Artificial color perception using microwaves

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Abstract We report the feasibility of artificial color perception under microwave illumination using a standard microwave source and an antenna. We have sensed transmitted microwave power through color objects and have distinguished the colors by analyzing the sensed transmitted power. Experiments are carried out using a Gunn diode as the microwave source, some colored liquids as the objects and a microwave diode as the detector. Results are presented which open up an unusual but new way of perceiving colors using microwaves.

Keywords Color sensing · Artificial color · Microwave imaging

1 Motivation

The perception of color is not unique in the nature. Color vision varies from animal to animal. It even changes from person to person. As for example, a color blind person may perceive a color differently in some scene than a ‘normal’ human being. In other words, color perception depends on specific color filtering abilities in the eyes and also upon the brain processes that create the color in their percepts of the scene. Humans and other animals[1] cannot change or adjust these color filters provided by their cone cells. On the other hand, the color filters in an artificial eye, e.g., of a camera, may be customized according to the needs. Thus, color sensing

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1 So far as we know, only the very remarkable mantis shrimp has that capability.
of a camera can be customized to yield a color perception which may be called
artificial color [1,2]. Here the word ‘artificial’ simply means something humans
rather than nature has chosen.

In fact, images captured by ordinary color cameras may be processed on the
computer to achieve results of artificial colors [3,4], which can improve applications
in binary logic and biometric recognition [5,6]. A question arises, whether one can
perceive colors beyond the visible band of wavelengths. In what follows, we try to
address the problem of artificial color perception using microwave radiation [7].

2 Introduction

Color is generally referred to as corresponding to the different visible wavelength
bands. But that view is plainly approximate and not very useful. Color is not some-
thing in the world awaiting detection. Rather it is the result of brain processing to
provide spectral discrimination. A visual percept of a scene may contain objects
at various 3D locations in the scene but it also contains spectral discriminants cal-
culated by the brain and attributed to objects in the percept. Those discriminants
are what we call color. Color perception comes to reality by the response of the eye
to these visible radiations. In Sun light, Newton found seven colors but could not
find ultra-violet, infrared and microwaves, because only visible wave bands can be
seen by us. Thus, the concept of color has never been associated with ultra-violet,
infrared or microwave radiations. But color and spectrum are not the same kinds
of things. Spectra come from the outside world and colors come from the brains
of animals that sense some of that spectral information.

Microwave sources radiate a wide band of frequencies of 1 GHz to 100 GHz and
the wavelength varies from 30 cm to 0.33 cm. On the contrary, optical radiation
fall in the frequency range of 670 THz to 450 THz corresponding to wavelengths of
0.4 µm to 0.7 µm. Though both microwaves and optical waves are electromagnetic
in nature, the different wavelengths produce different imaging characteristics. For
example microwave radiation is capable of penetrating objects that are opaque to
visible light. Microwaves are very dominant in communication systems where a
variety of antennas can receive microwave signals [8]. Microwave radiations have
a very popular application in our households as microwave cooking ovens [9]. Mi-
crowave imaging is extensively used in medical diagnostics, building research and
military applications [10]. However, color perception in the microwave bands has
not yet been found in the literature so far.

We explore artificial color perception in the microwave bands utilizing stan-
dard microwave antennas. A microwave antenna is proposed to sense the wave
fields transmitted through an object having different visible colors into it. The
microwave source may be a variable frequency source, such as a Klystron or a
Gunn diode. Microwaves are affected by the dielectric properties of the matter,
so transmission of microwave radiation through otherwise visual colored objects
will show variations in transmitted power due to the variation of dielectric values
in the object. Some intuitive experimentation suggests that microwaves may of-
fer an unusual forte for sensing the otherwise visual color percepts into artificial
microwave color percepts. To the best of our knowledge, this is the first effort of
exploring color perception under microwave radiation.
3 Intuitive Experiments

There are a variety of microwave antennas available, such as horn, microstrip antennas etc. [8]. Among them horn antennas are commonly available. We propose to use a common horn antenna and a microwave diode detector to sense the transmitted microwaves through an object. We try some simple experiments using a Gunn diode as source. Ideally, we wish to capture the transmitted microwave radiation by scanning the detector antenna on a straight line orthogonal to the propagation axis. That means we are interested in capturing the transmitted radiation in one dimension only. In fact, we have moved the object instead of the antenna, because the antenna is fixed on the bench. This does not affect the sensing since we are interested to see how much amplitude of microwaves is transmitted by the object.

