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Development and evaluation of low-cost frequency based sensor for non-destructive detection of Paneer spoilage

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Abstract

Food spoilage occurs due to the microbial and enzymatic activities which alter the composition of the product with their metabolites. Paneer, also called Indian cottage cheese, gets spoiled due to poor quality of milk, faulty production methods, unhygienic processing conditions, and poor refrigeration facilities. The spoilage has been detected conventionally by destructive sampling methods. This paper proposes a non-destructive method of detecting paneer spoilage using a Radio-Frequency (RF) based sensor. For generating a low frequency of 100 kHz, and passing it through the sample, a set up was made. Spoilage changed the composition of the medium which subsequently changed the dielectric constant of the medium. Therefore, frequency change was occurred in case of low frequency's passage through the sample. Initially, prepared paneer samples were deliberately spoiled keeping at temperatures of 0, 10 and 25^{0}C up to 21 days. Then, the frequencies were measured every three days. The results showed that for the paneer kept at 25^{0}C, the frequency changed from 67±0.2 kHz on day 0 to 57±0.2 kHz on day 21.

Keywords: RFID, Sensor, Antennas, Mixed Milk, paneer, Coagulation

Introduction

Food quality is an important aspect for assuring public health and safety. Assuring and monitoring of food quality are important steps in food manufacturing, storage and distribution. Food safety is a growing concern as mentioned in the Hazard Analysis and Critical Control Point (HACCP) by the U.S. Food and Drug Administration (FDA).

It is a challenge for the food microbiologists, engineers, and technologists to develop the best ways to prevent the entry of microorganisms, inhibit those already present along with their enzymes, and prevent the growth and action of those that survive processing treatments. There are different variety of spoilage microorganisms among dairy products because of the variation of methods followed in production, formulation, processing, packaging, handling, storage, and distribution. The primary spoilage microorganisms include aerobic psychrotrophic Gram-negative bacteria, yeasts, molds, hetero-fermentative lactobacilli, and spore-forming bacteria (Ledenbach and Marshall, 2009). Psychrotrophic bacteria can produce extracellular hydrolytic enzymes, and the extent of post-processing contamination of thermally processed milk products with these bacteria determines their shelf life (Ledenbach and Marshall, 2009). Fungal spoilage of dairy foods is attributed to the production of several metabolic by-products, causing off-odours and flavours, apart from visible changes in colour or texture. Coliforms, yeasts, hetero-fermentative lactic acid bacteria, and spore-forming bacteria can produce gas, and cause blowing defects in cheeses (Ledenbach and Marshall, 2009). The rate of spoilage of many dairy products has been slowed by the application of various treatments in combination or individually: pH reduction by fermentation of lactose to form lactic acid; adding acids or other approved preservatives; introducing a desirable micro flora that restricts the growth of undesirable ones; adding sugar or salt to reduce the water activity (a_w); water removal; packaging in modified or controlled atmosphere; and freezing.

The Operation Flood program, the world's largest and most successful integrated dairy development program initiated in 1970s in India, has led it to rise as the largest milk producing nation in the world. According to the data published by Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India, India ranks first in milk production, which is about 18.5% in the world, with an annual production of 165.0 million tons during 2016-17 as compared to 155.5 million tons during 2015-16. About 45-50 % percent of the total milk produced in India has been used in manufacturing of traditional dairy products viz, ghee, khoa, chhana, paneer (Kumar *et al.*, 2005). Milk products have longer keeping quality than milk at ambient temperatures. Moreover, the

