D4.3 – Sensing modules ready for integration in the QAS module

Demonstration of the operation of the different sensors

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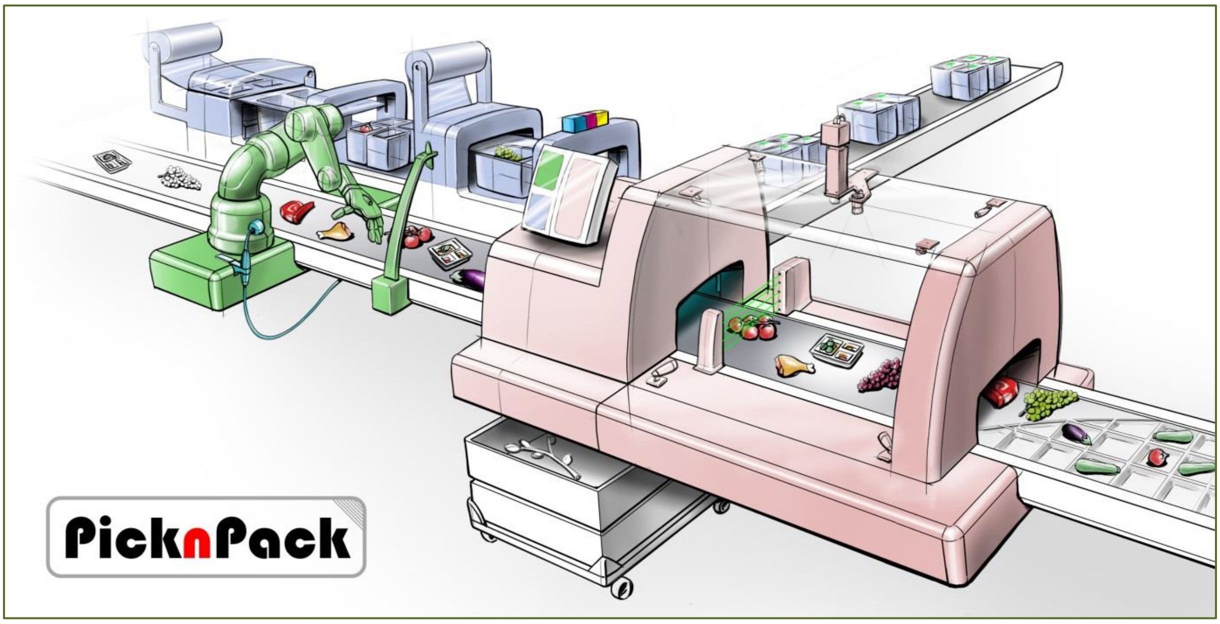

Flexible robotic systems for automated adaptive packaging of fresh and processed food products

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Dissemination level		
PU	Public	X
PR	Restricted to other programme participants (including the EC Services)	
RE	Restricted to a group specified by the consortium (including the EC Services)	
CO	Confidential, only for members of the consortium (including the EC Services)	

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1 Introduction

This deliverable contains an overview of the different sensors that will be used in the QAS-module of the PicknPack project. This deliverable is the results of Task 4.3 (Quality measurement of the products to be handled) and Task 4.4 (Development of a quality sensing platform). As explained in the 1st periodic report, it was decided to split the Quality Assement and Sensing module into two sub-modules: one for X-ray sensing and one for all other sensors: camera vision, 3D camera technology, hyperspectral imaging and microwave sensors. These sensors will be placed above a transportation system, specifically designed for PicknPack, which will be built in WP7, but is not yet available. For this reason, KU Leuven has ordered a conveyor belt to move the samples under the different sensors. Due to a mistake of the provider, the delivery of this conveyor belt has been delayed to October 6th, 2014.

The development of the X-ray module has been delayed since the respective hardware partner, Spectroscan, went bankrupt. A replacing partner has been identified and the necessary procedures have been started. The DoW has been updated to include a new, replacing deliverable for the X-ray module. Furthermore, it is important to mention that the delay on the X-ray submodule will not have an effect on the ongoing efforts for development and integration of the other submodule.

