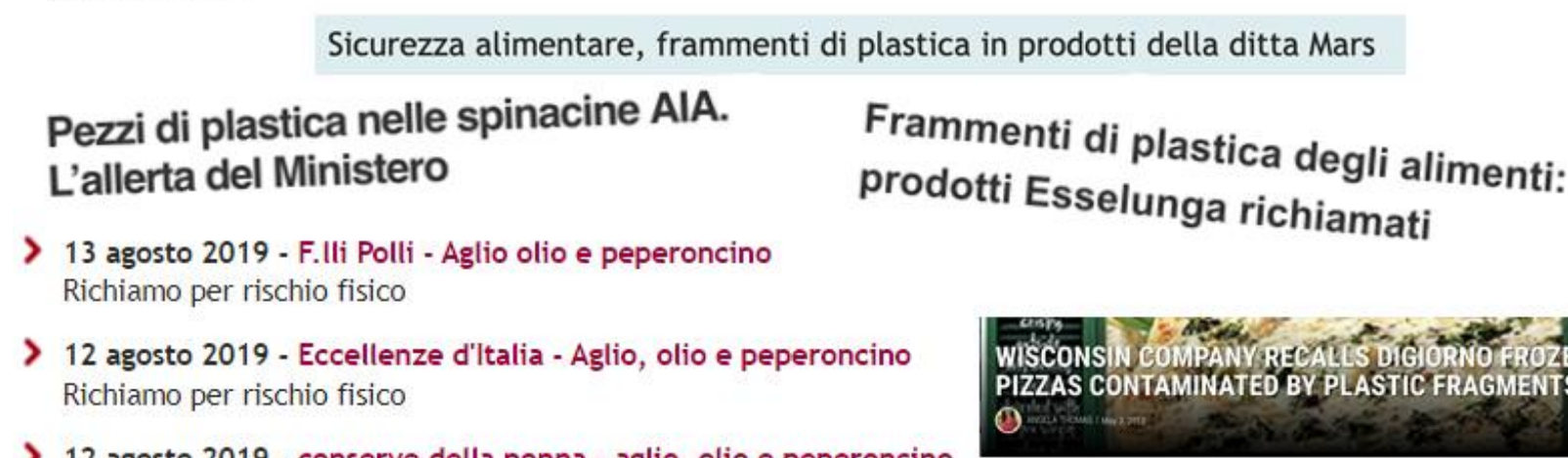


Research context and motivation

- The contamination of food and beverage with industry materials, such as metal, plastic, glass and wood, is still an open problem, even if safety mechanisms are usually installed to avoid these contaminations.



Sources	Examples of Contaminants
Field	Rocks/stones/sand, asphalt, metals/bullets, concrete particles, bones, wood fragments, and thorns
Processing	Glass, ceramic/shards, metal fragments, staples, blades, clips, needles, keys, screws, magnet fragments, washers, bolts, screening, plastic, grease/lubricants, rubber, insulation/seal materials, nail polish, jewelry, coins, pieces of gloves, finger cots, bandages, cigarette butts, gum, bones, pits, fruit stones, nut & animal shells, medications/tablets/capsules, wood, pens, and pencils
Storage and distribution	Metal, plastic, and wood fragments