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conversion of milk into products utilizing processes of heat and acid coagulation, heat desiccation, separation and fermentation is more profitable than the sale of fluid milk. The major strength of this milk product industry is likeability of the products by people. Milk and milk products have been an essential part of Indian diet since times immemorial. These products play a very important role in human health and dairy industry. In the Kusana and Saka Satavahana periods (75-300 AD), there were references of a product made from warm milk and curds. During that period, the Sakas and Gujars migrated from central Asia first to Persia then to India. These nomad people produced a certain kind of cheese for the first time. In Iran, this nomadic kind of cheese is called Paneer Khiki (paneer means cheese and khiki means a container made of stomach lining from goat or, sheep, hence the name for similar type of cheese made from rennet). In Afghanistan, it is a staple food that is called Paneer-Khom (from raw milk) and Paneer-e-Poktha (from boiled milk). It is very popular now in north, west and central India. A product like soft unripened cheese, similar to paneer named Kareish is found in Egypt, Armavir in west Caucasus and Feta in the Balkans (Kumar *et al.*, 2014).

Paneer production consumes around 5% of the total milk produced in India (Kumar *et al.*, 2014). Paneer is a heated and acid coagulated indigenous milk product. It contains less than 70 percent moisture, and approximate 25-27 % fat on dry matter basis. It is very widely used in India as a base material for the preparation of various sweets like Paneer Tikka, Paneer Karahi, Paneer Khurma, Paneer Kopta etc. The production of Paneer was largely confined to the eastern region of the country. But nowadays, it is produced throughout India, Pakistan, Bangladesh and Nepal.

The spoilage of food products can be detected by sensory evaluation, and validated by chemical and microbiological analysis. These methods of evaluation of spoilage involve destructive sampling. The result is that the food samples cannot be reused. Catering to this need, several food spoilage detection sensors have been fabricated. Electronic nose and tongues, revolutionary sensors for aroma sensing food products were developed years back. The application of electronic nose in dairy products has been reviewed elsewhere (Ampuero and Bosset, 2003). A sensor based on cysteine modified silver nanoparticles (AgNPs) for milk quality evaluation has been developed (Lakade and Shetty, 2017). A non-destructive method of detecting paneer spoilage was proposed in this study using a Radio-Frequency (RF) based sensor. It was based on the idea that when food is spoilt the ionic content, dielectric constant and thermal conductivity change. Passing a RF wave through the food and measuring it, showing decrease in the frequency of RF systems can vary from the lower ranges of the spectrum around 135 kHz to the range of 5.875 GHz. The earlier several RF based sensors have been fabricated by researchers. Passive (battery-free) RF identification (RFID) sensor has been developed to monitor food quality and freshness (Potyrailo *et al.*, 2012). A wireless sensor based on carbon black/ organic polymer composites (polyethylene vinyl acetate and maleic anhydride) to detect volatiles and biogenic amines in food has been developed (Fiddes and Yan, 2013; Fiddes and Yan, 2013). Another wireless sensor using ultra high frequency RFID tags monitoring permittivity of food sample as a function of time has been developed (Nyugen *et al.*, 2015). Another type of sensor based on polyethylene vinyl acetate and multi-walled carbon nanotube has been developed (Tanguy *et al.*, 2015).

Materials and Method

This research work Entitled "Development and Evaluation of Low-Cost Frequency Based Sensor for Non-Destructive detection of Paneer Spoilage" was carried out in the Food Science and Technology Laboratory of Agricultural and Food Engineering Department, Indian Institute of Technology (IIT) Kharagpur-721302, India during Post-Doctoral Research work of the first author.

Materials

Raw Materials:

The raw materials such as Fresh Buffalo milk and Fresh Cow milk were procured from Technology market IIT, Kharagpur. Paneer was prepared from milk as per the process flow chart given in Fig. 1 and Fig. 2.

Method

Treatment combination: Four different ratios of Buffalo milk to Cow milk viz. 100:0 50:50, 60:40, 70:30 & 80:20 and coagulation temperatures of 80 & 85^{0}C were used for making Paneer.

