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Using mobile phone as a ripeness sensor

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Abstract. In this paper, the possibility of using a mobile phone as a ripeness sensor is considered. The concept of differentiation based on changes in the dielectric constant of the product as it matures (increase in sugar content) is proposed. A scheme is considered in which one device plays the role of a base station and transmits a Wi-Fi signal at a frequency of 2.4 GHz, and another device uses a specially developed mobile application to analyze this signal and determine by its changes whether a fruit located in the near field of a telephone antenna is edible. The results of the distinctness of different types of products, as well as different degrees of ripeness (unripe/ripe) for one product (avocado) are presented. The sensitivity of the method is also evaluated based on comparison with laboratory measurements using high-quality patch antennas.

Keywords: product ripeness, smartphone sensor, agriculture, smartphone application

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Использование мобильного телефона в качестве сенсора спелости

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Аннотация. В данной работе рассматривается возможность использования мобильного телефона в качестве сенсора спелости. Предлагается концепция различения на основе изменения диэлектрической проницаемости продукта по мере его поспевания (увеличение содержания сахара). Рассматривается схема, в которой один аппарат играет роль базовой станции и передает вай-фай сигнал на частоте 2,4 ГГц, а другой аппарат при помощи специально разработанного мобильного приложения анализирует данный сигнал и по его изменениям определяет, съедобен ли фрукт, находящийся в ближнем поле телефонной антенны. Приводятся результаты различимости различных видов продуктов, а также различных степеней спелости (неспелый/спелый) для одного продукта (авокадо). Также оценивается чувствительность метода, исходя из сравнения с лабораторными измерениями при помощи добротных патч-антенн.

Ключевые слова: зрелость продукта, сенсор, сельское хозяйство, приложение для смартфона

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Introduction

Smartphones have firmly entered human activity and, with the help of many imperceptible changes, significantly improve the quality of life. Various nuances associated with the growth of the world's population force the agrotechnical sector of the market to grow proportionally, throwing new challenges to sensorics. It is required to provide many agricultural enterprises with accessible, but at the same time reliable device. In this paper we propose to use an antenna inside smartphones as sensors for the ripeness of products. There are nearly 7 billon people using smartphones in their daily routine that make this idea easily accessible. In contrast, many sensors for the ripeness of products have been known, for example, non-invasive nitrate sensors [1], external sensors connected to the phone [2], optical systems [3] and others. However, a rather big disadvantage of all these systems is that they are, in essence, separate devices. Smartphone antennas [4] themselves are rather sensible resonators, which allows them to accurately react on changes in such parameters of the immediate environment, such as dielectric permittivity. Thus, we already have a compact spectral analyzer, for the full functioning of which it is necessary to develop software. Such a solution will also allow analyzing all products right on the spot in a non-invasive way and in real time, reducing the logistical costs of laboratory research.

Methods

To measure the incoming signal, a Wi-Fi antenna operating in the range from 2.412 GHz to 2.472 GHz was selected. By default, the Android system can provide periodic information about the signal from this antenna (in dBm), however, such a series is highly discrete in time, since one measurement occurs approximately once every 15 seconds to reduce overall power consumption. However, it is possible to neglect this protection and disable the built-in smartphone throttling in the application for the duration of its operation, customizing it to the required needs. In the following experiments, we settled on two measurements per second. The WifiManager [5] service was used to obtain the relevant data (RSSI signal strength). The graphical interface was implemented in the Kotlin language.

It was found that an external signal (from a base station at the nearest cell tower) is not enough to determine nearby fruits: the random noise of the incoming signal played a more significant role than the change in the environment. Therefore, we decided to put the experiment as follows. Two smartphones are located close to each other, and access point mode is enabled on one of them. This mode is autonomous and even in the absence of an external network creates a local signal picked up by a second mobile device on which the developed application is running.

To assess the possibility of measuring the signal in such a system, numerical modeling was carried out using the finite element method in electrodynamics in the CST Studio Suite software package. Due to the uncertainty of the exact topology of the antenna, as well as the differences in it for different brands of phones, we are further operating only with relative values, and we assume the geometry as IFA [4], as a common version of a telephone antenna. We placed two antennas at a fixed distance from each other (Fig. 1,*a*). There were various dielectric samples between them, simulating real products. In addition, the antenna was surrounded by battery packs, which are simple metal screens at these frequencies, as well as an effective phone frame consisting of various plastics and composites, whose permittivity was assumed to be equal to 2. The dielectric constant and the loss tangent of the products were taken from the article [6]. In full-wave modeling, 3 cases were considered: free space, a cucumber (ε = 56+14i) and an avocado (ε = 77+9i). The results of

