivity and stability of expensive bench-top lab equipment is not available here. Nevertheless, within the limitations of a portable detection system, optomechanical design must work towards a high sensitivity and reliable stability of the sensory measurements.

In particular, optimal use must be made of the available light. This principle also entails that components of the sensing sub-unit must exhibit a high optical and mechanical quality. Otherwise light is easily “lost” in absorption or scatter, due to poor choice of materials and coatings, or simply due to misalignment when mechanical tolerances cannot be guaranteed. By choosing suitable components, we provide the hardware basis for an optimal outcome of the functionality tests in Work Packages 3 and 6.

Within the PhasmaFOOD *project*, the main focus remains to demonstrate the feasibility of the three Use Cases with our combined sensing approach. In this respect, also the initial notion that the sensors can be used “as is” and mounted onto an electronics board is not feasible. Optimal use of the light can only be made and the required high sensitivity can only be obtained when each illumination and sensor component receives an appropriate optical interface and is mounted with a priority on optical requirements. Therefore, the sensing sub-unit will be large than originally expected. However, it must clearly fulfill the requirements of a small portable device as specified in D1.2. We aspire to make the optical interfaces as compact and manufacturable as possible without compromising functionality. The optical concept shown in Section 2.4.3 and the Optics design of Annex I is testimony to that ambition. While some of the sensing requirements may be relaxed later during productisation, when tests have revealed which issues are most critical, it is our primary task during the project to set a sound hardware fundament for the test experiments of the Use Cases.

Regarding the cost of the PhasmaFOOD device, high quality components are available for the prototype device at a reasonable cost. For a future commercialization, cheaper, lower quality alternatives are readily available for most off-the-shelf components. Moreover, optomechanical design will take into account the manufacturability of the custom-made hardware components, considering manufacturing techniques like 3D printing.

In accordance with the Description of Actions document (5), the PhasmaFOOD sensing device will undergo a design revision in Year 2. Therefore, it is worthwhile to equip the present, first design iteration with a sufficient degree of flexibility, which will allow an uncomplicated implementation of later changes. In particular, this applies to variables that will likely undergo optimization such as the intensity of the NIR and UV light on the sample. The following section describes the design process of the sensing sub-unit from the selection of the sensing components and lighting concept, to the final optics concept of the sensing sub-unit.

2.2 Choice of sensor components for the sensing subsystem

2.2.1 UV-VIS spectrometer

The fluorescence measurements planned in Use Case 1 (mycotoxin detection) rely on the availability of a highly sensitive spectroscopic detector in the visible spectral range >400 nm (1). While this is best achieved in the framework of a bench-top laboratory setup, PhasmaFOOD stands for other priorities, namely a portable multifunctional sensing device that works under standard ambient conditions such as the presence of daylight. Optical simulations can be employed to optimize the light input onto the food sample and the collection of fluorescence to the sensor, as shown in Annex I.

A highly sensitive UV-VIS or VIS spectrometer is required as the fluorescence sensor. Besides its sensitivity, the spectrometer should also be easy to integrate into the PhasmaFOOD sensing device, regarding both the size of the spectrometer component and the availability ofmechanical construction data. Several options are available on the market for miniature UV-VIS or VIS spectrometers, as shown in Table 1.

Table 1 – Choice of UV-VIS microspectrometers that may be suitable for integration into the PhasmaFOOD sensing device.

Manufacturer	**Ibsen** (6)	**Ocean Optics** (7)	**Hamamatsu** (8)	**Hamamatsu** (9)
Model	Freedom UV-VIS FSB101	STS VIS	C12880MA	C10988MA-01
Spectral range	190 – 850 nm	350 – 800 nm	340 – 850 nm	340 – 750 nm
Dimensions [mm³]	48 x 54 x 16	40 x 42 x 24	20.1 x 12.5 x 10.1	27.6 x 16.8 x 13
Sensitivity	Hamamatsu sensor alone: 1300 V/lux-sec (10)	6.74V/lux-sec typical (555nm) (7)	Hamamatsu sensor alone: 1300 V/lux-sec (10)	Hamamatsu sensor alone: 100–200 V/lux-sec (9)
Optical link	Fibre SMA	Fibre SMA	Open beam or fibre SMA	Open beam or fibre SMA
Electronic link	Pin connector	Wi-Fi, USB, Ethernet, Bluetooth	Pin connector	Pin connector

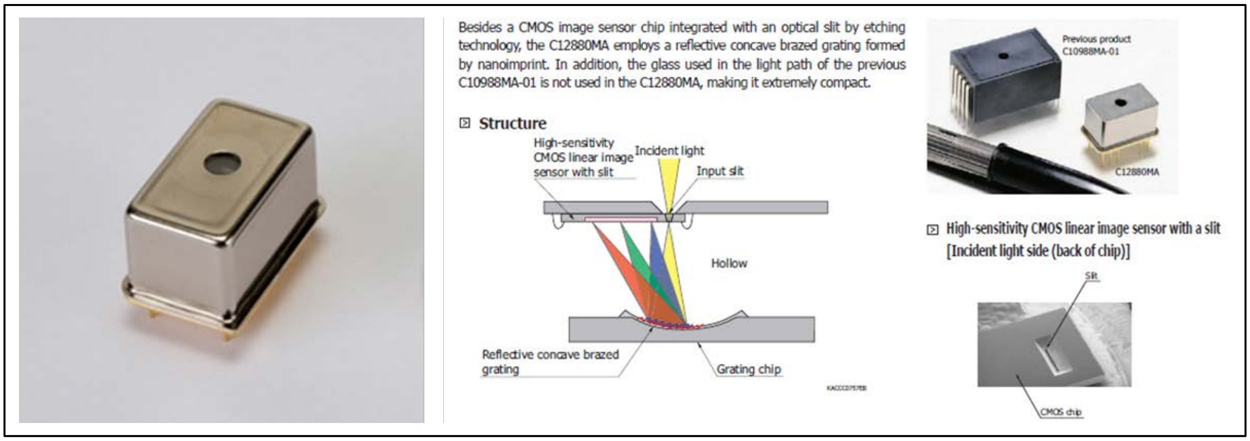


Figure 2 – The Hamamatsu C12880MA spectrometer. Left: Photograph. Centre: Optical setup. Right: Comparison to Hamamatsu C10988MA-01 and detail of the optical chip with input slit. Taken from (8).

From the number of manufacturers, in particular Hamamatsu spectrometers are interesting for our purpose, as this is the world leading manufacturer of CMOS sensors for optical detection. Other companies use Hamamatsu CMOS line sensors as the basis of their UV-VIS spectrometers. In addition, Hamamatsu offer their own range of microspectrometers with very small outer dimensions, high quality of housing and components, at affordable prices. Therefore, the two Hamamatsu spectrometers of Table 1 were compared in test measurements by PhasmaFOOD partner CNR. Finally, the Hamamatsu C12880MA microspectrometer was selected for integration into the PhasmaFOOD sensing device due to its superior optical sensitivity. It is available with an evaluation kit as well as the CAD construction files and opto-mechanical information needed for the integration design.

2.2.2 NIR spectrometer

Compared to VIS or UV-VIS spectrometer modules, true miniature NIR spectrometers are rare. However, research and development in this field is rapidly increasing in the context of the “Internet of Things” wave, which predicts a large and growing market for NIR applications in the agri-food sector. PhasmaFOOD and several other publicly funded research projects are part of this movement. Speed of development and accessibility of a suitable instrument are of critical importance in order to prevail in this market.

A miniature NIR spectrometer is directly available to the PhasmaFOOD project through partner Fraunhofer IPMS, who develops NIR spectrometers based on a MEMS scanning grating technology. While portable instruments are already on the market for over a decade (11), a miniature spectrometer is available at TRL6 from IPMS.

Figures 3 to 5 from a publication of 2016 (12) illustrate the basic functions of this miniature NIR spectrometer of Fraunhofer IPMS. Please note that spectrometer development at IPMS is an ongoing process and technical details may have changed in the meantime. Figure 3 shows the active element of the NIR microspectrometer, which is a MEMS scanning grating fabricated out of a silicon chip. The grating moves in a tilting fashion, driven by the electrostatic forces of comb structures. At the hinges of the grating, piezoelectric position detectors measure the precise tilting angle of the grating. The entrance and exit slits of the spectrometer are located on the same chip.

A setup of mirrors and spacer completes the spectrometer (see Figure 4). Spectrally broad NIR light is fed into the spectrometer through the input slit and onto the grating. When the grating moves, the spectrally dispersed NIR light from the source is scanned across the output slit. The InGaAs sensor diode then senses light of different wavelengths depending on the grating position. Via the position detectors, the read-out of the InGaAs diode can be related to the wavelength of the light at each point in time. Thereby, NIR spectra are recorded.