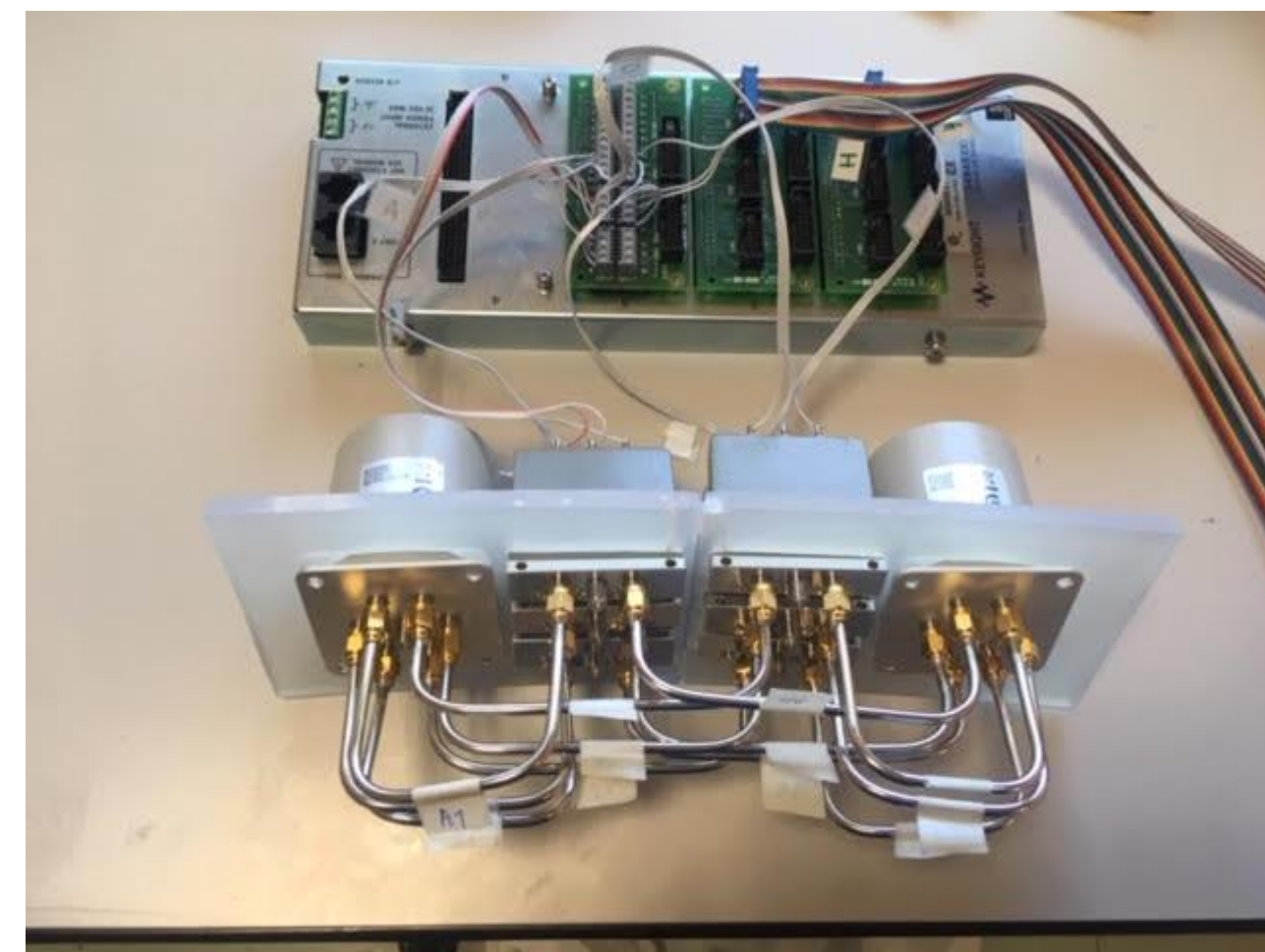
Table 1. Sources of Physical Contaminants in Foods

Available technologies	Limitations
Metal detectors	Conductive materials only
X-ray imaging	Low-density plastic, thin glass; ionizing radiations
Visible / Near-infrared imaging	Limited penetrating depth; water absorption
Hyper/multi-spectral imaging	Limited penetrating depth; expensive, time consuming
TeraHertz imaging	Expensive, limited penetrating depth
Ultrasound imaging	Contact required

	Class	Freq- uency	Wave- length
Ionizing radiation	Y	Gamma rays	300 EHz
	HX	Hard X-rays	10 pm
	SX	Soft X-rays	3 EHz
	EUV	Extreme ultraviolet	300 PHz
Visible	NUV	Near ultraviolet	3 PHz
	NIR	Near infrared	300 THz
	MIR	Mid infrared	30 THz
	FIR	Far infrared	3 THz
Micro- waves and radio waves	EHF	Extremely high frequency	300 GHz
	SHF	Super high frequency	30 GHz
	UHF	Ultra high frequency	3 GHz
	VHF	Very high frequency	300 MHz
	HF	High frequency	30 MHz
	MF	Medium frequency	3 MHz
	LF	Low frequency	300 kHz
	VLF	Very low frequency	30 kHz

Novel contributions

- An industrial application, complementary to existing device to ensure food safety, exploiting MWI and analyzing packaged food at the end of production chain, so that there are no further sources of physical contaminants