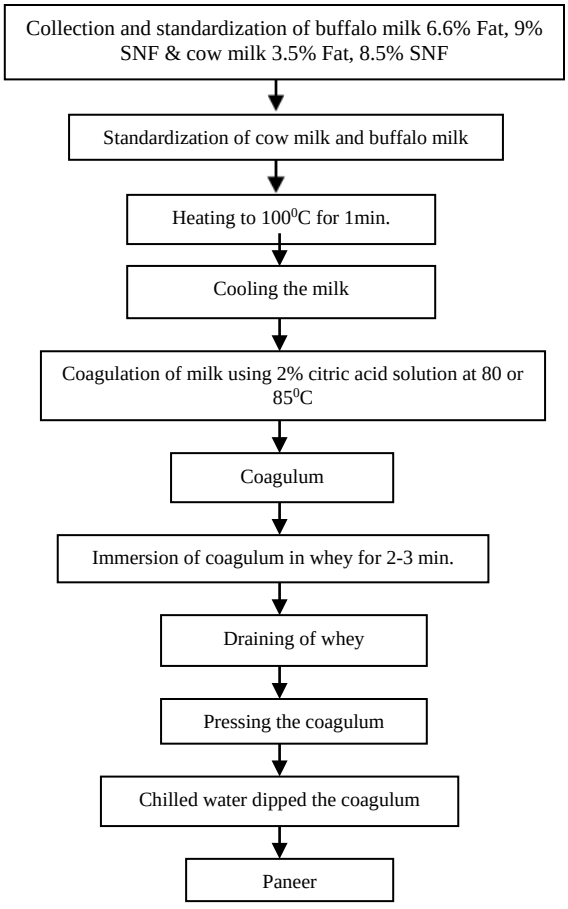

Fig. 1 Flow diagram for paneer making

The analysis of milk revealed its fat content for cow milk to be 3.4±0.2 %, buffalo milk to be 5.8±0.1 % and total solid of cow milk to be 9.1±0.4 %, buffalo milk to be 8.6±0.3 %. Moisture content of Paneer made from cow milk was found to be 56.5±0.2 % and buffalo milk to be 57.8±0.3.

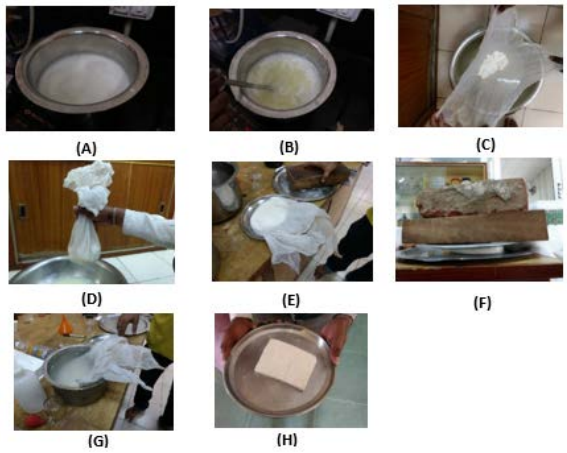

Fig. 2 (A) Boiling of milk (B) Coagulation of milk after addition of 2% citric acid (C) Separation of whey from coagulated product (D) Hanging of coagulated mass to separate rest of whey (E & F) Pressing of coagulated mass (G) Dipping of Paneer into cold water for 10 mins and (H) Paneer cut into piece

Method of Analyses

Chemical analysis: Fat, Protein, Lactose, Ash, Total Solids and pH were estimated by using standard procedure laid down in FSSAI Lab Manual in Milk and Milk Products (2015) (FSSAI Manual of methods of Analysis of Foods, 2015).
Microbial Analysis: Standard Plate count, Yeast & Mold count, and Coliform test were evaluated by using standard procedure laid down by regulatory agencies (Indian Standard, 1977; Manual in Dairy Bacteriology, 1972; Indian Standard, 1999; FSSAI Manual of methods of Analysis of Foods, 2012).
Sensory Evaluation: The products developed were subjected to sensory characteristics comprising of color, flavor, texture, taste and overall acceptability of paneer samples by a panel of five judges. The evaluation of the product was carried out by using the 9-point Hedonic scale (Srilakshmi, B. Food Science, 2002). The data obtained was analyzed statistically for its validity by using factorial design and critical difference (C.D.) technique (Imran RL, Coover WB, 1983).