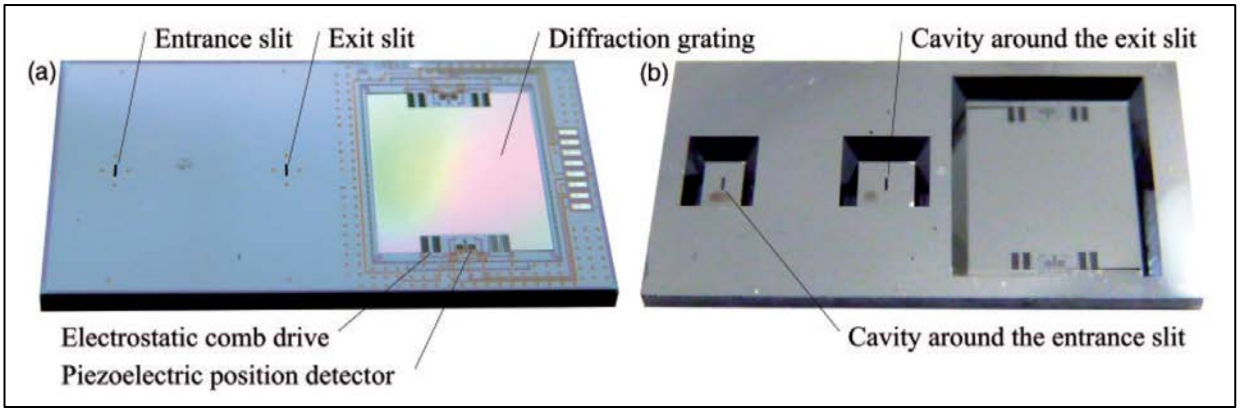


Figure 3 – Scanning grating MEMS device, dimensions 9.6 mm x 5.3 mm x 0.5 mm. (a) face up and (b) face down. Taken from (12).

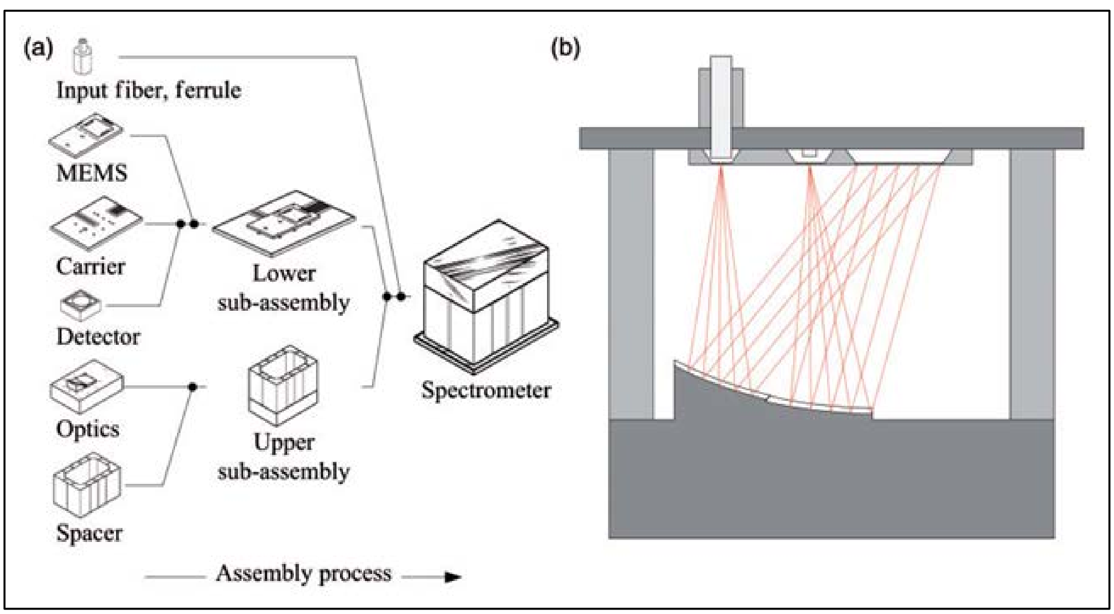


Figure 4 – (a) Assembly process for the production of a hybrid integrated grating spectrometer; (b) cross-sectional view of the complete system with the optical path highlighted in red. Taken from (12).

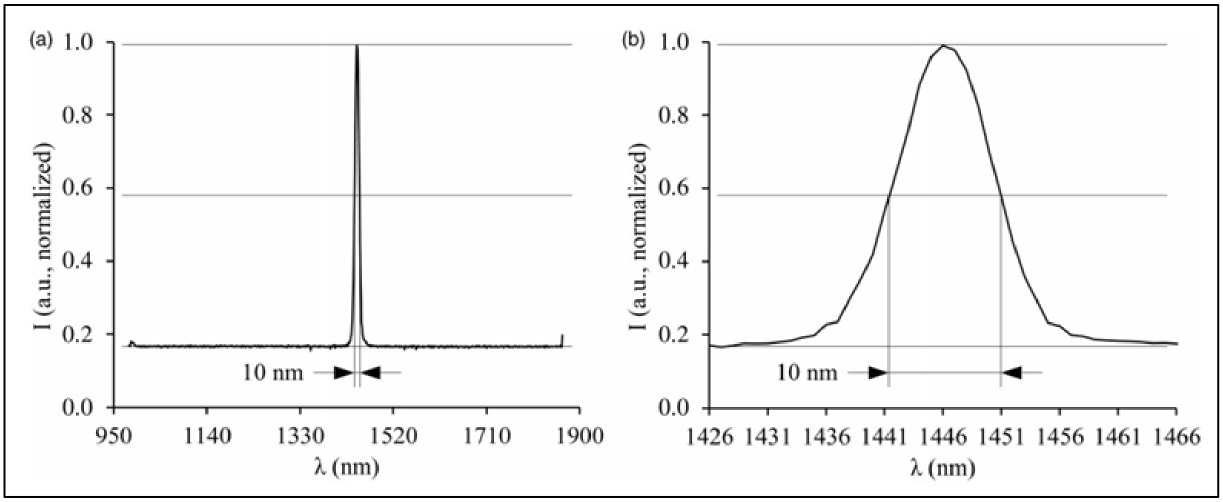


Figure 5 – Spectrum of a Xe short arc lamp source filtered by a monochromator to a peak of <10 nm width, measured with Fraunhofer NIR MEMS microspectrometer with 100x averaging. (a) Complete spectral range. (b) Magnified section of the peak. Taken from (12).

As an example, Figure 5 shows the spectrum of a single line of a Xenon arc lamp, which was recorded to determine the spectral resolution of the NIR microspectrometer. With 10 nm, this resolution is comparable or better than that of typical portable NIR spectrometers. Moreover, it fulfills the requirements of the PhasmaFOOD sensing device (1). The size of the actual spectrometer head is only 17 x 12 x 16 mm^3.

In short, the Fraunhofer IPMS NIR microspectrometer will be integrated into the PhasmaFOOD sensing device. It offers the following properties and benefits:

1. Fulfilment of the specifications, in particular large spectral range 1000 – 1900 nm and spectral resolution.
2. The NIR spectrometer setup shown in Figure 4 is suitable for integration into portable devices such as PhasmaFOOD, with a volume of only 2.1 cm^3 (12) – comparable to a sugar cube.
3. Direct access to the spectrometer module.
4. Direct access to CAD files and optical design details required for a speedy, accurate integration.

2.2.3 Board-level VIS camera

The PhasmaFOOD sensing device will also integrate a CMOS board-level VIS camera. The precise role of this component in our combined sensing approach is not finally defined and will be evaluated within the Work Packages 3 and 6. The camera may have standalone functions such as detecting simple colorimetric properties of a sample. Or it may be used to detect any macroscopic occurrence of microbial activity. However, it is clear that the camera must mainly work in support of the other, spectroscopic, sensors:

- sense the light level scattered back from a food sample and thereby help adjust the illumination light to obtain optimal spectroscopic results
- detect inhomogeneities of the food sample which may be used to identify spots that are suitable for spectroscopic measurements

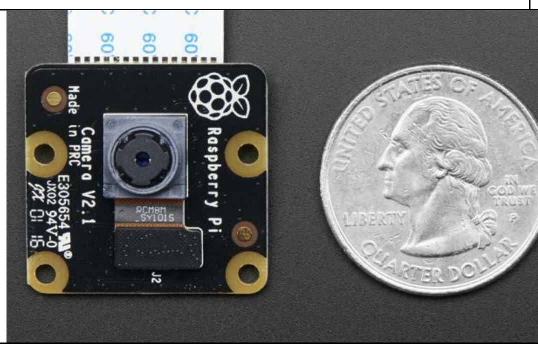
Therefore, the main requirement towards this component is a stable integration with the VIS and NIR spectrometers, such as to ensure a reliable and stable positioning between these components. Moreover, the optical properties of the camera must be compatible with the size requirements of the PhasmaFOOD demonstrator, i.e. be suitable for imaging at a short focal distance of only few centimetres.

Out of the multitude of available board-level VIS cameras, we show two exemplary candidates in Table 2.