Adopted methodologies

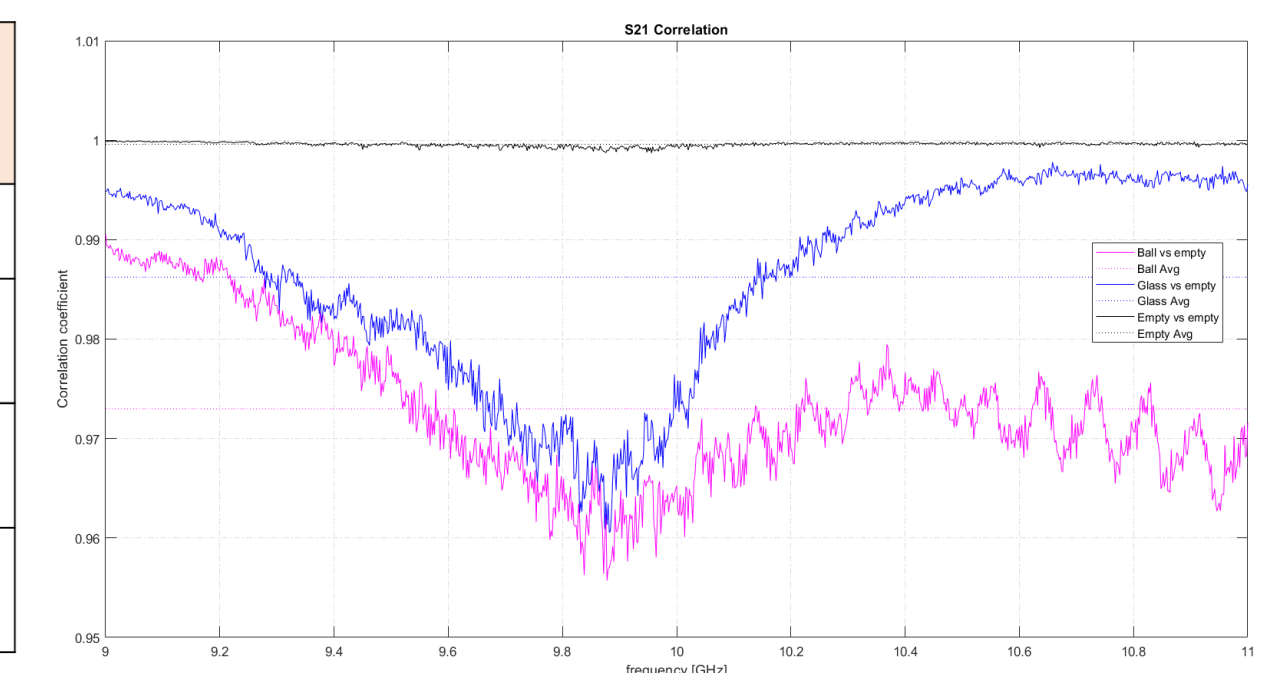
- Imaging approach: perturbation of a known scenario, adopting the distorted Born approximation

$$\Delta S(\mathbf{r}_p, \mathbf{r}_q) = \frac{-j\omega\epsilon_b}{4} \int_D \mathbf{E}_b(\mathbf{r}_p, \mathbf{r}) \cdot \mathbf{E}_b(\mathbf{r}, \mathbf{r}_q) \Delta\chi(\mathbf{r}) d\mathbf{r} = L(\Delta\chi)$$

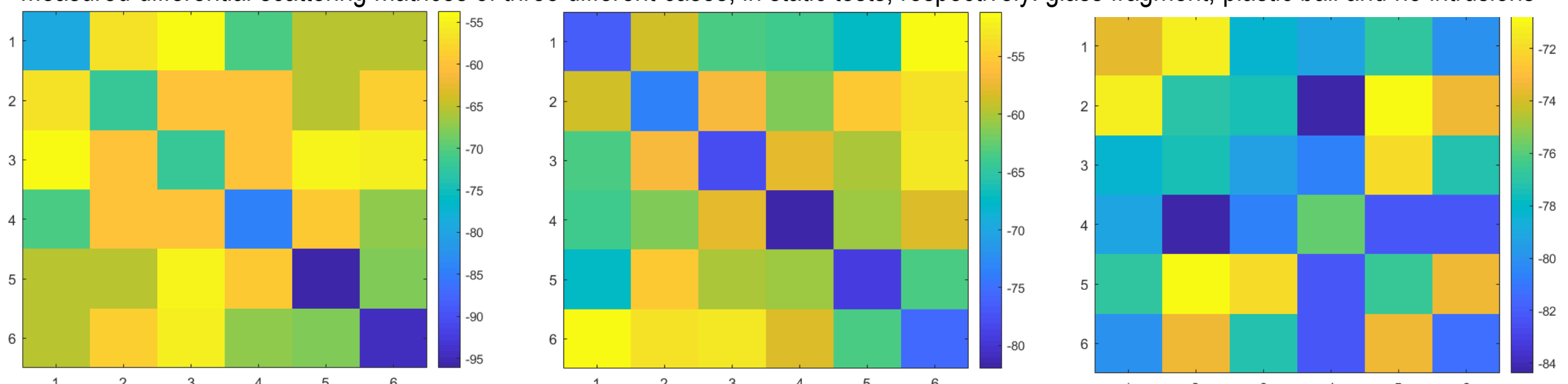
- Truncated Singular Value Decomposition as image reconstruction algorithm