2 Overview of the different sensors of the QAS-module

2.1 Overview of the design of the sensing module

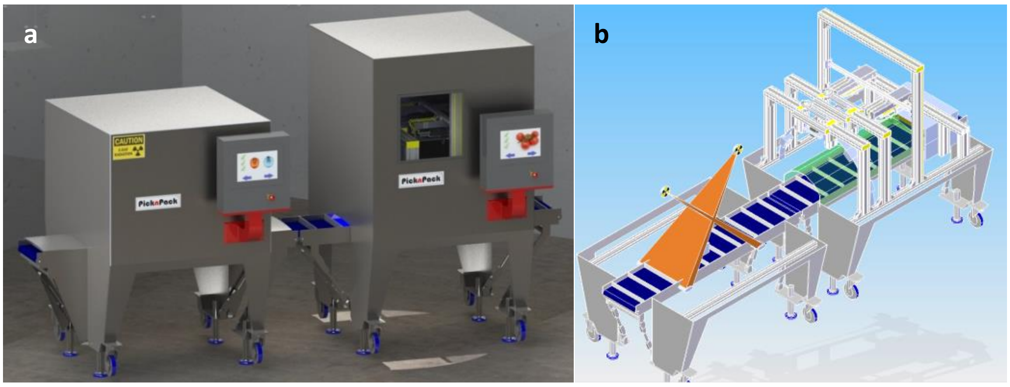

Figure 1 - Drawings of the sensing module. A) The outside view of the quality assessment module, b) the sensing module without the casing. From left to right: X-ray-imaging, RGB-imaging, hyperspectral imaging, 3D-sensing, microwave sensor. The green drawing in the right figure is a tunnel made of Plexiglas to protect the products from contaminations

In Figure 1 an overview of the complete sensing module is given. To mimic the transportation system used in the PicknPack project, it was decided to buy a flexible conveyor belt system that can mimic the behaviour of the final transportation system. In the PicknPack setup, all the sensors will be triggered based on the movement of the conveyor belt. The belt will send out a trigger pulse every so-many milliseconds. By triggering based on the travelled distance of the belt, we ensure that we obtain a uniform spatial resolution irrespective of the speed of the belt.

2.2 Camera vision and 3D-camera

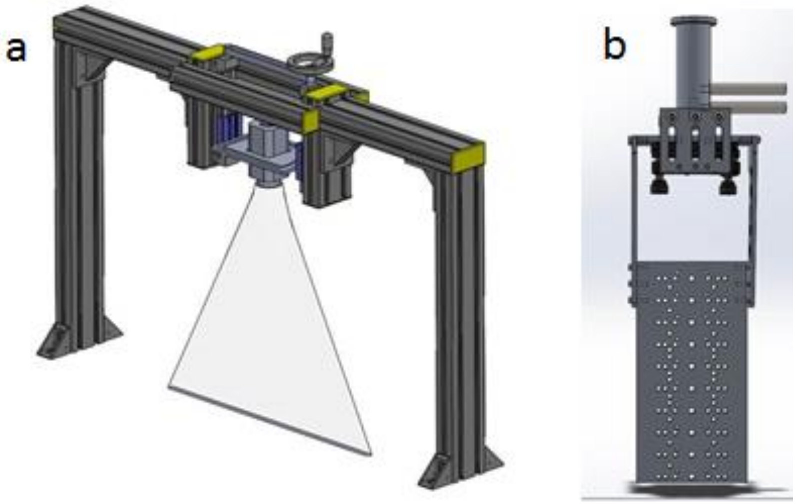

Figure 2 – Design of the mounting place of the RGB and hyperspectral camera. a) Drawing of the bridge to mount the camera above the packages. b) Drawing of the developed system to install the camera on the bridge, while preserving flexibility.

In Figure 2 the design of the mounting place for the RGB-camera and the hyperspectral camera is shown. The mounting place has been developed such that it maintains high flexibility in vertical and rotational movement, such that the camera mounting with respect to the conveyor belt or the transportation system can be optimized.

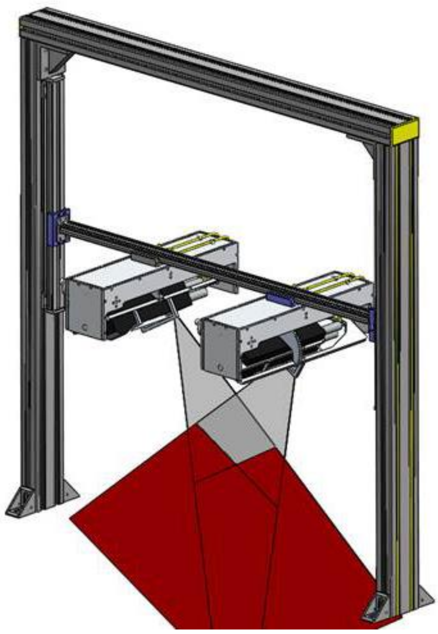

Figure 3 – Design of the bridge to mount the 3D-laser triangulation sensors above the packages.

In Figure 3 the mounting of the 3D-laser triangulation sensors above the package is schematically illustrated. This mounting allows to rotate the sensors and to move them in the vertical direction. The mounting setups described in Figure 2 and Figure 3 are currently in production.