<u>Camera 1: Pi NoIR - Raspberry Pi Infrared Camera Module </u>(13)

This camera is a cheap standard component sold for the Raspberry Pi 1, 2 and 3. The Pi NoIR camera is sensitive to visible and short-wavelength IR radiation (up to 880nm). It has a Sony IMX219 8-megapixel sensor and comes with a preinstalled plastic lens, which can be adjusted for focal distances between infinity and 1 m. Furthermore, the camera has an aspect ratio unfavourable for opto-mechanical integration. As the camera will be facing the food sample directly, the electronics board of the Raspberry Pi NoIR would be in the way of the adjacent spectrometers' optical paths, increasing with the overall size of the PhasmaFOOD device. This camera was designed from an electronics point of view, and for "quick-and-dirty" image recording. It is mounted on a driver board in a plastic housing. The tolerances for both mounting and housing depend on the original manufacturer in China and probably vary between batches. Therefore, this camera is not suitable for integration within the PhasmaFOOD project, where we look for stable mounts and reliable dimensions. Opting for a cheap version for cost reasons might jeopardise the success of the Use Cases if it leads to optical misalignment. A future PhasmaFOOD product, however, could make use of this camera after the initial proof-of-concept stage.

Table 2 – Candidates for the CMOS board-level VIS camera and their properties.

Model	**Pi NoIR - Raspberry Pi**	**Ximea MU9PC-MH**
Electronic image size	8 MPx	5 MPx
Camera size	24 x 25 x 9 mm³	15 x 15 x 8 mm³
Cost	~ 30 €	~ 600 €
Weight	3 g	5 g
Electronical interface	CSI-2 flat cable	USB 2.0 flat cable
Optical interface	Custom plastic lens on plastic thread mount	C-Mount for standard lenses
Mechanical interface	Mounted on electronics board	Bore holes in housing
Picture		

Camera 2: Ximea MU9PC-MH (14)

The second type of camera is available for around 600 €, which is reasonable and feasible within the PhasmaFOOD project. Optical components like lenses are bought separately as high-quality standard components. The camera is sensitive to visible light with a CMOS RGB Bayer Matrix sensor chip. A monochrome version is also available. However, RGB functionality is likely needed in the sensing device. The Ximea camera is slightly smaller than the above Raspberry PI NoIR, with a compact aspect ratio favourable for optomechanical integration. The electronics board of the Ximea camera is integrated into the back of its housing, where also a USB connector can be attached. Importantly, the camera is designed for easy and stable optomechanical integration, with 4 boreholes in the housing at fixed positions with respect to the optical axis. The camera features a C-mount connector for optical attachments such as lenses. CAD files of such standard components are available for optomechanical design simulations. In summary, the Ximea RGB microcamera offers numerous advantages and is, therefore, selected for integration into the PhasmaFOOD sensing device.

2.3 Lighting concept of the sensing subsystem

2.3.1 General lighting requirements

According to the specifications of the PhasmaFOOD sensing device, three types of light source are required:

1. UV lighting at a wavelength of 365 nm, for the fluorescence measurements of Use Case 1. Detection of the fluorescence light will be facilitated in the VIS spectral range, by the VIS spectrometer.
2. NIR lighting over the broad spectral range from 1000 to 1900 nm, for the measurements of mainly Use Cases 2 and 3, using the NIR spectrometer.
3. VIS lighting over the entire VIS spectral range from 400 to 850 nm, for imaging with the VIS camera and VIS spectroscopy.

Each of these types of illumination presents its own set of requirements associated with the purpose of its use.

2.3.2 UV lighting hardware

Due to the low concentration of mycotoxins in the food samples, the expected fluorescence emission in Use Case 1 will be weak. However, its intensity increases with the intensity of the UV excitation light up to a point where the sample is damaged and photobleaching occurs (15). It will be a matter of testing in Work Package 6 to balance these effects and optimize the irradiance required for mycotoxin detection, by adjusting the driving current or the number of UV LED sources. As shown in the optics design in Annex I, between 1 and 3 UV LEDs may be installed. However, it is the task of Work Package 2 to provide a high UV irradiance in the first place. This is done by making several choices:

- *UV source.* Spectrally narrow illumination at a wavelength of 365 nm is available from commercial UV LEDs. In particular, high power UV LEDs can be used in cases where high output intensity and optimal conversion efficiency is needed. The use of spectrally

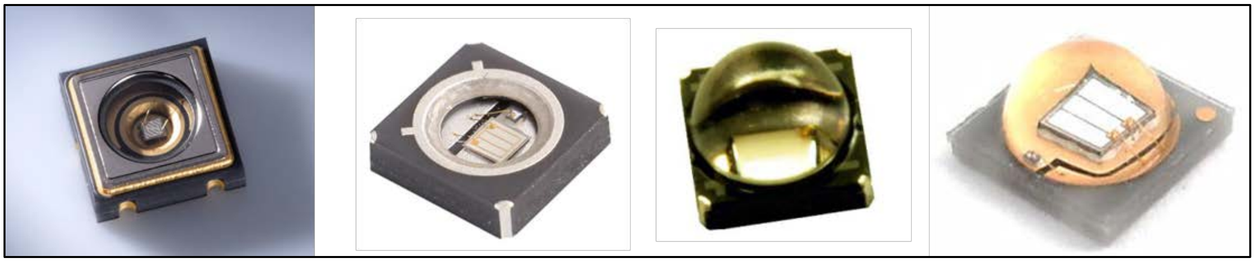


Figure 6 – High power UV LEDs at 365 nm emission wavelength are available from several manufacturers including Nichia NCSU275 (left), OSA Optolight 440-UE365 (second), LedEngin LZ1-00U600 (third) and SSC Viosys 365 CUN66A1B (right).

broad UV illumination combined with a spectral pass filter for 365 nm is no alternative here, as it would consume too much space and electrical power, both of which are expressly limited in the PhasmaFOOD portable sensing device.

- *Beam shaping.* The output of such high power UV LEDs can be focused or collimated, in order to increase the irradiance on the measurement spot of the food sample, which will be ~ 1 mm in size. This approach will be taken to ensure that sufficient excitation light is available for the fluorescence measurements of Use Case 1. Besides, this decision has the benefits of using the UV LEDs efficiently, whose number and power consumption will have to be limited in the PhasmaFOOD sensing device. Thereby, less energy will be wasted, which would otherwise increase the heat build-up in the sensing device.

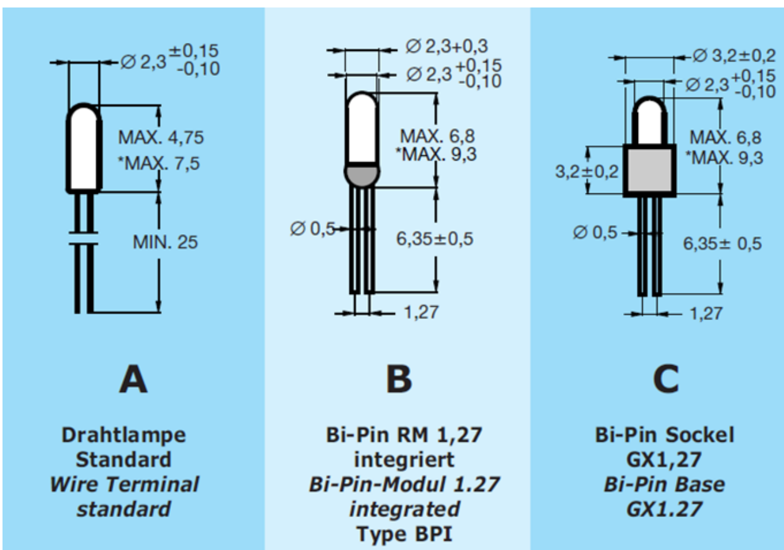
Several options are available for the high power UV LED hardware, as shown in Figure 6. All of them feature an intrinsic Lambertian emission profile, some of them can be equipped with lenses or reflectors attached to the SMD package. Concerning package and mounting, heat management is of crucial importance as these LEDs typically consume a forward current between 200 and 1000 mA at a driving voltage of ~ 3.6 V. Only 10 - 15 % of that power is emitted in the form of UV radiation, the rest as heat. Given the compact design approach of the PhasmaFOOD sensing device, heat that builds up at the light sources will affect the performance of all sensor components, because their dark noise increases at higher temperature. This must be avoided by using LED packages with a high thermal conductivity, e.g. made from ceramic material, or by using bulk metal heat sinks and metal core PCBs.

Another consideration concerns the safety aspects of UV irradiation. “Precautions must be taken to prevent looking directly at the UV light and UV light protective glasses must be worn to avoid eye damage. Exposure of the skin and other body parts to the UV light should be avoided.” (16) The PhasmaFOOD sensing device is being used in the laboratory by trained personnel throughout the project. Here, the implementation of UV and other safety measures (including careful handling of the device demonstrator) will be straightforward within the measurement protocols of Work Package 3. However, beyond the PhasmaFOOD project, the sensing device will be developed further into a customer product. Here, the implementation of eye safety measures or safety warnings will not be natural. This is no show stopper for the future PhasmaFOOD product but must be taken into account like similar considerations in the development of ophthalmic scanners or laser pointers.

To conclude, hardware for UV lighting is readily available. Light must be focused to be used efficiently. The optical design shown in Annex I is done for high power OSA Optolight 440-UE365 LEDs. The final decision about LED hardware will be done in the course of the mechanical design of Task T2.4. Please note that due to the high sensitivity of the Hamamatsu spectrometer, it will receive an UV-blocking filter as specified in D1.2, in order to avoid damage and facilitate detection of the weak fluorescence light. This is shown in Annex I.