Correlating fat content of sample with storage time and temperature:

Fat is a rich source of energy. Microorganisms use this as the carbon source, and grow in number thereby increasing the colony forming unit (CFU) level. So, the fat content of paneer decreases with time. Hence, an experiment was setup to detect the change in fat content of paneer along with days up to 21 and storage temperature (2^0C, 10^0C and room temperature).

Development of Radio Frequency based sensor:

Measuring fat or CFU of paneer is a destructive process, and the resultant paneer sample would be improper to use. A non-destructive method of detecting spoilage has been used in this study. Every medium has its own dielectric property. Setup has been made to generate a low frequency of 100 kHz and detect it via an oscilloscope. A change in composition of the medium changes the dielectric constant of the medium. Measuring Dielectric is a costly process. In this process, the low frequency is passed through the sample. When a low frequency is passed through the sample, the change in the frequency is being detected. This frequency change is being brought about due to the changes in the dielectric constant of the medium.

Setup to generate frequency using 555 timer IC and the detection of change in frequency:

A simple setup was made using a 555 timer IC to generate frequency of 100 kHz and detect it via an oscilloscope. The components of the setup are shown in Fig. 3-6. Paneer was wrapped in foil and put into the sample holder. The frequency was measured for samples stored at temperatures of 0^0C, 10^0C and 25^0C up to 21 days for every 3 days.