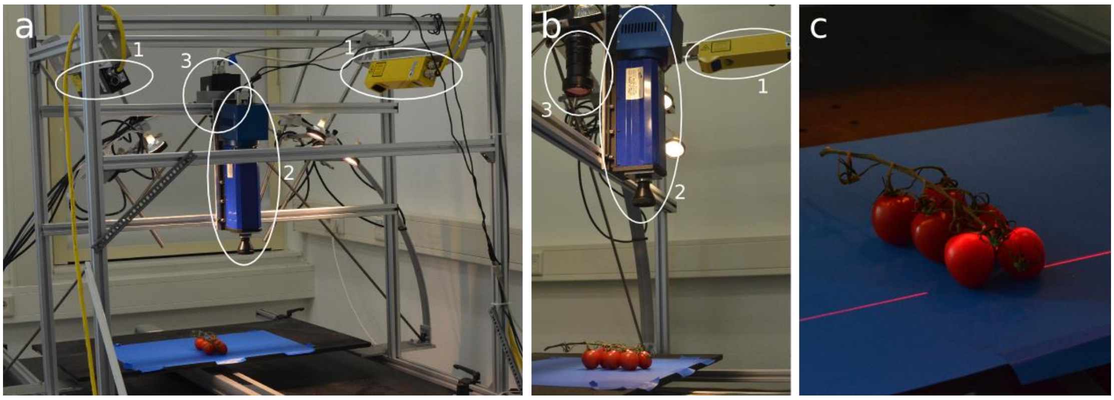

Figure 4 - A prototype version of the sensing module in Wageningen. The sensors shown in a) and b) are: 1) two 3D laser-triangulation sensors, 2) a near-infrared hyperspectral camera, and 3) a RGB line scan camera. c) shows a bunch of tomatoes that is being scanned by the 3D laser-triangulation sensor

In Figure 4 a prototype version of a part of the sensing module, as it is built in Wageningen by DLO is shown. This module contains three different sensors: 1) two 3D laser-triangulation sensors to sense the 3D structure of the products, 2) a hyperspectral camera to sense the product in the near-infrared part of the electro-magnetic spectrum, and 3) a 3-CCD RGB line-scan camera to get visual colour information about the surface of the object. The lighting arc to illuminate the scene for the colour and hyperspectral cameras is also visible in the back of the figure.

2.2.1 Colour camera

The 3-CCD colour line-scan camera is a camera that acquires high-quality colour information thanks to the fact that it records the Red, Green and Blue light separately, instead of using a Bayer filter. The camera has a resolution of 2048 pixels in the direction perpendicular to the movement of the conveyor belt (x-direction). For the PicknPack setup, with a width of the conveyor belt of 540mm, this results in a spatial resolution of approximately 3.7 pixels/mm. We deem a resolution of 1-2 pixels/mm to be sufficient for assessing the quality of the products.

The camera is currently synchronized with the other sensors in the module using a common trigger signal. The frequency of this signal can be altered to obtain higher or lower resolution in the direction of the movement of the belt (the y-direction).

To accurately measure angles and surfaces in the images, we need to compensate for lens deformations, sensor misalignments and perspective projections. This can be done by performing image rectification. To do so, we calibrated the camera to obtain the intrinsic camera parameters. This procedure requires several (10+) recordings of a calibration pattern in different orientations and distances from the camera. Based on the detected position of the circles in the images and the known dimensions of the calibration plate, the intrinsic parameters can be estimated. This procedure is currently a manual procedure. However, we will develop a semi-automated calibration procedure to be run on the QAS module. Moreover, the intrinsic camera parameters only have to be estimated ones if no changes to the lens or mounting of the camera with respect to the belt are made.

Acquisition software has been developed to get colour information for every object on the conveyor belt. Although the camera constantly scans the belt on its full width, the software analyses each scan line to segment the foreground (product) from the background (conveyor belt). The pixels belonging to each separate product are accumulated and once the product has completely passed the sensor, the colour image of only that product is sent to other processes for the analyses of the quality. The software can deal with multiple products placed side-by-side, as long as the products are separated and not touching each other.

2.2.2 3D laser-triangulation

We utilize two laser-triangulation sensors, viewing the products from 45 and -45 degrees off the vertical. This allow us to observe approximately 50% of the surface of the products (the top half).

The mounting setup developed in PicknPack allows accurate aligning of the two sensors, so that their laser lines are perfectly in parallel. The 3D point clouds that both sensors obtain are then aligned with a simple calibration procedure, consisting of two black dots on the conveyor belt so that the red laser light is completely absorbed by the dots and not by the rest of the conveyor belt. Using this, the orientation and offset of both sensors with respect to the belt and each other is determined.

Similar to the colour acquisition, we developed software to acquire the 3D profiles of the products. Only points above the conveyor belt are stored as part of the object. DLO is currently in the process of applying the same algorithm as in the colour acquisition, so that multiple products on the belt are separated in the 3D data and individually sent to other processes for further analyses.