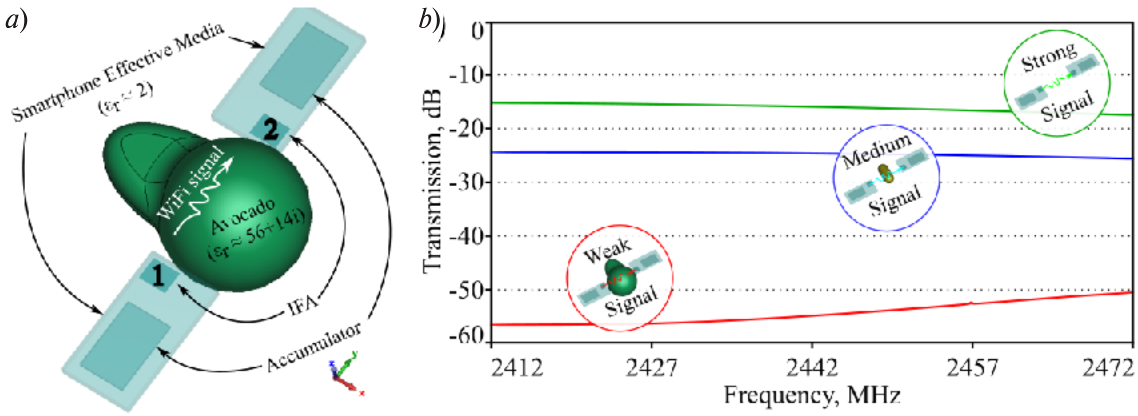

Fig. 1. Numerical experiment to distinguish different types of products: general setup (*a*); results (*b*)

the calculations can be seen in Fig. 1,*b*. It is noticeable that the transmitted signal (S_{21}) strongly depends on the object under test. In free space, the antennas exchange energy well, and when a dielectric is placed between them with losses, part of the electromagnetic energy, depending on the size of the sample and the magnitude of losses in the dielectric, goes into thermal.

Thus, the numerical experiment predicted that using an internal smartphone antenna to distinguish the types of products based on the electrodynamic response. To verify this statement, two modern smartphones (Doogee S40Pro and Redmi Note 8 Pro), driven by Android system, were used. Since the position of the antenna in them was unknown in advance, and the information in the manuals is a trade secret, it was decided to find the direction of the best communication of the antennas, i.e. the relative location of the phones, in which the signal received by the second device from the first would be maximized. This direction is equivalent to the lobes of the antenna pattern pointing at each other.

We found that the maximum communication between the phones was carried out by turning them to each other with touchscreens (Fig. 2,*a*). The graphical interface of the application (Fig. 2,*b*) in the measurement mode plotted the dependence of the signal strength on time and saved data, as well as showed the instantaneous magnitude of the signal and the width of the band used. In this experiment, only one 20 MHz wide band was used at a frequency of 2412 MHz. The results of measurements distributed over time are shown in Fig. 2,*c*. The colored line shows the median, the box contains 50% of the sample, and also each of the whiskers extends another 24.65% to the side. The punctured dots on the graph indicate single outliers. It is clearly noticeable

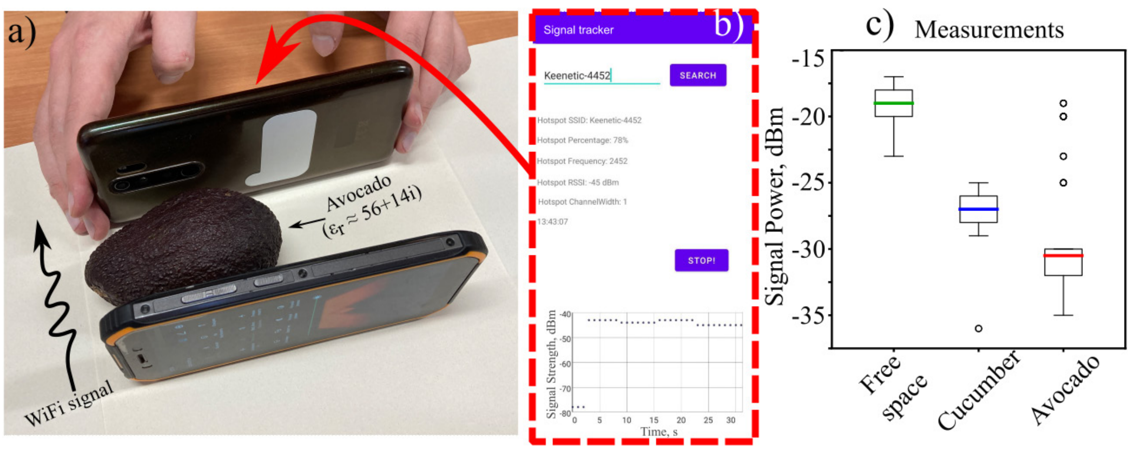

Fig. 2. Measurements of different types of products: general setup (*a*); application user interface (*b*); results of the measurements (*c*)