$$\Delta S(\mathbf{r}_p, \mathbf{r}_q) = L(\Delta\chi) \quad \Delta\chi = \sum_{n=1}^T \frac{1}{\sigma_n} < \Delta S, u_n > v_n \quad [u_n, \sigma_n, v_n] = SVD\{L\}$$

Measured S12	Empty vs empty	Empty vs contaminant I (plastic ball)	Empty vs contaminant II (glass splinter)
L2 norm single frequency	0.0006317	0.0052	0.0041
Correlation single frequency	0.9994	0.9649	0.9730
Correlation average value 9-11 GHz	0.9996	0.9730	0.9862
Standard deviation 9-11GHz	0.0002106	0.0076	0.0099



Measured differential scattering matrices of three different cases, in static tests, respectively: glass fragment, plastic ball and no intrusions

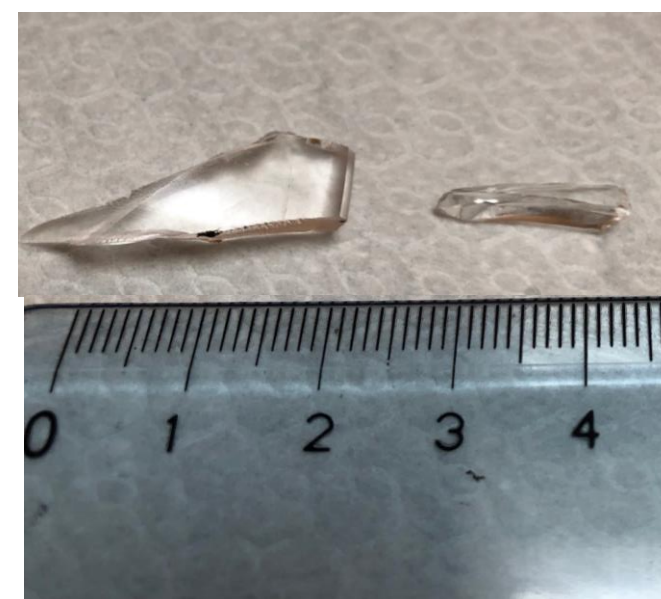
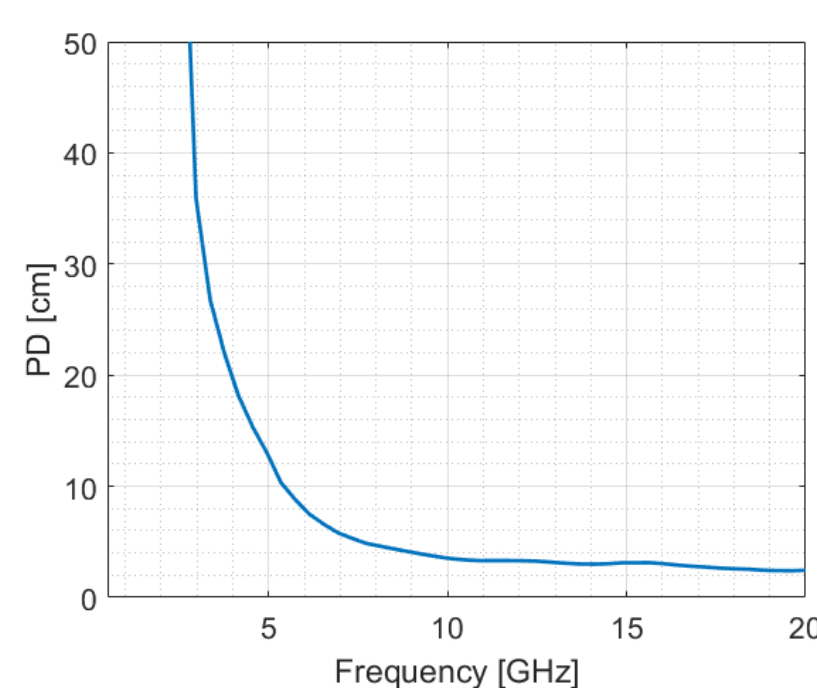