2.3 Hyperspectral camera

The advantage of hyperspectral imaging in comparison with conventional RGB imaging is that, in hyperspectral imaging, the light spectrum is divided in many narrow wavelength bands, while conventional RGB imaging only measures three broad bands. This enables us to get a spectral fingerprint of each pixel in the image, yielding physical and chemical information regarding the measured products.

The setup that has been designed to mount the hyperspectral camera above the conveyor belt is the same as the one used for the RGB-camera, as illustrated in Figure 2. To be able to use the hyperspectral setup in an industrial environment it is necessary to get high quality and robust image detection. To achieve this, illumination should be as homogeneous as possible. For this reason, several different hygienically designed illumination setups have been simulated by using the ray-tracing software TracePro (Lambda Research, USA). The homogeneity and intensity of the simulated illumination on a flat sample and on a ball-shaped sample have been compared for each of these setups. From this analysis it was concluded that an arc-like setup which uses four halogen spots as light sources gave the most homogeneous bright illumination of the sample. This setup is illustrated in Figure 5a.

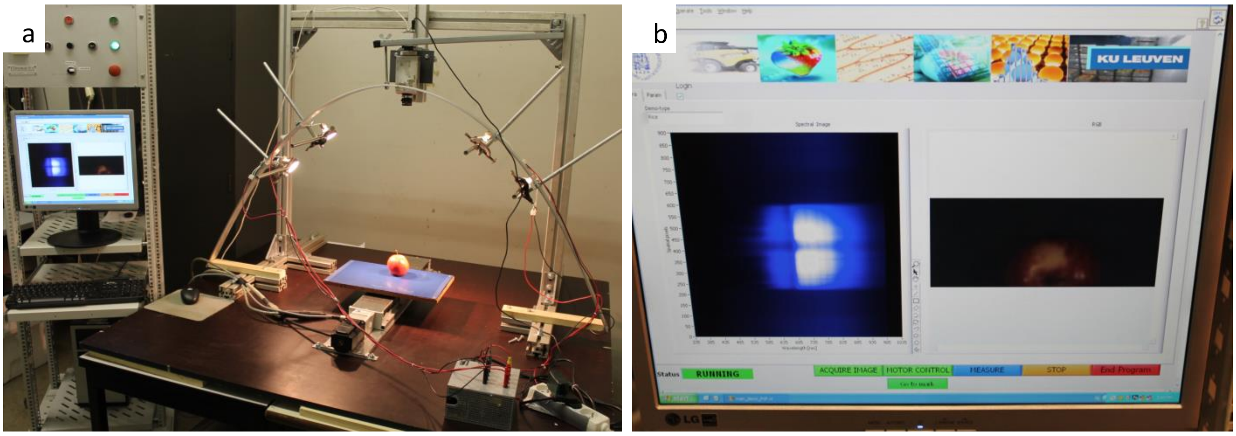

Figure 5 – Setup for hyperspectral imaging a) Setup with illumination unit, translation stage, hyperspectral camera (Specim + Baumer) and computer; b) LabView interface with the spatial-spectral image of the line of sight on the left and a fake-RGB image constructed line by line on the right.

In Figure 5 measurement of an apple on the laboratory setup for hyperspectral imaging is illustrated. This measurement is performed using a Baumer TXG14NIR-camera in combination with a Specim Imspector V10 spectrograph. The spectrograph separates the incoming light into its different wavelengths, which are measured by the camera. It is a line scanning device with a maximum frame rate of 39fps and it is sensitive for light in the VisNIR range of the electromagnetic spectrum (400nm – 1000nm) (spectral resolution is 9nm). At maximum frame rate, the camera has a resolution of 696 pixels in the direction perpendicular to the movement of the conveyor belt (x-direction). For the PicknPack setup, with a width of the conveyor belt of 540mm, this results in a resolution of approximately 1.3 pixels/mm.

The data gathered with the hyperspectral setup exists of images with spatial information in the x-direction and spectral information in the λ-direction (Figure 5b, left). By moving the product underneath the camera (y-direction), a series of consecutive images of different narrow spatial lines of the product is captured. These images are combined into a hypercube, which is a 3D-matrix containing spatial and spectral information from which virtual images, such as a fake RGB image can be calculated (Figure 5b, right). This hypercube contains relative reflectance values which have been calculated based on a white reference and a dark current image, which have been acquired separately (calibration). By processing these hypercubes, physical and chemical information can be gathered from the product. The workflow to process the raw data to usable data is presented in Figure 6.

