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A New Approximation to Classify the Liquids Measured in Microwave Frequency Range

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Abstract

Different classification techniques have been proposed to analyze the measurement results in order to show that the liquids measured in the microwave frequency range can be separated. Furthermore, it has been shown that the proposed process can be applied successfully with different liquid quantities. Furthermore, the effect of different type containers has been demonstrated. In this context, five different liquids have been measured between 0.8-5 GHz in this study, by using ring resonator method. Thus, the ability of the proposed model has been demonstrated by the success of the measurement method and classification techniques.

Keywords: classification, liquids, ring-resonator method, transmission parameter, PCA, k-means

1. INTRODUCTION

The dielectric parameters can be used for quality control process. Because, each sector wants to know the structure of the material they use and follow the content change. Recent studies have shown the wide range of applications of liquids in science and industry by their characterization [1], [2]. Monitoring changes suffered during the processing of a product is important for the quality-control process. Therefore, the preliminary information about the preferred sample will facilitate the next steps. For example, the change in grape juice or fresh milk that is converted into another product can be explained by the analysis results obtained in raw condition.

The complex permittivity of high-loss liquids was measured in the frequency band of mm wave and wine analysis was performed. The reason for preferring the mm wave frequency band is that the complex permittivity of water reaches its maximum values in this frequency range. In addition, when the amount of water is increased in this study, the change in the complex permittivity (ε) of the mixture (wine and musts) has been shown for wine quality [3]. A new method has been proposed to analyze the dielectric effects at four different single-frequency measurements by positioning two sensor antennas in a linear fashion in order to determine the impurities in aqueous substances [4]. In addition, a Group Method of Data

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Handling (GMDH), which is a kind of neural network, has been used to predict the permittivity values by using the correlation process [5].

Many measurement methods can be used in microwave and millimeter wave frequency bands to determine the complex permittivity of the liquids or solids [3], [6], [7]. Ring Resonator Method (RRM) is used to obtain the dielectric properties of any materials. In this context, this process can also be applied for quality control of a product. Thus, a brief review of the contributes of permittivity measurement, which is related to the molecular structure, can be repeated. A non-destructive measurement of the permittivity can be used for the desired purpose after developing the most appropriate model and algorithm after performing measurement methods [8]. Since the complex permittivity is sensitive to the ionic content of the material and the water, it is possible to understand the structural change of the measured material [9], [10]. The quality structure of asphalt pavements was investigated by measuring the permittivity value between 7-17 GHz [11]. The permittivity of liquids as well as solids can be calculated non-destructively with the aid of the S_{11} reflection coefficient [12], [13]. On the other hand, the permittivity of mixture was extracted by considering the aggregation of solute and solvent molecules in the liquids using mixing rules [14].

In recent studies, it has been observed that machine learning methods are frequently used in characterization and classification processes. This approach may be particularly useful in the production of a new material or in the determination of properties of a material. In this context, 3D materials are used to characterize metallic materials in order to lead texture analysis, and the results are analyzed by Failure analysis method [15]. The color and texture properties used in existing algorithms as well as the lighting conditions supported by the thermal image and the effect of color diversity on the identification of materials have been successfully demonstrated [16]. With a different approach, nearly 400 organic molecules have been analyzed, by presenting three different algorithms for predicting viscosity at room temperature, taking

into consideration hydrogen bonds as another attractive feature [17]. Furthermore, various methods (principal component analysis and k-means etc.) have been presented to analyze the multivariate data in engineering applications [18], [19]. Besides that, artificial neural networks or genetic algorithms approaches have been used for classification, however, they need training process [19]–[21]. Therefore, PCA and K-means algorithms were selected for proposed model.

This paper presents a method to collect the transmission parameter of liquids in different quantities and distinguish them according to whether they are reliable or not. A successful classification and identification have been made by evaluating the various liquids among themselves without the need for any reference measurements. Furthermore, it has been shown that the intended target can be achieved by varying the amount of liquids. Moreover, the containers which will not absorb the samples are selected to avoid the absorption effects of liquid with container. In this context, the liquids are distinguished successfully by proposed measurement and classification approaches.