Future work

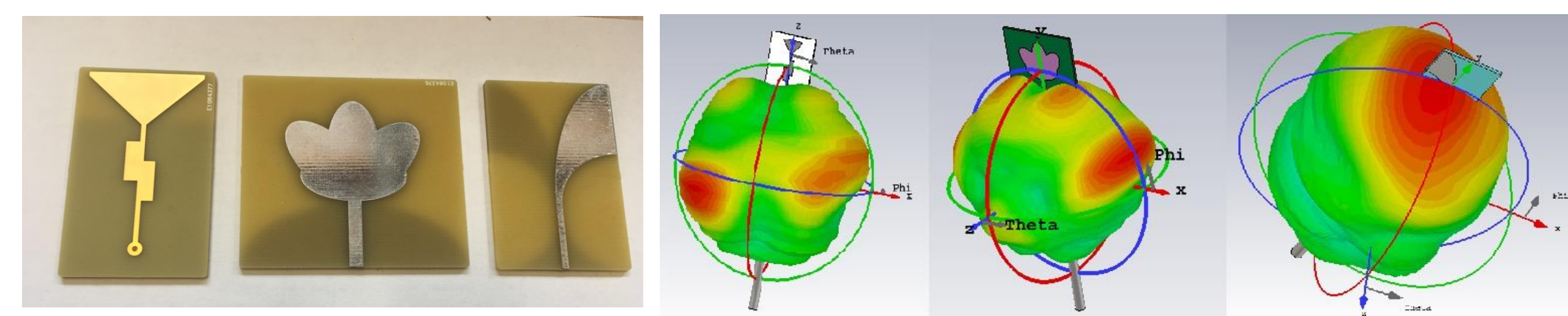
- Test the whole system with object in motion on the production line, employing all the developed antennas
- Train a classifier to better discern among different cases, with/without intrusions
- Investigate other reconstruction algorithms (Multiple Signal Characterization)
- Further test cases for different objects to analyze and made of different materials

Addressed research questions/problems

- The interest in MWI technology is increased in the last years, thanks to both the remarkable progress of the involved components and devices and the increase in computational power
- MWI is non-destructive and contactless, safe for operators thanks to low-power non-ionizing radiations, cost efficient and easy to operate and it aims to provide real-time and in-line monitoring of sealed food, with suitable hardware and software implementations
- Operating at microwave frequencies will allow to meet a proper trade-off between EM waves penetration depth and resolution in order to find intrusion in the order of millimeters



- Matter is composed by charged particles that are affected by the application of an external field; in a dielectric, as many food and relative packaging, electrons are well-bounded and cannot move throughout the material, but they slightly shift in position relative to each other
- MWI exploits the difference in dielectric properties of materials; the object under test is illuminated by low-power electromagnetics waves radiated by a set of antennas surrounding it; the resulting scattered EM waves are collected by the same antennas and analyzed properly in order to ensure the food safety
- Three different kind of antennas have been developed and printed on a PCB, aiming to find the best performing for each case scenario



Submitted and published works

- M. Ricci, J. Tobon., R. Scapatucci, A. Litman, L. Crocco, F. Vipiana "Microwave Imaging Technology for Food Contamination Monitoring", to be presented at Eucap 2020

List of attended classes

- 01NVSOQ – Advanced antenna engineering (6/2/2019, 6)
- 02NKUOD – Elettromagnetismo applicato (30/1/2019, 8)
- 01QDNRP – La sicurezza degli alimenti - identificazione dei pericoli e gestione dei rischi (28/3/2019, 6)
- 01SFURV– Programmazione scientifica avanzata in Matlab (15/05/2019, 4)
- 01SYBRV – Research integrity (19/2/2019, 1)
- 01MMRRV – Tecniche numeriche avanzate per l'analisi ed il progetto di antenne (14/3/2019, 4)