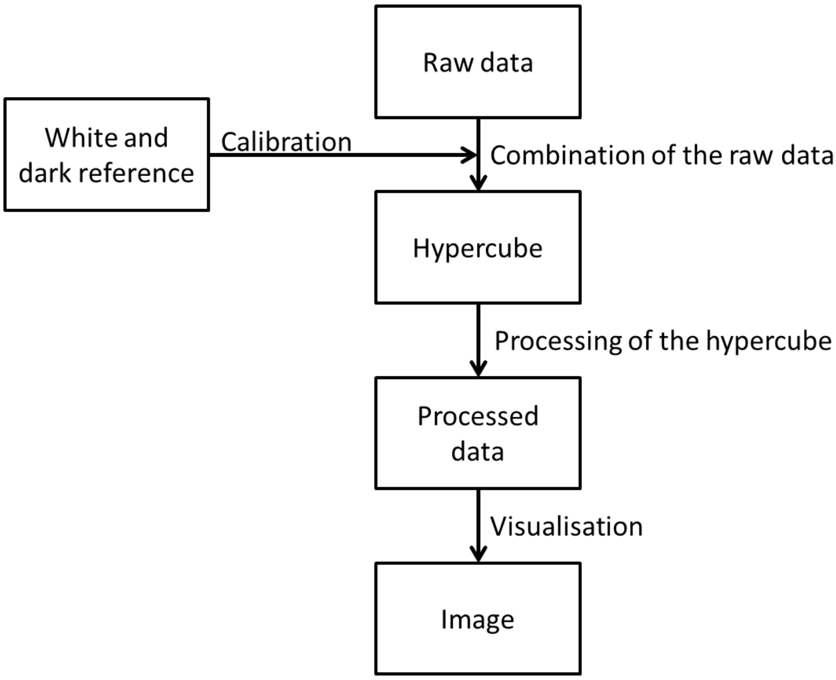

Figure 6 – Overview of the data flow in hyperspectral imaging

The disadvantages of the single line scanning system illustrated in Figure 5 are the rather low maximal frame rate of the Baumer camera (39 fps) and the fact that only one line is scanned at a time. For the required spatial resolution of 1 pixel/mm this corresponds to a maximal scanning speed of 39 mm/s, which is too low to reach the desired capacity of 30 packs per minute in the PicknPack project. Therefore, KU Leuven has acquired a prototype on-chip hyperspectral line-scan camera from IMEC (Leuven, Belgium) which scans 1088 spatial lines (128 different wavelengths) at the same time and has a maximal frame rate of 180 fps. This high frame rate is achieved by using another technology than the one used in the setup discussed above, i.e. wavelength separation by means of a spectrograph. The IMEC hyperspectral line-scan imager uses 128 static spectral filter structures covering the CMOS image sensor wafer (Figure 7). By using this technology, 128 spatial bands of 8 lines are measured at the same time, and each of these 128 bands corresponds to a different waveband. At maximum frame rate, the camera has a resolution of 2048 pixels in the direction perpendicular to the movement of the conveyor belt (x-direction). For the PicknPack setup, with a width of the conveyor belt of 540mm, this corresponds to a resolution of approximately 3.8 pixels/mm. At a 1 mm spatial resolution in the y-direction, the maximal scanning speed is 260 mm/s, which is far more than the maximal speed of the packages in the PicknPack line. This camera is ready to be used in the PicknPack line as shown in Figure 8. In Figure 8a a picture of a measurement of an apple is shown. Figure 8b shows a detail of the program. One frame of the measurement of the camera is displayed where every horizontal band of 16 lines corresponds to a different waveband in the 600-1000 nm range.