2. MEASUREMENT SPECTROSCOPY AND CLASSIFICATION TECHNIQUES

RRM can be used to characterize the materials as well as they performed for oscillators and filters in microwave. RRM has wide application areas such as radar detectors, modern medicine, wireless mobile communications, and military facilities [22]. RRM consists of a microstrip line with two feed lines and coupling gaps as shown in Figure 1. The measurement process is very short for this method. Therefore, the simple of measuring process makes the method easy to use.
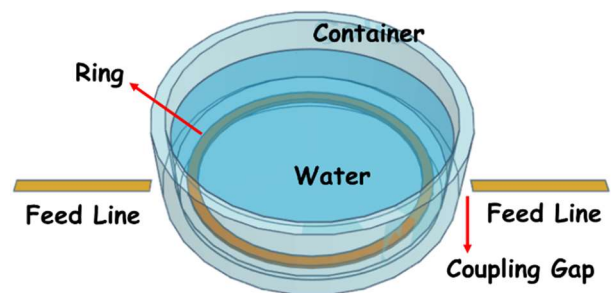

Figure 1. Presentation of RRM with a container

For this measurement process, a container (made by glass and teflon) is placed to contact with ring as shown in Figure 1. Before measurement process, ring resonator is calibrated. The transmission coefficient is measured by using ring antenna with a vector network analyzer [23]. This method is a non-destructive, although it is not non-contactless. The liquids as well as solids can be measured by using RRM [24], [25]. Therefore, it can be used to measure the liquids.

The Principle Components (PCs) of PCA are achieved by eigenvalue decomposition of correlation or covariance matrix of predictive variables. The PCs can be computed using statistical software, after the variables and data set are composed. Hence, the outputs of eigen vectors (linear coefficients) are provided along with standard and mean deviation of each variables. By this way, the PCs are computed for regression process. A sample can be identified using a few components instead of thousands of variables [26].

The problem can be defined as determining the k (integer) points in Rd (d-dimensional space), called centers, in n data points for K-means technique. Hence, the distance of mean squared from every data point to nearest center. This process is called squared error distortion. The number of clusters should be pre-specified in data set. The appropriate cluster number is determined by a trial and error process and this is a blind side due to it makes more difficult the clustering process. Therefore, a set might be adopted instead of a single default K. Because, the reflection of specific characteristic of reasonable large data set is very important to achieve a good clustering [18].
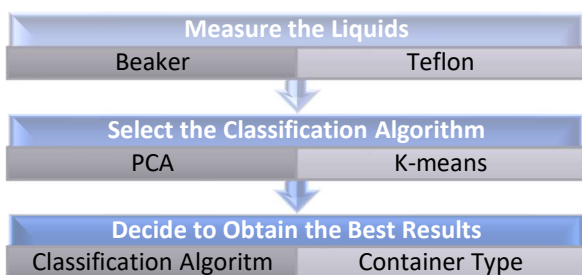

Figure 2. The flowchart of proposed model

The proposed model can be summarized with three steps: Measure the liquids with different quantities, use the classification algorithms, and determine the container and classification techniques to obtain the best results. The types of algorithms and containers used in this study are shown as seen in Figure 2.

3. RESULTS AND DISCUSSION

The transmission parameter can be used as a determinative property. Hence, the differences of measured liquids can be exposed using characteristic indication of liquids. As mentioned above, two different classification techniques were used to classify the liquids which were measured in two different containers by using RRM between 0.8-5 GHz. These classification techniques can explore the differences of S_{21} parameter as shown in Figure 3.
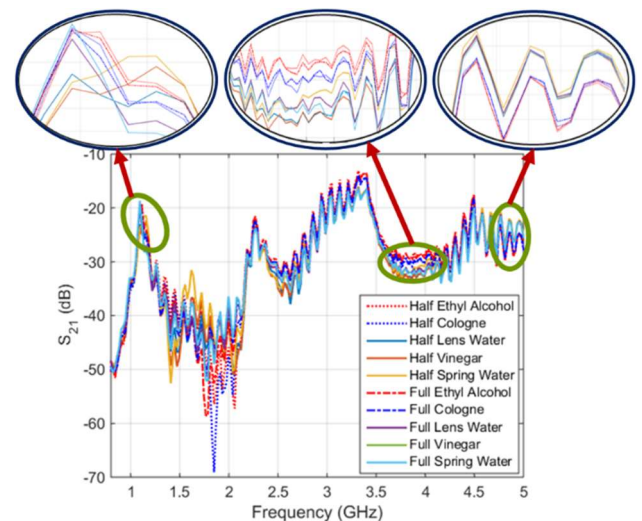