2.3.3 NIR lighting hardware

In order to be suitable for NIR spectroscopy, spectrally broad NIR lighting should be spectrally flat, i.e. without strong spikes at single wavelengths, and stable over time. Such light is available from halogen or tungsten sources. Halogen light is often used in daily life for room lighting, car headlights, high power spot lighting or even radiator heaters. The individual illuminants are available as small bulbs or rods with dimensions of several centimetres. They emit radiation more or less evenly in all angular directions and consume at least 20 W of electrical power, roughly 3 % of which is converted into VIS and NIR light. These properties are beneficial for the detection purposes of PhasmaFOOD but also problematic. The benefit lies in the supply of sufficient NIR irradiance. However, the disadvantages are related to the excessive power consumption and heat generation of halogen sources. Moreover, beam shaping for even the smallest bulbs would consume space beyond the possibilities of the PhasmaFOOD sensing device. Due to these reasons, we opt for the use of tungsten illuminants.



Nennspannung *Design Volts* [V]	Nennstrom *Design Amps* [mA]	Lichtstärke *Candle Power* [MSCP]	Lebensdauer (AC) *Life (AC)* [h]	Wendelaufbau *Filament*
1,0	40	0,0020	5.000	C-6
1,0	45	0,0055	2.000	C-6
1,2	45	0,0100	500	C-2R
1,5	15	0,0020	500	C-6
2,0	50	0,0300	1.500	C-6
2,5	250	0,2200	4.000	C-2R
4,0	50	0,0250	15.000	C-2R
4,0	100	0,1500	4.000	C-2R
4,0	115	0,1500	7.000	CC-6
5,0	15	0,0200	800	C-2R
5,0	15	0,0250	400	C-6
5,0	20	0,0030	20.000	C-2V
5,0	20	0,0150	4.000	C-2R
5,0	21	0,0340	1.000	C-2R
5,0	45	0,0800	4.000	CC-6
5,0	60	0,0300	100.000	C-2R
5,0	60	0,0400	60.000	C-2V
5,0	60	0,0500	100.000	C-2R
5,0	60	0,0500	100.000	CC-6
5,0	60	0,1500	5.000	C-2R
5,0	75	0,0900	40.000	C-2R
5,0	75	0,0900	40.000	CC-2R
5,0	80	0,1500	6.000	C-2R
5,0	115	0,1500	40.000	C-2R
5,0	115	0,1500	40.000	CC-6
5,0	115	0,2000	8.000	C-2R
6,0	25	0,0500	700	C-2R
6,0	50	0,0300	25.000	C-2V
6,0	50	0,0500	15.000	C-2V
6,0	60	0,0500	50.000	CC-6

Figure 7 – Left: Selection of MGG tungsten microlamp types with T3/4 fittings. Right: Selection of low voltage microlamp configurations. Taken from (17).

Tungsten light sources convert only 2 % of their electrical supply power into VIS and NIR light. However, they are available as microlamps in the shape of millimeter sized bulbs, which makes them manageable within the limited space of the PhasmaFOOD sensing device. Focusing or collimating the emitted light onto the measurement spot becomes feasible using small standard mirror and lens components, which ensures that both light and consumed electrical power are efficiently used.

A suitable supplier of tungsten microlamps is MGG, with catalogues of various shapes, sizes and fittings, as shown in Figure 7. These bulbs typically consume ~ 1 W of electrical power. We chose an MGG microlamp type of a slim and simple build, a low voltage fitting the requirements of the PhasmaFOOD device, and a comparably high optical output power. It features a T3/4 fitting, 5 V driving voltage, 115 mA driving current and 0.150 MSCP light output. In Annex I, we elaborate on the optical beam shaping for this lamp type. Due to their low consumption of energy and space, several (up to three) tungsten microlamps may be installed inside the PhasmaFOOD sensing device. Again, it will be a matter of testing in Work Package 6 to optimize the irradiance required for NIR spectroscopy by adjusting the driving current or the number of installed sources.

2.3.4 VIS lighting

The installation of spectrally broad VIS light sources is also foreseen in the PhasmaFOOD sensing device. It will serve to provide illumination for VIS imaging and also for VIS spectroscopy. As both the Ximea VIS camera and the Hamamatsu VIS spectrometer are sufficiently sensitive, the intensity of the white VIS illumination is no critical parameter. Standard white LED sources will be optimal for this purpose due to their small size and convenient mounting options. Also, the light from these sources does not need to be focused or collimated. Instead, it is advantageous to keep the illumination as homogeneous as possible. In conclusion, the white LEDs should sit at the front of the PhasmaFOOD sensing device, facing the sample at a short distance, without beam shaping. In order to make the handling and cleaning of the sensing device as convenient and practical as possible, it is suggested to use encapsulated white LEDs, such as the OSA Optolight OLS-170 MW (18).

2.3.5 Unified lighting concept

In summary, the unified lighting concept for the PhasmaFOOD sensing device includes:

1. Focused high power UV LEDs (wavelength 365 nm), for VIS fluorescence measurements.
2. Focused tungsten microlamps as NIR light sources.
3. Unfocused, encapsulated white VIS LEDs for VIS imaging and spectroscopy.

In accordance with the combined sensor approach of the PhasmaFOOD project, all light sources shall illuminate the same measurement spot on the (food) sample.

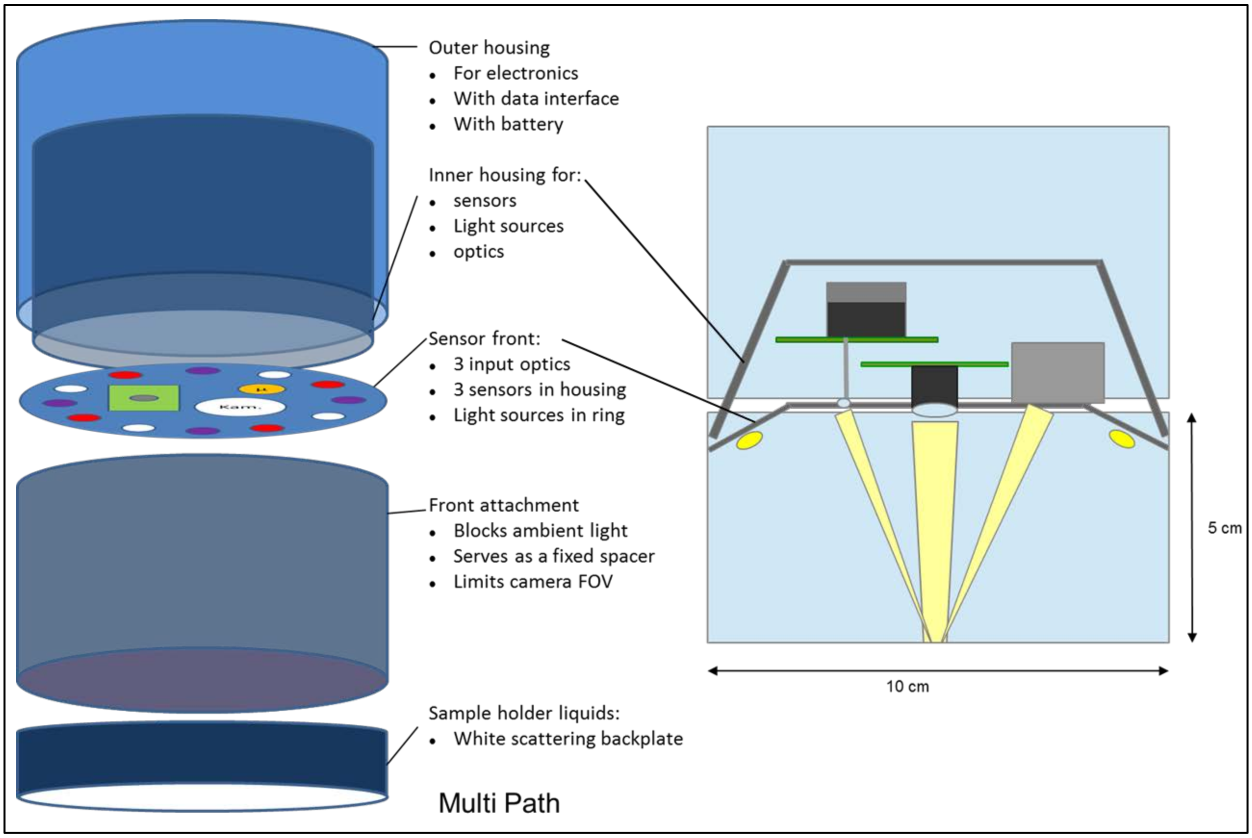


Figure 8 – Multi path concept. Left: 3D schematic. Right: Cross section with approximate scale; Grey box – VIS spectrometer; Black box – camera; Black-grey box – NIR spectrometer; yellow ellipses – white LEDs; yellow areas – light path; green lines – driving boards; dark grey lines - housing.