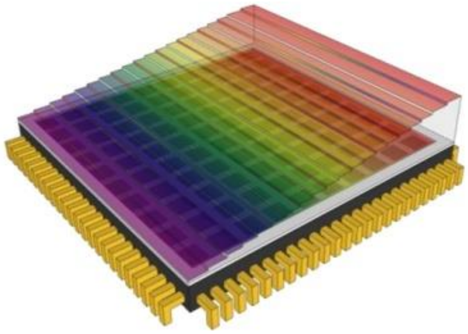

Figure 7 – Concept of the IMEC hyperspectral line-scan imager

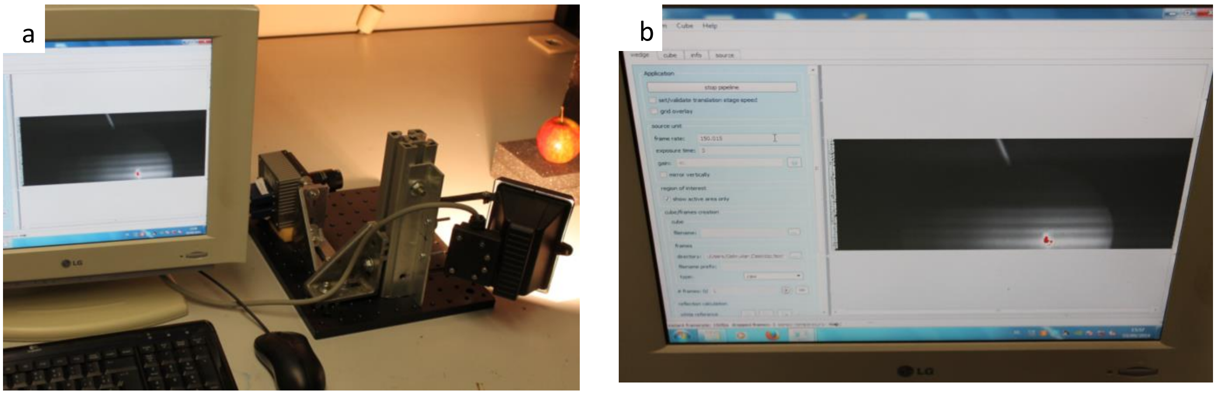

Figure 8 – Photos of the measurement of an apple with the IMEC hyperspectral line-scan imager: a) Setup with from left to right: computer, camera, light source and apples; b) Detail of the output of the camera.

While this technology can provide hyperspectral imaging at high speeds, the requirements for image registration are much higher. As the different wavebands for a spatial line in the image are acquired sequentially, speed variations might lead to registration errors and erroneous pixel spectra. It is expected that the shift from constant speed scanning to the stop and creep cycle will create considerable synchronization challenges for this camera technology. Therefore, the impact of the speed profile of the PicknPack line on the image registration and hypercube construction will be investigated by KU Leuven as soon as the exact speed profiles have been provided by WP6.

2.4 Microwave sensors

The proposed hardware and software used to acquire and analyse the magnitude and phase are introduced in this section. In Figure 9 the block diagram of the most recent version of the free space microwave transmission sensor setup is illustrated. As a result of the change in belt width, the number of antennas has increased from 16 in the first version to 32. The circuits have also been re-designed.

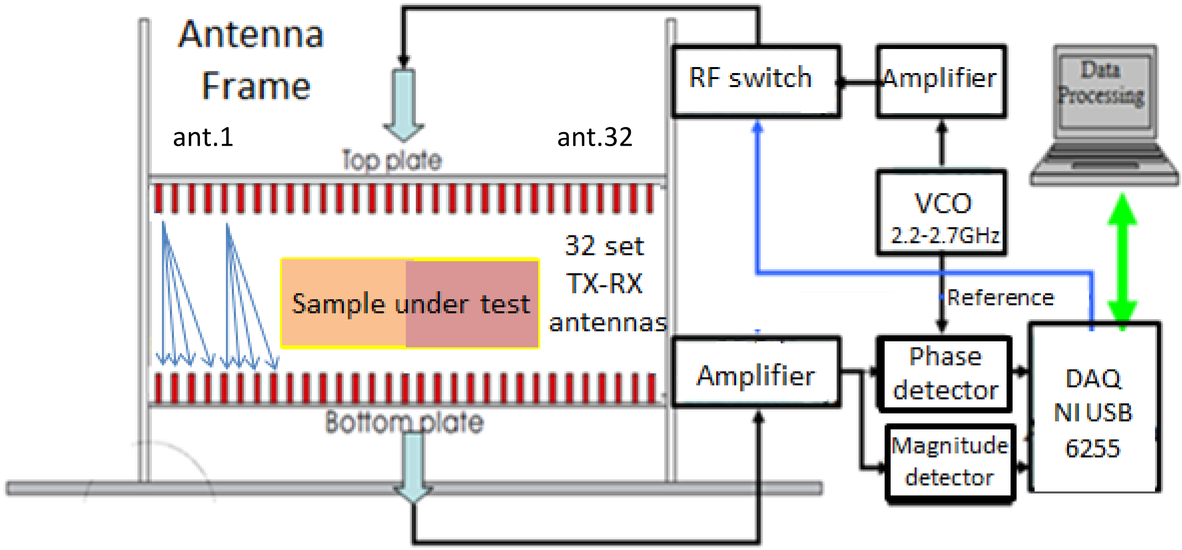

Figure 9 – Block Diagram of Microwave Sensor

2.4.1 Microwave Sensor Design and Implementation

2.4.1.1 Circuit Blocks

The free space microwave transmission prototype system consists of three main sections. The first section is the transceiver section, including RF source, a set of TX-RX antenna, and RF detector for both magnitude level and phase detection. The second section is the data acquiring section, which contains a Digital Input/Output Data Acquisition Card (DAQ). The third section is the Processing and Display section, which deals with the saving, analysing, and displaying the acquired data.

2.4.1.2 RF Source Design

Eight VCOs (Voltage Controlled Oscillator) of different frequencies have been designed as RF sources. They are listed in Table 1.