that, although the absolute values of the energy received in a real experiment do not coincide with the predictions of numerical modeling, however, monotony is quite preserved, which suggests that with proper calibration and collection of a database of various responses, the proposed method is fully suitable for determining the type of product based on its dielectric properties.

However, in addition to the goal of identifying the type of product, the idea was also to find out whether this product is ripe or unripe. To do this, we found a statistical difference in the readings of the received smartphone antenna power next to the corresponding products. An avocado was chosen for this experiment because it can ripen while in a warm illuminated place. Thus, it is possible to dynamically monitor the electrical response from our system for several days, and then evaluate the points of ripeness and rotting according to the data.

In this experiment, the signal level coming to the smartphone antenna remained the same, around −30 dBm, while the difference in signals between start (unripe fruit) and finish (ripe fruit) was lesser than 1 dBm, which is about 0.3%. To make sure that there is a difference in the dielectric constant of this fruit at various stages of ripeness, a laboratory experiment was conducted. For this purpose, two patch antennas were manufactured (Fig. 3,*b*), impedance matched (Fig. 3,*a*). To carry out the experiment, P9374A Keysight Streamline USB Vector Network Analyzer was used. During these measurements, it was found that, indeed, there is a statistically significant difference between ripe and unripe avocados, however, even with antennas matched at −15 dB, this difference is only 2 dB at −30 dB (Fig. 3,*c*). This, in particular, explains the fact that with the help of ordinary smartphone antennas, we were not able to get noticeable differences.

In fact, this can be a predictable result since smartphone antennas are created by engineers in such a way as to be able to receive a signal in a very different dielectric environment.

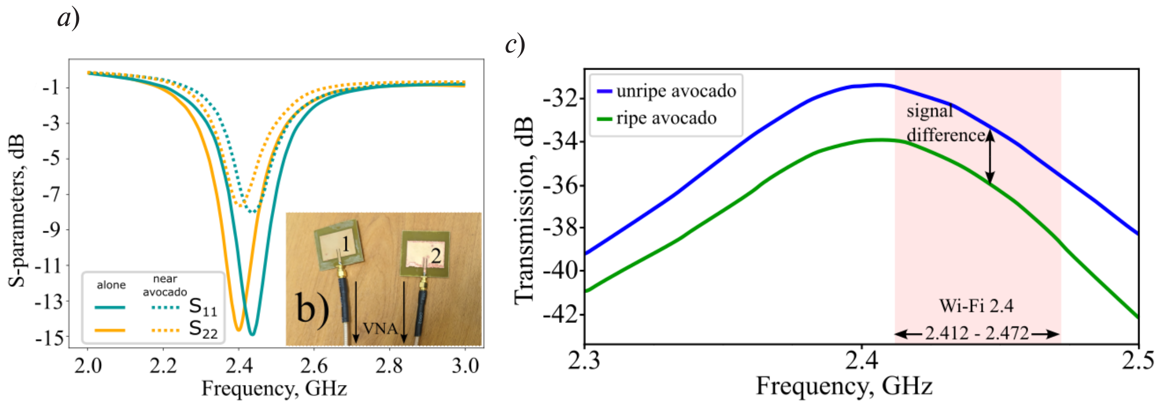

Fig. 3. Measurements of differences between ripe and unripe avocados: return loss graphs (*a*) of manufactured patch antennas (*b*); energy exchange between patch-antennas through the tested objects (*c*)

Conclusion

Thus, it can be concluded that at this stage it is impossible to obtain accurate results by the proposed method on the ripeness of medium-sized fruits. The intended field for study is the determination of the efficiency of the method on large berries (such as watermelon or melon). In addition, these methods are still working to determine the type of product located near the phone, respectively, the second area of development will be the collection of a database of various responses and analysis of the results obtained, depending on the brand of the phone (antenna model) and the size of the product.

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