2.4 Optics concept of the sensing subsystem

The above components of sensors and illuminants must be integrated into a single compact device, which provides the basis for highly sensitive and stable measurements within the possibilities of the available hardware and space restrictions. Several optical concepts can be used to implement these ideas. Below, we present three approaches that were discussed as options by the PhasmaFOOD consortium, out of which one was chosen for the PhasmaFOOD sensing device.

2.4.1 Multi path concept

The first, very simple concept for the PhasmaFOOD sensing device is obtained by simply placing the sensing components and their input optics next to each other, facing the sample. Thereby, each sensor collects light in an individual light path, independent of each other. The left panel of Figure 8 shows a sketched cross section of this approach. In three dimensions, the concept could be implemented in a cylindrical or box shape.

For this approach, it is critical that the distance between the sensor optics and the sample interface is fixed and stable. This could be achieved by a spacer attachment at the front of the housing that faces the sample. This schematic drawing shows the correct dimensions of the sensor components but does not take into account the distances required for the optical paths towards the sensors. Light sources can be integrated in the same way as the sensors inside the housing or placed at the front face of the housing without optical collimation. The VIS camera is placed in the centre of the assembly in order to ensure imaging with minimal distortion.

As an interface to the electronics sub-unit, all sensor components are contained inside an inner housing such that the sensing sub-unit becomes an independent body that can be assembled and adjusted separately, with electrical interfaces to the electronics main board (see Section 4) and then delivered for further assembly with the electronics sub-unit. This structure has various benefits for organizing the development of the PhasmaFOOD sensing system, in particular that the sensitive assembly of optical components can be carried out in dedicated optics laboratories at partner IPMS and that the development of the electronics sub-unit is given more freedom by separating off the mechanical design of the back part of the device housing, which is to be done by partner WINGS who also develop the electronics sub-unit.

This initial version was discarded because it was unclear how the positioning of one sensor with respect to the others can be fixed in a stable way. Naturally, this property is critical for the success of the combined sensing approach of PhasmaFOOD.

2.4.2 Single path concept

The second concept tries to implement measures in order to fix the relative position between the optical paths for all sensors. The most rigorous way of doing this is by setting all sensors on the same optical path, with beam splitters at the back end to feed light to each individual sensor. Here, the detection spots of both spectrometers and the camera field of view automatically always overlap.

While its intention is good, this approach leads to a convoluted mechanical design and a complex assembly procedure, as can be seen from the sketch in Figure 9. However, the main drawback is that light is collected from the sample over only a narrow solid angle. This light is then split off into portions for each sensor, further diminishing its intensity. Moreover, beam splitters and optical filter introduce losses via absorption and reflection at their interfaces. This constitutes a drawback particularly for the collection of fluorescence light from mycotoxins. At the sample surface, fluorescence is emitted into a wide solid angle, of which only a small portion would be used. As this light is expected to be very weak, efficient collection must be attempted into order to make fluorescence detection feasible. Similar arguments apply to NIR spectroscopy. Therefore, alternatives were sought for this single path concept.

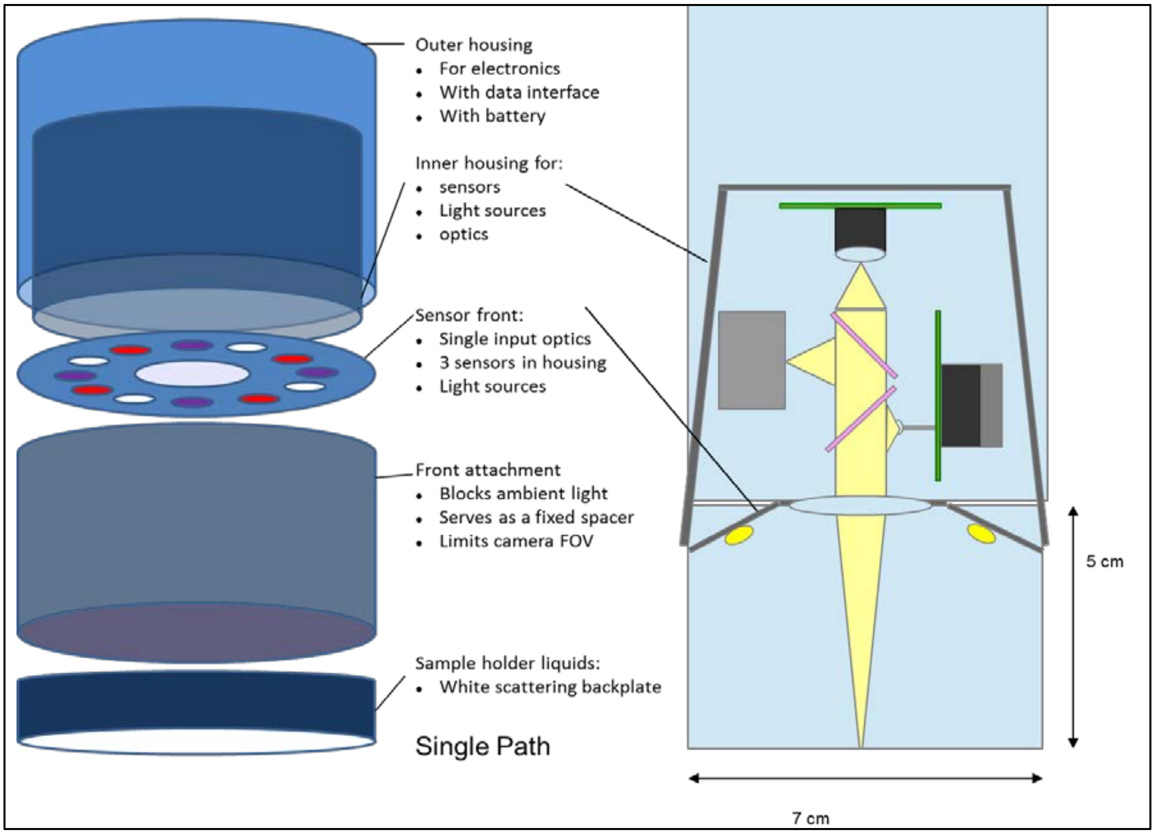


Figure 9 - Single path concept. Left: 3D schematic. Right: Cross section with approximate scale; Grey box – VIS spectrometer; Black box – camera; Black-grey box – NIR spectrometer; yellow ellipses – light sources; yellow areas – light path; green lines – driving boards; dark grey lines - housing.

2.4.3 Modular concept

The final optical concept for the PhasmaFOOD sensing device takes into account the positive aspects and drawbacks of both of the previous versions. As in both designs before, the sensing sub-unit is separated from the electronics sub-unit, as shown in Figure 10.

The modular design incorporates all sensors and the UV and NIR illumination into the housing of the sensing-sub-unit. Only the white LEDs for broadband VIS illumination are located on the sample-facing front of the housing. Moreover, each sensor and light source inside the housing is equipped with their input or output optics. In so far, this concept is similar to the multi-path concept. The critical difference is that each optical path of a light source or sensor is contained inside a module.

There are six modules available in total, each of them inclined at an angle of 30° to the vertical. One additional module or channel is aligned along the vertical, in the centre of the optical assembly. This channel is reserved for the VIS camera similar to the arrangements before. Out of the six modules, one is allocated to the Hamamatsu VIS spectrometer, another one to the