Figure 3. S_{21} parameter of liquids in beaker container between 0.8-5 GHz using RRM

Although this classification process is difficult, the used techniques can be clutched the changes which were specified using zoom regions in Figure 3. It is not possible to make the distinction by using S_{21} parameters at first glance. But the cologne and ethyl alcohol samples are dissociated in zoom regions as shown in Figure 3. The measured liquids by using RRM were sorted as 1) Half-Ethyl Alcohol 2) Half-Cologne 3) Half-Lens Water 4) Half-Vinegar 5) Half-Spring Water 6) Full-Ethyl Alcohol 7) Full-Cologne 8) Full-Lens Water 9) Full-Vinegar 10) Full-Spring Water.

With the number of measured liquid samples, the number of data collected by the VNA in the RRM spectroscopy system (0.8-5 GHz) is very large (as 201 points). For this reason, K-means and PCA classification are applied to the algorithms which are successful in multivariate data analysis. To show the separation of liquids, firstly PCA algorithm was performed for the measurement of beaker container as seen in Figure 4.
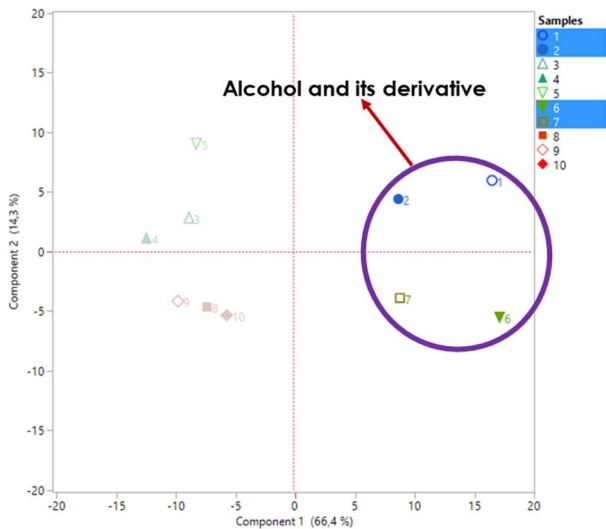

Figure 4. Clustering of liquids measured in beaker container for PCA algorithm

In fact, although a successful classification process has taken place, it may be desired that the unsafe group appear more clearly. The k-means algorithm was used as an alternative to PCA algorithm and the results of PCA were confirmed. After entering the number of possible groups by the user, the results are achieved as shown in Figure 5.

Using K-means algorithm, the distance between the safe and unsafe groups has become more prominent and there are also two different colors for the two groups that have arisen due to the structure of the algorithm used. In this way, the intended groups are reached as safe (green) and unsafe (red) groups. The same liquids were measured using teflon container to repeat the results obtained in the beaker container in a different container and to verify the results. As in the beaker container, the results were first analyzed by PCA algorithm and the separation was obtained as seen in Figure 6.
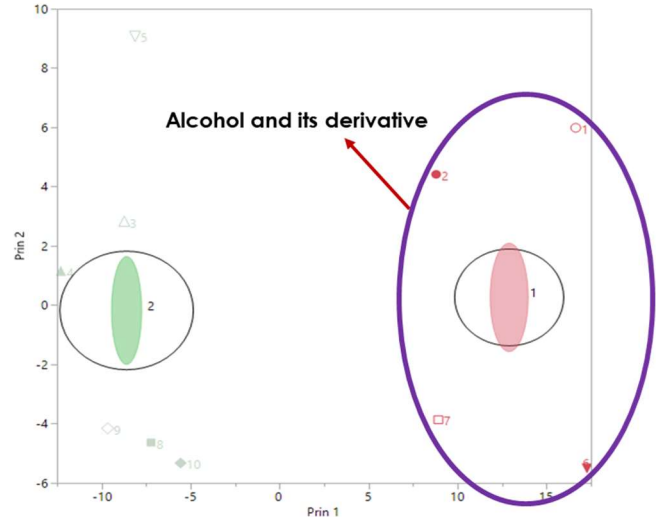