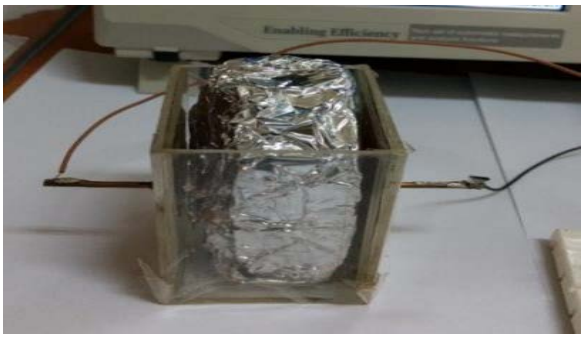

Fig. 3 The sample holder

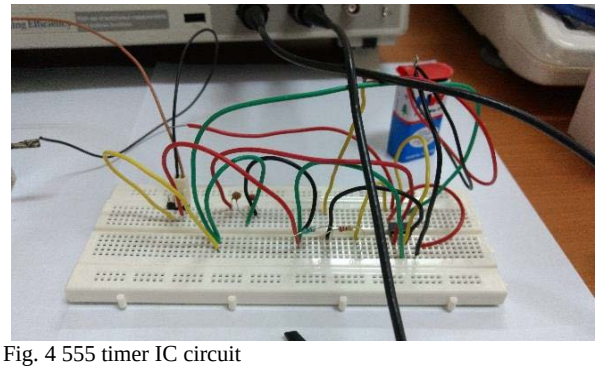

Fig. 4 555 timer IC circuit

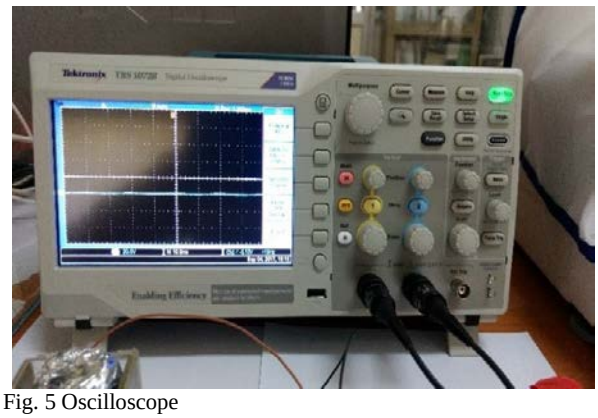

Fig. 5 Oscilloscope

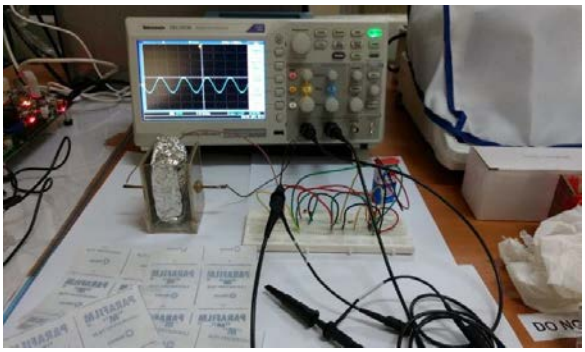

Fig. 6 The setup along with the paneer sample

Setup made of WARP Kit along with Sample holder:

WARP kit as in Fig. 7 was programmed using Xillinx software for 2 RF antenna configurations. Then, Matlab programming was used for developing a program to send a frequency of 100 KHz through the sender antenna and detect the received signals through the receiver antenna.

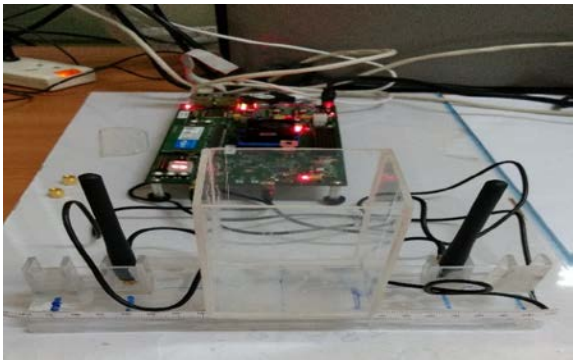

Fig. 7 The WARP Kit along with the Sample holder

Results and Discussion

Effect of temperature and number of days on the fat content:

The paneer sample fat% was evaluated for every 3rd day up to 21 days for different storage temperatures. The data was plotted graphically as shown in Fig. 8.

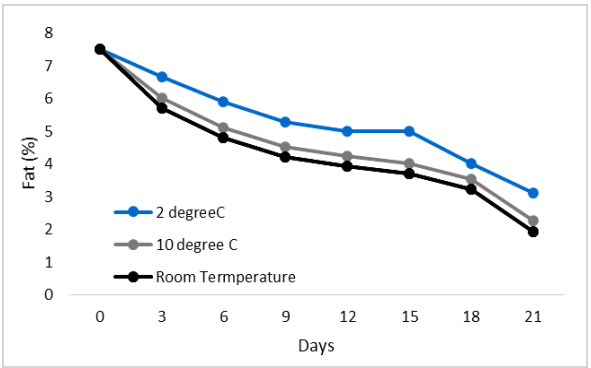

Fig. 8 Fat content of paneer as a function of storage time and temperature

The fat content of paneer samples decreased with storage time at each storage temperature. The change in fat content of paneer was more prominent for the sample stored at room temperature.

Effect of temperature and number of days on the CFU count:

Microbial analysis was done by measuring Colony Forming Unit (CFU) of the paneer sample for the different storage temperatures of 4^0C, 7^0C and the room temperature. The data was calculated and plotted as shown in Fig. 9. X-axis contains number of days over which the experiment was carried out and Y-axis contains the Log_{10} Scale data of CFU.