Table 1 - Frequency Setting for VCO

RF source& reference	Freq.(MHz)
1	2200
2	2550
3	2250
4	2600
5	2300
6	2650
7	2350
8	2700

2.4.1.3 Antenna Design

The antennas are microstrip antennas operating around 2.45 GHz. One element is shown in Figure 10 together with its radiation pattern. The 32-element array is shown in Figure 11 with 16 mm spacing between elements.

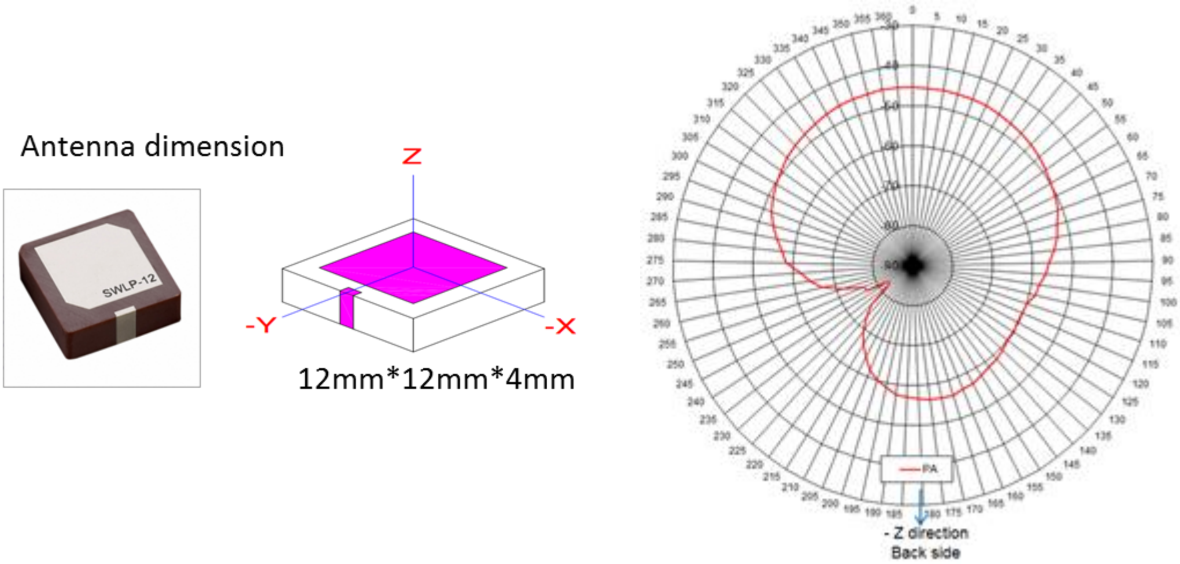

Figure 10 - Dimensions of Microstrip Antenna and Its Radiation Pattern

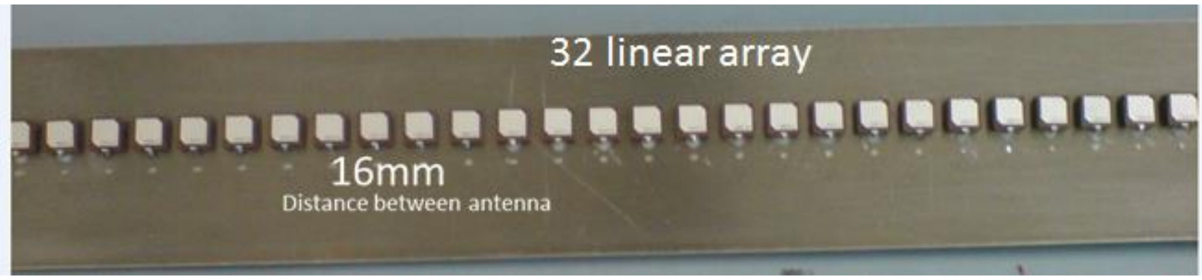

Figure 11 - 32-element Patch Antenna Array

The RF switch circuits have been designed to control the antenna elements in the transmitting array on the top plate to transmit and the antenna elements in the receiving array on the bottom array to receive so as to form multiple projections through the samples being measured.

2.4.1.4 Magnitude and Phase Detector

Circuits have been designed to measure the magnitude and phase of RF signals. In order to reduce interference from other VCOs, each detector is added a narrow band RF filter as a means of isolation.

2.4.1.5 Data Acquisition and Signal Processing

Free space microwave transmission sensor systems rely on signal processing algorithms to obtain the final results. The prediction algorithms may range from simple energy sensing procedures to sophisticated sensing algorithms. In our application, there is a requirement for software which performs three main tasks. Firstly, it controls the DAQ and switches to select the antennas required. Secondly, it acquires the transmission data of both the magnitude and the phase. Thirdly, it saves the data of the magnitude and phase. Matlab is selected to implement the ability to control the DAQ, acquiring the data from the magnitude and phase detector, and finally saving the data in files as a text.