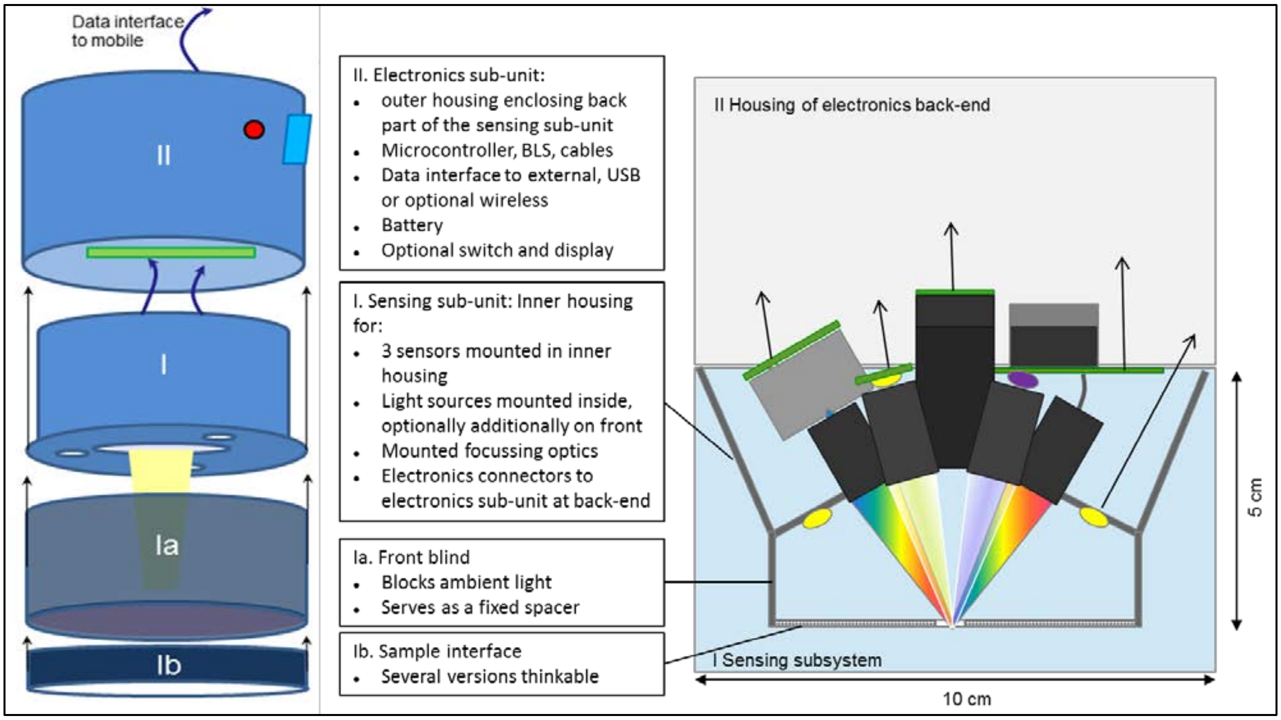


Figure 10 – Modular concept of the PhasmaFOOD sensing sub-unit and interfaces to the electronics sub-unit. Left: 3D schematic, as in Figure 1. Right: Schematic side view of the interior of the sensing sub-unit with approximate scale; Grey box – VIS spectrometer; Black box – camera; Black-grey box – NIR spectrometer; dark grey – module tubes; ellipses – light sources; green lines – driving boards; dark grey lines – housing; arrows – electrical connectors.

IPMS NIR spectrometer and the remaining modules are left for illumination. To start with, the first optical design will take into account two UV LED modules and two for NIR microlamps. Later on, this arrangement may be changed to a 1+3 or 3+1 configuration according to the validation results Work Package 6.

Each component receives its own optical design and assembly but the modules will be interchangeable. The modular approach offers a particular benefit in foresight to the assembly of the sensing sub-unit because each module can be aligned on its own, giving flexibility for the optimization of each measurement method independent of the rest of the assembly. A stable interrelation between the individual module tubes is achieved by fixing them into a single, conical mount. Thereby, the measuring spots of all sensors and the illumination spots of the light sources can be made to overlap at the sample interface in a stable and permanent way.

A spacer will be used to fix the distance between sensing device and sample, which double serves as a cylindrical blind to block ambient light. In addition to the spacer, the interface to the food sample can also be fixed by other mechanical means such as a grid or window.

Most importantly, the conical arrangement of the modular device concept results in an optimal use of the light scattered or emitted from the sample by collecting light from the largest possible solid angle. Annex I elaborates on the details of the optical design, which implements the modular concept and provided the basis for a subsequent mechanical design of the sensing sub-unit. Please note that Annex I is confidential and only intended for Reviewers access.

As an outlook, some thought has already been given to the mechanical implementation of this device concept:

1. The front with tubes and unfocused white LEDs will be wipeable (with windows adapted to each channel).
2. The sample interface will be detachable and washable or easy to replace.
3. The tube holder can be made via 3D printing from metal or plastic.
4. The lateral size of the entire assembly will be ~ 10 cm, depending on the size of the sensor-near electronics boards, wall thickness and mounting interface to the electronics sub-unit.

It will be the work of Task T2.4 to implement these features into a manufacturable mechanical design. The results of this work will be shown in Deliverable Report D2.3 in month 11.

3 Structure and concept of the electronics subsystem

3.1 Governing principles

The PhasmaFOOD device must meet some principal requirements regarding the power consumption, the level of data processing, the stability and compactness of the mechanical design, the noise on the sensory data and the flexibility in functionalities.

The main electronics board will integrate a rechargeable battery in order to provide the energy required for the PhasmaFOOD device operation. The overall power consumption of the PhasmaFOOD device including both the sensing subunit and the main electronics subsystem must be kept at low levels (Deliverable Report D1.2 (1), Requirements References POWER-1, POWER-2, POWER-3, POWER-4).

Preprocessing functionalities, such as noise filtering (Deliverable Report D1.2 (1), Requirements References ELECTR-L-5), data compression, data normalization and feature extraction (Deliverable Report D2.1 (3), Section 1.2), will be assessed in order to reach a solid design solution based on the hardware resources (i.e., memory, processing performance) they demand, their execution time and the power they consume during their execution.

The mechanical design of the PhasmaFOOD device must ensure a stable environment for both the sensing subunit and the main electronics board. For this purpose, auxiliary sensors (i.e., accelerometer, temperature/humidity sensors) will be integrated on the main electronics board as close to the sensing subunit as possible (Deliverable Report D1.2 (1), Requirements References ELECTR-L-6, ELECTR-L-8, ELETR-L-9). Also, the PhasmaFOOD device must be compact enough in order to be easily used by any end-user.

The driving boards of both the UV-VIS and the NIR spectrometers inside the sensory subunit should integrate analog to digital converters (ADCs) in order to avoid adding any noise to the raw analog sensory data due to their cable transfer from the one subsystem to the other. The digital outputs of the ADCs can then be transferred to the main electronics board via proper digital interfaces (e.g. SPI).

Any dark and white references for the UV-VIS and NIR spectrometers may be stored on the main electronics subsystem. Thus, higher levels of compactness are achieved for the sensing subunit by eliminating the need for any external storage on the electronic boards of the spectrometers. Also, we exploit the memory that will be available on the main electronics board and store there any information needed for any processing functionalities on the sensory data. The alternative solution of transferring the dark and white references for the spectrometers each time that we need them may be slow and exceed the hardware resources.

3.2 General structure

Figure 11 shows the general electronics structure of the PhasmaFOOD device incorporating the sensing subunit and the main electronics subsystem. The main electronics subsystem of the PhasmaFOOD device will integrate a microcontroller / microprocessor environment with enough on-board memory for both the operation of the processing module (i.e., boot, code/application storage) and the storage of the sensory data. The external memory on the main electronics board should be large enough in order that both the raw sensory data and the ones resulting from various preprocessing functionalities can be stored in it (Deliverable Report D1.2 (1), Requirements Reference MEM-1).

The microcontroller / microprocessor will integrate different modules, which will be configured as masters for the SPI connections to the UV-VIS, the NIR and the lighting electronic boards inside the sensing subunit. Also, a module configured as a USB host in the microcontroller / microprocessor will be integrated for the communication with the camera electronic board.

A micro-USB and a Bluetooth / BLE modules will be integrated on the main electronics board for communicating with the mobile device of the PhasmaFOOD architecture (Deliverable Report D2.1 (3), Section 2.3). A rechargeable battery will provide the energy required for the operation of the PhasmaFOOD device. A small screen on the PhasmaFOOD device will inform the end-user on

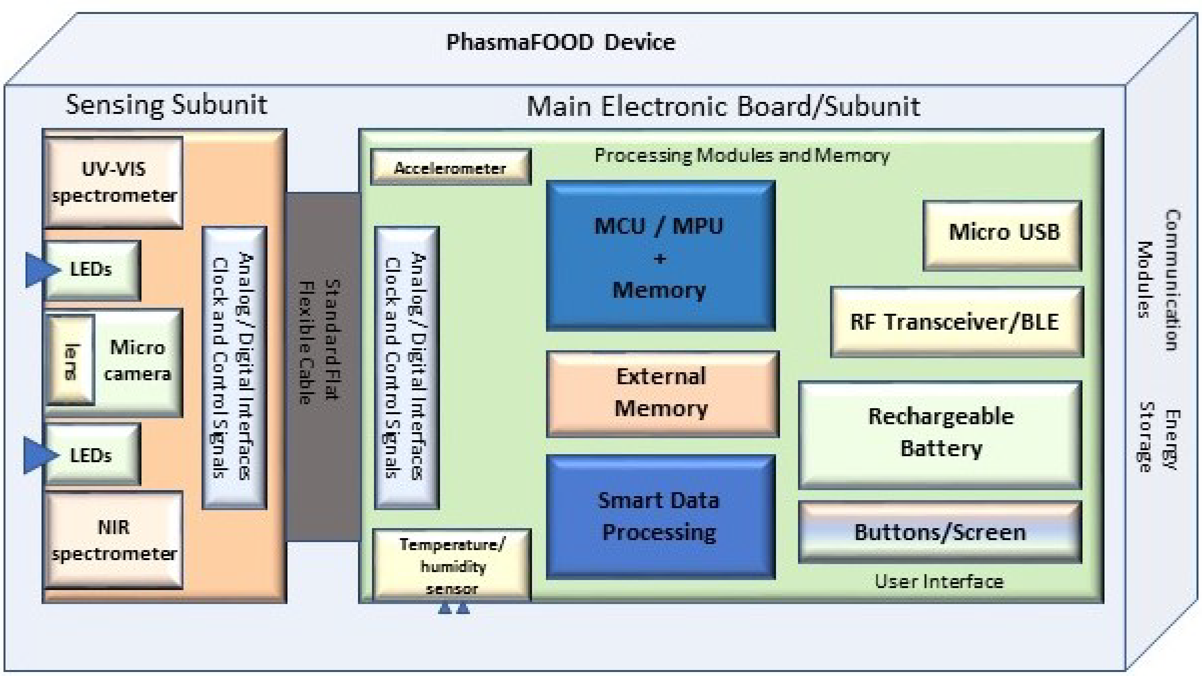


Figure 11 - The electronical structure of the PhasmaFOOD sensing device.

the device status or notify them about various triggered events (Deliverable Report D1.2 (1), Requirements References ELECTR-L-7 and Deliverable Report D2.1 (3), Section 2.1). Auxiliary accelerometer and temperature/humidity sensors will be integrated on the main electronics board as well.