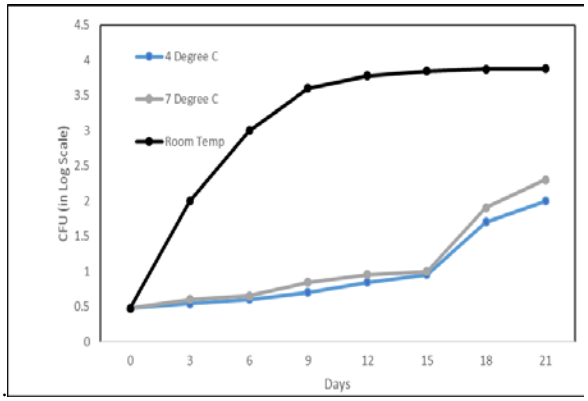

Fig. 9 CFU (in Log_{10} Scale) vs. days at three different temperatures

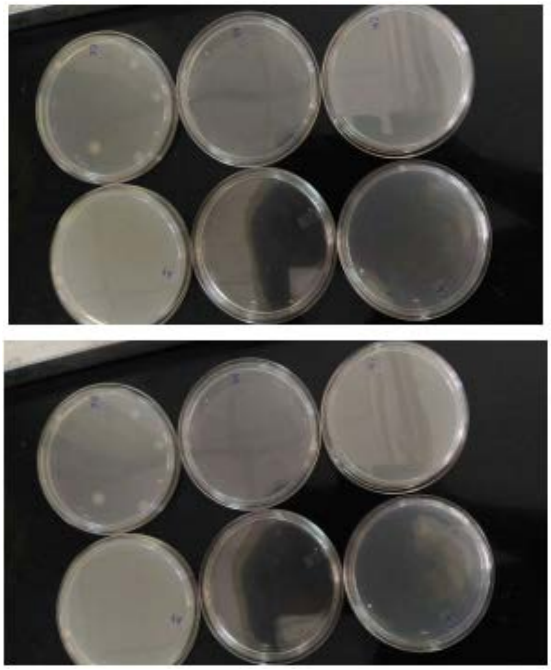

Fig. 10 Microbial colonies as visible in the plates

Sensory evaluation of paneer samples:

Initially, paneer was prepared using different combination of coagulation temperatures, and mixed milk ratios (buffalo milk: cow milk). Among all, the paneer made by coagulation of mixed milk (85:15) at 85^0C was found to score the highest in terms of

flavour, body & texture, colour & appearance on a 9-point Hedonic scale.

Setup using a 555 timer IC to generate frequency and detection of change in frequency:

A frequency of 100 kHz was passed through paneer sample wrapped in foil, and put into the sample holder and detected via an oscilloscope by connecting Pin 3 to the probe. The data obtained from the setup for every 3rd day up to 21 days at 0^0C, 10^0C and 25^0C is tabulated as below in Table 1.

Table 1- Frequency obtained after passing 100 kHz through samples

Days	Storage temperatures		
	0^0C (kHz)	10^0C(kHz)	25^0C(kHz)
0	67±0.2	67±0.1	67±0.2
3	62.5±0.3	62±0.2	61±0.2
6	62±0.1	61.5±0.2	59±0.2
9	61.5±0.1	60±0.3	58±0.2
12	61±0.2	60.5±0.1	57±0.3
15	60.5±0.2	60±0.3	57±0.1
18	60±0.3	59.5±0.1	57±0.2
21	59.5±0.1	59±0.3	57±0.2

Inconsistent decrease in temperature was seen with the 555 timer IC setup. Also, when the setup was used for a long time, it got heated up which caused a change in the supplied frequency of 100 KHz. Hence, an alternate method was used. WARP kit was used to generate a frequency of 100 KHz, and further analysis was carried out.

Setup made of WARP Kit along with Sample holder:

The WARP kit frequency of 100 kHz was sent through the sender antenna, and the received signal was detected through the receiver antenna. The data generated is tabulated in Table 2 and seen as constellations and waveforms in Figures 11 & 12. The final difference was noted as a graph.