Figure 5. Clustering of liquids measured in beaker container for K-means algorithm
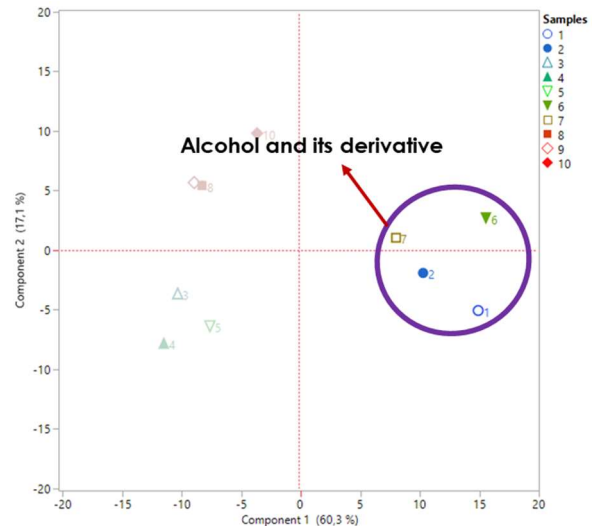

Figure 6. Clustering of liquids measured in teflon container for PCA algorithm

Finally, the measurements made in teflon container were analyzed by K-means algorithm and a successful classification was obtained as in beaker container. The distance between the groups has become more pronounced as shown in Figure 7.

The preferred classification techniques differ from other algorithms, and can classify more materials, especially as they reduce the size of the data. Therefore, the locations of used parameters (pin and component) in figures show where the groups will be located eventually. It should be considered the average distance from the main

points; the groups are composed after the characteristic analysis of each sample in data set. In addition, to present the homogeneous data set of this study, two components and two pins were used.
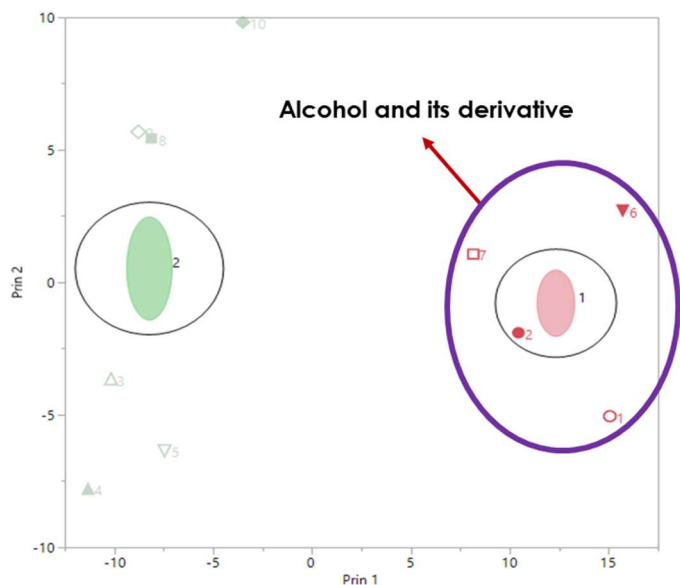

Figure 7. Clustering of liquids measured in teflon container for K-means algorithm

The measurement results of liquids in beaker and teflon containers were analyzed with different quantities. The classification process has been done with high accuracy using multivariate data algorithm. K-means algorithm was found to be better than PCA, when the results are examined. It was determined that the amount of liquid in the container partially affected the classification process. The number of liquid types measured in this study eliminates this negative situation. However, in order to obtain a better classification result, the best of the multivariate data algorithms should be determined when the liquid type is too high.

4. CONCLUSION

It has been shown that without the need for any additional process, it is possible to have information about a liquid with the assistance of other parameter predicted using an available parameter. Furthermore, different quantities of liquids have been measured by RRM between 0.8-5 GHz to demonstrate the ability of recognition of samples using two different classification techniques. The results show that a spectroscopy system will be able to develop to detect unknown and hazardous liquids. However, studies should be focused to identify different types of fluids that occur with molecular interactions. Thus, it may be possible to identify mixed liquids. On the other hand, a new classification algorithm can be tried to classify the liquids.

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