The schematic figure of the experimental setup is shown in Fig.1. The Gunn diode source is made to radiate at a frequency of approximately 10 GHz which is equivalent to a wavelength of approximately 3 cm. A small polythene cup filled with a liquid is placed as an object in front of the Gunn diode. The microwave radiation transmitted through the object is detected with a horn antenna and a diode detector. The detector is connected to a microwave power meter (not shown in Fig.1). The actual photograph of the experimental arrangement is shown in Fig.2. The polythene cup is filled with plain water and is moved orthogonal to the axis of propagation and subsequent data are recorded. Now, the experiment is repeated after filling the cup with milk tea. The same experiment is repeated after
filing the cup with colored water by blue ink of marker pen. The photographs of the objects (polythene cup filled with liquid) used in the experiments are shown in Fig.3. The photographs show the cup filled with plain water [Fig.3(a)], cup filled with milk tea [fig.3(b)] and the cup filled with water colored blue by marker pen ink [Fig.3(c)]. The experimental data plots for the cup filled with liquid is shown in Fig.4. The plot of the experimentally recorded transmitted microwave power in mW versus the lateral position (in arbitrary unit) of the cup filled with plain water is shown in red color, that for the cup filled with milk tea is shown in green color and that for the cup filled with blue marker pen ink colored water is shown in blue color. Figure 4(a) shows the plotted data points, whereas Fig.4(b) is the same data plotted with polynomial curve fitting. It is discernible from Fig.4 that the microwave transmission due to plain water filled polythene cup and due to the polythene cup filled with milk tea and blue colored water are not same.

Fig. 3 Photographs of the objects (a) cup filled with plain water, (b) cup filled with milk tea, (c) cup filled with water colored by blue marker pen ink.

Fig. 4 Plots of transmitted microwave power (mW) versus detector (or object) position in arbitrary unit for (i) plain water (red), (ii) milk tea (green), (iii) blue colored water (blue). (a) Plots with data points, (b) Plots with curve fitting.
4 Analysis of the Results

The results (Fig.4) of the experiments with liquid as the transmissive object shows difference in the transmitted microwave power through plain water, milk tea and blue colored water. Since, microwave is affected by the dielectric properties, and the result is an effect of dielectric properties of the dissolved materials (milk, tea and color) in the water. The dielectric constant of water is very high (~ 73), and adding milk tea and blue ink to it yields a finite changes in the dielectric values. The differences in the readings due to different colored water are due to the relative changes in dielectric values. The bending of the plots at the right hand bottom may be accounted for probable dielectric lensing action of the water filled cups on the microwaves. It may be noted that the same color on different objects with different dielectric properties may also result in ambiguities in the sensed colors.

We may call these unusual color percepts as microwave sensitive dielectric color, or simply dielectric color. These can be viewed as color detection sensitivities in microwave artificial color. As shown in Fig.4(a) and Fig.4(b), they are so similar as to be of little value, but they are distinctly different. The difference needs to be amplified and the similarity decreased. Those distinct differences in the three curves of Fig.4(a) and Fig.4(b) can be converted into three orthonormal signals using the Caulfield-Maloney filter [11], or Gram-Schmidt orthogonalization [12]. These curves provide color specific sensitivities which are useful for looking at the three kinds of liquids in a scene. If the result is to be displayed to a human, an arbitrary mapping between the microwave sensitivity curves and the normal human three color sensitivity curves will enable that.

The results of our experiments prove the feasibility of using microwave radiation for discriminating visible color information of objects that can produce a sufficient change in its dielectric properties. The possibility of detecting color signals may be improved by using more than one microwave frequencies. The more elaborate experimentation need some dedicated sources, sensors and test benches which presently we don’t have.

5 Conclusion

We have proposed color sensing and perception using microwaves. Empirical experimental studies show that artificial color in the microwave domain can be achieved very simply using readily available antennas. It can produce results different from conventional microwave images in that far more than simple intensity is displayed. The spectral ‘meaning’ of the received radiation may be displayed as in any other color display, be it natural or artificial.

Acknowledgements The authors are indebted to Mr. G. Das and Mr. G. Lohar for assistance in experiments. Logistic supports have also been received from Mr. S. Das and Mr. R. Sengupta.

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† Professor H. John Caulfield is no more with us. His sole rests in peace in heaven since 31 January 2012.