Table 2- WARP V3 Kit was used to see the change in frequency with increase in spoilage days

Days	Transmitter (Tx)	Receiver (Rx)	Δ (Rx –Tx)
0	0.9487	1.037	0.0883
3	0.9417	1.027	0.0853
6	0.9347	1.017	0.0823
9	0.9277	1.007	0.0793
12	0.9207	0.997	0.0763
15	0.9137	0.987	0.0733
18	0.8967	0.967	0.0703
21	0.8897	0.957	0.0673

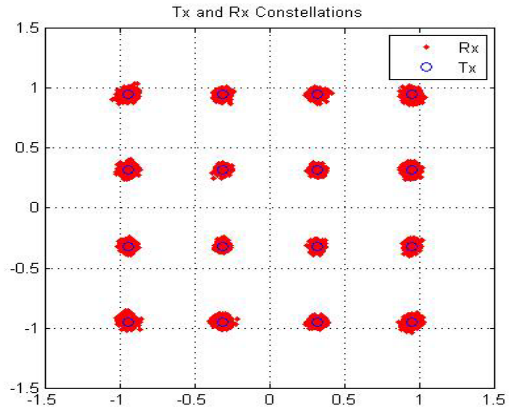

Fig. 11 Constellation data for sender and receiver antenna

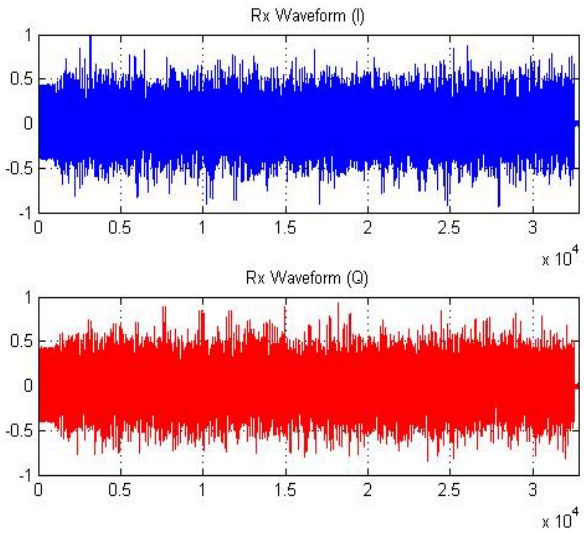

Fig. 12 Waveform data for sender and receiver antenna

From, the data analysis of the constellation plot it can be seen that there was a changed difference in the plot when spoiled paneer sample was used. Further, the analysis of the waveform data was carried out which also showed marked differences which can be observed by naked eyes. Also, an experiment has been carried out with changing the distance between the two antennas.

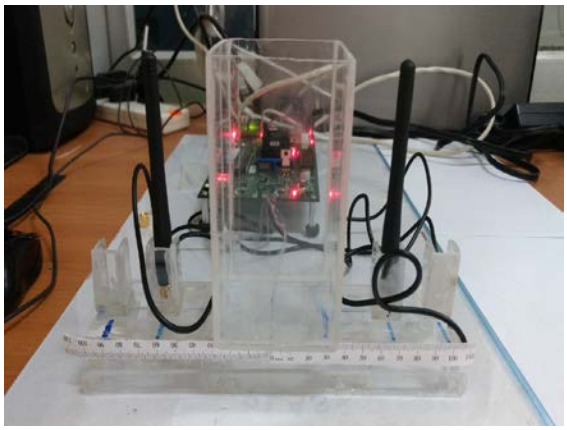

Fig. 13 Changing the distance between the two antennas

Conclusion

From, the data analysis it can be seen that there was a difference in the frequency when spoiled paneer sample was used. It can be concluded that RF based sensors can be used for non – destructive evaluation of food spoilage. Radio Frequency Identification (RFID) systems were favoured over other identification and detection techniques mainly because of their robustness, non – line – of – sight operation and versatility.

Declaration of conflict of interests:

The authors declare no conflict of interest, in terms of scientific, financial and personal.

Acknowledgement

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