2.4.2 Assembling of Microwave System and Associated Circuits

The prototype microwave sensor system consists of:

- VCOs with 8 frequencies
- RF switches
- 8 Power splitter that split RF signal 1 to 4
- 32 narrow filter of coaxial resonator
- 32 detectors magnitude and phase
- Use 64 analogue input and 4 digital I/O
- Power supply 5V/8A, +-5 V/1A, and 12 V/1A.

The data collected using Matlab shows that the assembled hardware system works properly.

2.4.2.1 Evaluation of the Microwave Sensor for Product Composition Assessment

Sample preparation

The container has been made from thin plastics with dimensions W-L-H (9-14-3) cm. Each container was filled with potatoes in half and meat in the other half, and so on as shown in Figure 12 below.

Figure 12 – Food Samples

Experimental results

The experiment has been focussing on testing the quality of a pack of a ready meal by placing a sample on the antenna frame. The existence of food will be quantized and displayed on the monitor as a colour bar to represent existence (location) of a sample. The colour bar representation is as shown in Figure 13 below. The interference bar is considered as air/space close to sample.

Figure 13 - Sample Index Representation

The goal of the experiment was to check the sensor performance when using more than 1 container. Antennas are sequenced from left to right, from antenna number 1 to antenna number 32. In Figure 14, the results of the monitoring of different food products by microwave sensing are displayed. In Table 2, the measurement results and error calculations are shown. As a result, the system can determine sample quantities accurately even though it still includes some errors. One of the reasons is that the system has been calibrated only for a single container.

Table 2 - Measurement and Error Calculation for Figure 14

Figure	Experiment setup (%)				Measurement result (%)				Absolute error			
	Air	Pot	Meat	Veg	Air	Pot	Meat	Veg	A%	P%	M%	V%
Figure 14a	38	25	12.5	25	34.4	21.9	12.2	25	-3.1	-3.1	-0.3	0
Figure 14b	25	25	25	25	18.8	34.4	28.1	18.8	-6.3	9.4	3.1	-6.3

(a)

(b)

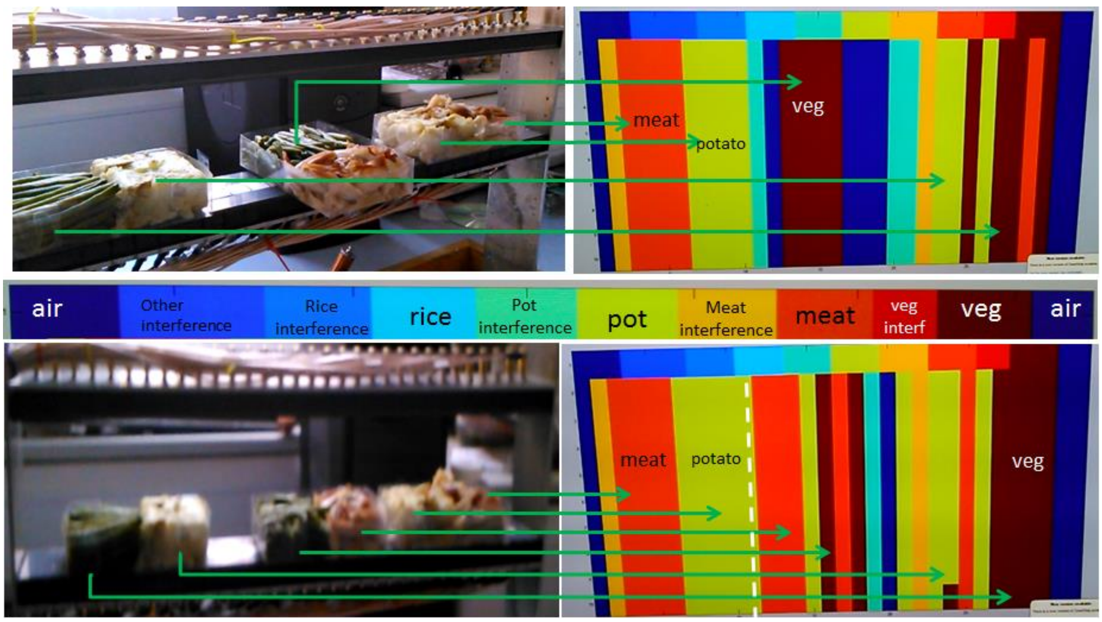

Figure 14 – Multiple containers placed on sensor

The hardware system of the microwave sensor is ready to scan products on a belt-driven production line. An algorithm for detecting and identifying the product and its composition has also been implemented. Tests have shown that the system can mostly determine sample compositions even with a small error.