4 Sensor-near electronics inside the optical subsystem

4.1 Driving board and electronics interface for UV-VIS spectrometer

The operation of the Hamamatsu C12880MA UV-VIS spectrometer will be supported by a small electronic board inside the sensing subsystem. The electronic board should meet any driving recommendations of the Hamamatsu company (8) regarding the inputs and outputs of the spectrometer and include any additional functionality for an initial processing of the analog video output of the spectrometer (amplification and analog to digital conversion) before further processing it on the main electronic board. Also, this supportive electronic board will integrate an interface (SPI) for communicating with the main one and transferring the sensor data to it. Figure 12 shows an abstract design of the electronic board of the UV-VIS spectrometer.

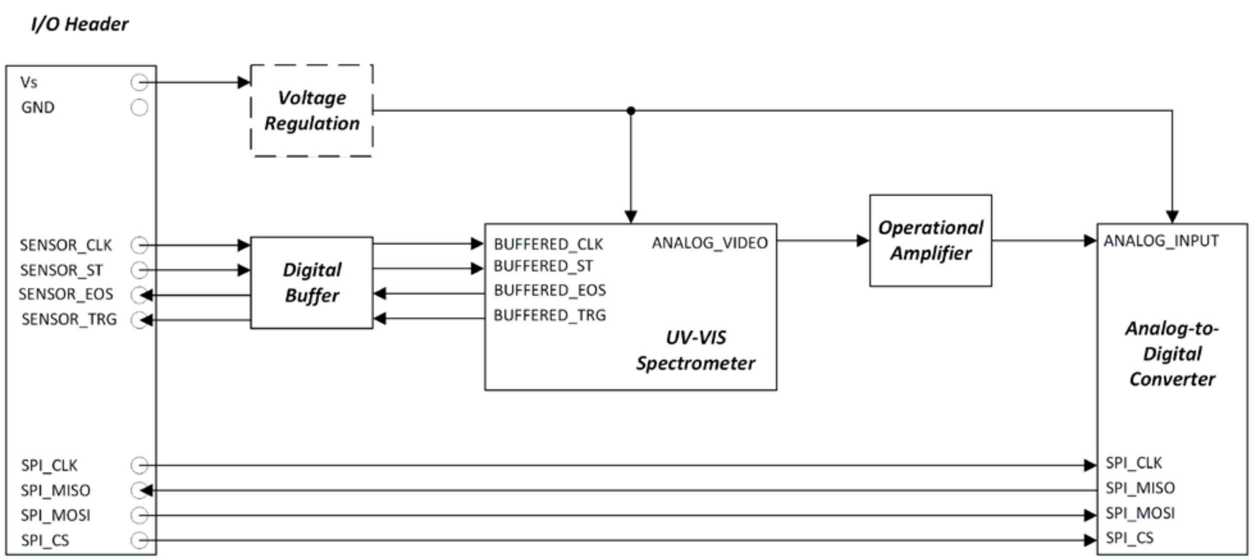


Figure 12 – Abstract design of the electronic board of the UV-VIS spectrometer.

A header of at least 10 pins will be included on the electronic board. The connection with the main electronic board should be achieved using a proper ribbon cable, which gathers all connections in a concentrated one and facilitates the electronic and mechanical designs of both boards. Two of the header's pins will be dedicated to provide voltage and ground supply to the electronic board from the main one. Four of the pins will be dedicated for driving the clock and control signals (digital signals) to and from the spectrometer. On top of the SENSOR_CLK, the spectrometer's clock signal, there are also the SENSOR_ST, the SENSOR_EOS and the SENSOR_TRG signals. The SENSOR_ST is the start pulse, the SENSOR_EOS is the end of scan pulse and the SENSOR_TRG is the trigger pulse for capturing sensor video signals. The SPI for the communication with the main electronic board regarding sensor data transfer to it is a 4-wire interface and, thus, the four remaining pins of the header will be dedicated to it.

Since the voltage supply signal is provided from an external electronic board through a cable, nonlinearities and instabilities at the voltage supply signal should be considered as potential. Thus, a linear voltage regulation circuit on the UV-VIS electronic board should be assessed for this reason.

The digital clock and control signals of the spectrometer will be driven to and from it through a digital buffer and not directly from the header of the electronic board following the driving recommendations of the Hamamatsu company (8). Also, an operational amplifier for the analog video output of the spectrometer will be integrated on the electronic board for the same reason.

An analog to digital converter will initially process the analog output of the spectrometer before any further processing will take place on the main electronic board. The output of the operational amplifier will be driven to the input of the ADC, which will handle its conversion to an equivalent digital signal. The sampling frequency of the ADC must be at least twice the bandwidth of the analog input signal (Nyquist sampling theorem). Since the value of the frequency of the analog output of the VIS spectrometer is equal to its operation frequency, which can take any value from 0.2 to 5 MHz, the sampling frequency of the ADC must be at least 0.4 MSPS (Million Samples Per Second). Also, the ADC will integrate a SPI in order that the MCU / MPU of the main electronic board can control its operation and its digital output can be transferred to the main electronic board. The SPI specifies four logic signals. The SPI_CLK is the clock signal with respect to which the data are transferred on the SPI bus. It is an output of the master module (i.e., the MCU / MPU of the main electronic board) and the slave module (i.e., the ADC of the UV-Vis electronic board) will receive the SPI_CLK signal as its clock input. The SPI_MOSI (Master Output Slave Input) signal is used for data transmission out of the SPI master module and data reception at the slave one. The SPI_MISO (Master Input Slave Output) signal is used for data transmission out of the SPI slave module and data reception at the master one. The SPI_CS (Chip Select) signal is used to enable a connection with the selected slave module.

4.2 Driving board and electronics interface for the NIR microspectrometer

4.2.1 Data interface

Data transfer from and to the NIR microspectrometer can be done via USB2.0 or alternatively also via SPI interface. In case of SPI, a connector of type Harting 151502626 (26 pin; 1.27 mm pitch) will be used (19). This matches with an IDC Connector of type Harting 1529026xxx for a 30 AWG ribbon cable (20) or compatible. The pin description of the SPI connector is given in Table 3. This is only to be used if the NIR microspectrometer is connected via SPI instead of the favoured USB2.0 connection.

Table 3 – Pin description which will be used if the Fraunhofer IPMS NIR microspectrometer is addressed via SPI connection. Please note that USB connection is also available

Pin	Signal	Description	Type (for spectrometer)	Logic level
A1	+ 5V	+ 5V	Power in	
B1	GND	Ground Potential	Power in	
A2	CS	Chip select (0 = selected, 1= deselected)	Logic in	LVTTL 3V3
B2	MOSI	Serial Data Mater Out Slave In	Logic in	LVTTL 3V3
A3	MISO	Serial Data Mater In Slave Out	Logic out	LVTTL 3V3
B3	SCK	Serial Clock	Logic in	LVTTL 3V3
A4	start	Synchronization start (1= start capture data)	Logic in	LVTTL 3V3
B4	busy	spectrometer busy (1= pleas wait, 0 = ready for new acquisition)	Logic out	LVTTL 3V3
A5	ready	acquisition finish (1= new spectral data available)	Logic out	LVTTL 3V3
B5	GND	Ground Potential	Power in	
A6-A13; B6-B13	do not use	do not use (for IPMS internal use only)		

Table 4 – Implemented protocol commands. * This is work in progress, the information represents the current status as of 31st August 2017.

Command	Send data length (in Byte)	Respond data length (in Byte)	Command Type	Default value(s)	Description
Status commands					
0x0000	0	4	GET	SPEC	Get identification word
0x0001	0	4	GET	00.00.00.01	Get Revision Number
0x0002	0	4	GET	00 00 00 00	Get Status of spectrometer
0x0003	1	1	SET		Set Software start of aquisition state; 0x00 = acq. off, 0x01 = acq. On
0x0003	0	1	GET	00	Get Software start of aquisition state
Tbd*					
Configuration commands					
0x0100	1	0	SET		Set number of averging
0x0100	0	1	GET	1	Get number of averaging
Tbd *					
Spectral commands					
0x0200		7	GET		Spectral data scaling:
				0	1 Byte sampling status
				1001	2 Byte sampling points
				900	2 Byte start wavelength
				1900	2 Byte stop wavelength
0x0201		s x 4	GET		(sampling points) x float (4 Byte) spectral data
Tbd*					

4.2.2 NIR spectrometer data protocol

Independent of the actual data connector used (USB2.0 or SPI), the following data protocol will be used. The communication is based on the classic Master-Slave Command-Response Model. The protocol has a binary format. Host (PC) is the Master (send commands) and Spectrometer is the Slave (respond to the commands).

Every command package corresponds to a respond package of the Spectrometer. There are two types of commands: GET and SET commands. GET commands have a data length = 0 (Host to Spectrometer) and data length > 0 (Spectrometer to Host). SET commands have a data length > 0 (Host to Spectrometer) and data length > 0 (Spectrometer to Host). Checksum is calculated similar to ihex86-file-format checksum (but currently not used).

The structure of data packages is given in Table 4 and Table 5.

Table 5 – Structure of data packets from NIR microspectrometer.

Command: Host → Spectrometer

Byte No.	1	2	3	4	5	6	7	8	9	…	n	n+1	n+2
Description	Command		Data Length				Data (Optional)					Checksum	

Response: Spectrometer → Host

Byte No.	1	2	3	4	5	6	7	8	9	…	n	n+1	n+2
Description	Command		Data Length				Data (Optional)					Checksum	

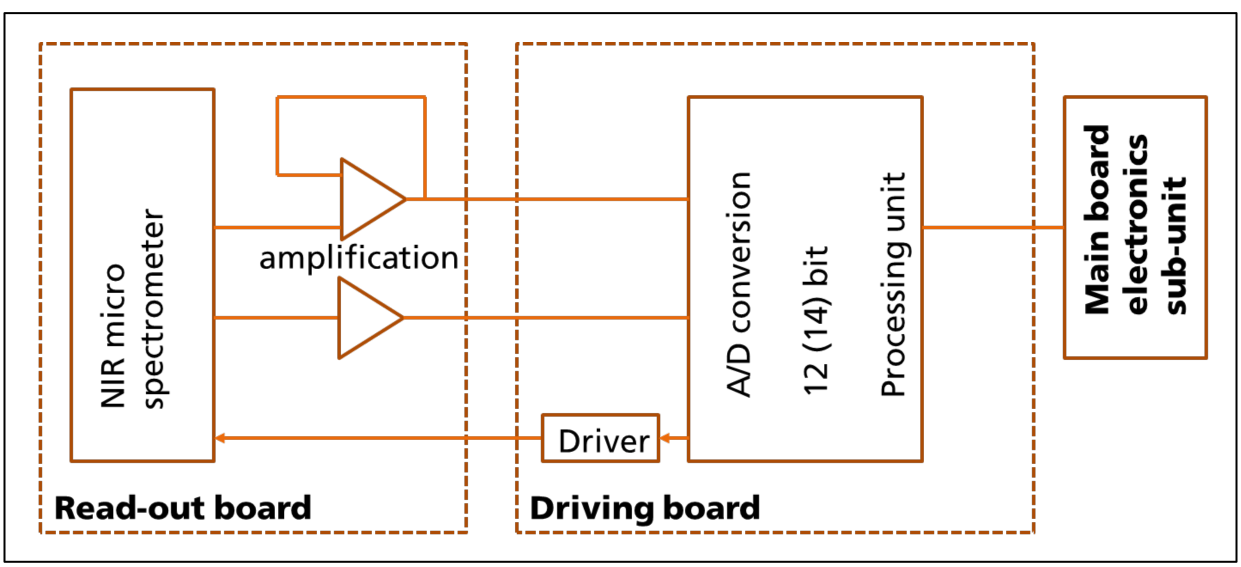


Figure 13 – Concept of the structure and functionalities of the driving board for the NIR microspectrometer.

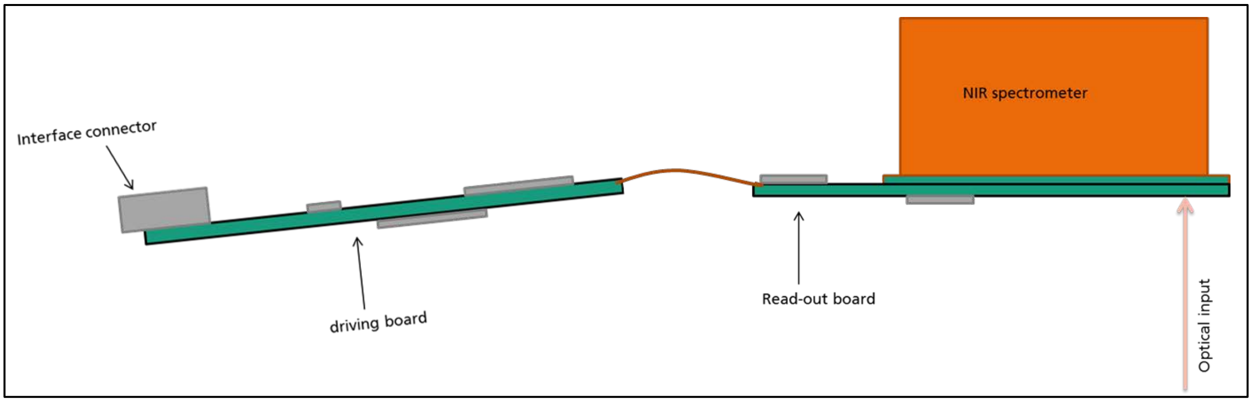


Figure 14 – Electromechanical concept of the Fraunhofer IPMS NIR microspectrometer showing the assembly and relative dimensions of spectrometer and boards.

4.2.3 Sensor-near electronics of the NIR microspectrometer

The layout and assembly of the driving circuits for the NIR microspectrometer is proprietary information of Fraunhofer IPMS and undergoes continuous development. For the PhasmaFOOD project, IPMS provides all information necessary for the electronics integration of the NIR spectrometer. This includes a sketch of the structure and functionalities of the sensor-near electronics as shown in Figure 13. The electronics hardware comprises a read-out and a driving board, which are separated for ease of assembly and flexibility during the mechanical integration of the boards.

5 Summary

The optical design of the PhasmaFOOD sensing sub-unit is complete and awaiting implementation into a mechanical design in Task T2.4.

Starting from the requirements of the three Use Cases, a common lighting concept was derived, consisting of focused high power UV LEDs, focused NIR microlamps and unfocused white LEDs. Types and suppliers of illumination hardware were researched and chosen. A detailed research into sensing hardware resulted in the choice of the three sensors namely:

1. The Hamamatsu C12880MA UV-VIS spectrometer for VIS spectroscopy
2. The Fraunhofer IPMS NIR microspectrometer for NIR spectroscopy
3. The Ximea MU9PC-MH board-level camera for VIS imaging.

Next, an integrated sensing concept was derived in extensive discussion with the PhasmaFOOD consortium, resulting in the choice of a modular approach to provide both stability during measurements and flexibility for future optimization. This modular concept was then elaborated via optical design simulations led by partner IPMS using the ZEMAX software, based on the selected components parameters. Finally, the optical design of the PhasmaFOOD sensing sub-unit integrates the miniaturized VIS camera UV/VIS spectrometer and NIR spectrometer as well as implementing the above lighting concept.

This optical design prioritises light throughput, in particular to boost the signal-to-noise ratio for the VIS fluorescence measurements. Miniature components and a compact design approach are compatible with the small device dimensions intended by PhasmaFOOD and suitable for a portable sensing device. Moreover, manufacturability was addressed focusing on the challenge of assembling and aligning such a highly integrated and compact optical system, which will be done module by module.

In line with the requirements given by the Use Cases, the sensing device will measure diffuse scattered light in a transflection geometry. Thereby, it is in principle suitable for measuring through transparent food packages. It will be the task of validation to test whether this capability can be practically used and stable calibrations can be obtained.

Considering the above optical sensing concept, the sensor components cannot be mounted on a single electronics board but each require their own read-out electronics, which then transfer data to the main electronics board. The work of Task T2.3 is still ongoing to design the main electronics board. More information on the electronics concept in documented in Deliverable Report D2.1. However, the choice of the sensing and lighting components fixes the properties and interfaces of the read-out electronics of the sensing sub-unit, which are therefore documented in this Report. In summary, this Deliverable Report provides a complete documentation of the optical and electronical properties of the sensor and illumination subsystems to be used in the PhasmaFOOD smart sensing system.

6 Outlook

The immediate next step after optics design is its implementation into a mechanical design, which will also take into account the dimensions and mounting of the electronical components and interfaces that are currently being designed in Task T2.3. Optical design data are now available to import into mechanical design software and construct the hardware of the PhasmaFOOD sensing sub-unit. The mechanical design will be reported in month 11, mainly with input from partners WINGS for the electronics sub-unit and partner IPMS for the sensing sub-unit.

After that, the sensing sub-unit and electronics sub-unit hardware will be manufactured or procured otherwise. Assembly, test and trouble-shooting of the optical modules will take place up to month 16 when also the electronics sub-unit will be available with all interfaces. In parallel to this, software will be set up for the electronics sub-unit, the mobile phone and the cloud database. Once the first PhasmaFOOD system is set up in month 18 of the project, a first validation phase will evaluate the use of the system in practice.

With the present optical design and through the choice of components, all requirements of the system specification were taken into account and – beyond that – we allow for spot-on flexibility in critical points. Thereby, we are confident that the present subsystem design provides the PhasmaFOOD system with a sound fundament for success.

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