NORMALIZED VEGETATION INDEX MEASUREMENT
COLOR SCIENCE LABORATORY 2014

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ABSTRACT

This paper covers the design, realization and evaluation of a research project within the *color research laboratory* course of the University of Eastern Finland. The research project aims to achieve a low budget recording setup to measure the *Normalized Differenced Vegetation Index* (NDVI) of given leaf samples. This should be achieved with two customary webcams. One of these webcams will be modified to an infrared camera. By recording the red and near-infrared reflectance of a leaf its *NDVI* can be calculated. The *NDVI* gives evidence to the amount of chlorophyll in the leaf and thus leads to the vitality of the plant. The results of the setup are not very satisfying and the proposed results could not be approved.

1. INTRODUCTION

The Normalized Differenced Vegetation Index (NDVI) is a measurement scale to determine the vitality of vegetation. Vital vegetation absorbs most of the blue and red light but therefore reflects a lot of green and infrared light. This happens mainly because of the chlorophyll that is contained by the leaves. A stressed or unhealthy plant contains less chlorophyll and thus reflects more red and less infrared light. [1]

The goal of the project was to design and develop a device and a piece of software, that is able to record the *NDVI* of a given leaf sample. Therefor a modified webcam, that is able to record infrared light, and a normal webcam, that records visible light, are used to record all information needed.

1.1. NDVI

The NDVI relates the reflected red light with the reflected near infrared light by the following formula:

$$\boldsymbol{NDVI} = \frac{\boldsymbol{NIR} - \boldsymbol{R}}{\boldsymbol{NIR} + \boldsymbol{R}}$$

Where *R* is the reflected red light and *NIR* is the reflected near-infrared light. This scale allows to estimate the amount of chlorophyll in the leaf which leads to the vitality of it. The result is a measurement of plant vitality and even a differentiation between vegetation and non-vegetation. [1]

1.2. Spectral Properties of Leaves

Due to its structure a leaf absorbs, transmits and reflects light at specific wavelengths at specific layers of the leaf. A leaf consists mainly of cellulose, water containing solutes, air and pigments which are located within the chloroplasts. The dominant pigment found in a leaf is chlorophyll (65%). Chlorophyll absorbs mainly blue and red light with peaks at 445nm and 645nm (see Figure 1). The absorbed light is turned into energy to perform photosynthesis. The main cause why plants appear green to us is, because the primary reflected visible light is green. Beyond the visible light leaves reflect infrared light. About 50% of the incoming sunlight will be reflected in near infrared range with a peak around 1 µm (see Figure 1). The infrared light further than 2µm is absorbed by the water in the leaf. [2]

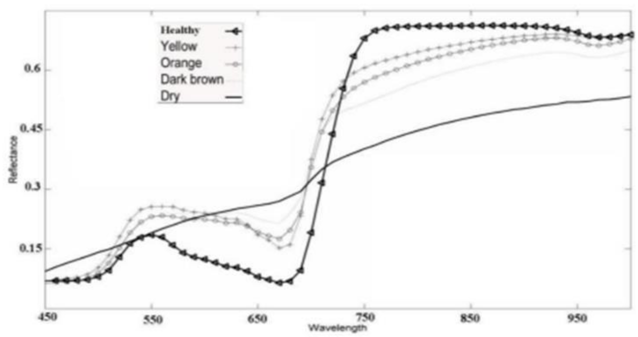


Figure 1: The reflectance curves of leaves [3]

2. EXPERIMENTAL SETUP

The NDVI is mainly used in large scale research. The NASA for instance makes use of this index and measures the vegetation of the whole world with infrared cameras on satellites [4]. This index could also be useful in a smaller environment for people how grow their own food or plants. People could use a device that helps them to keep track of the health of their own plants. In addition to some software.

2.1. Design

The proposed approach to record visible and infrared images will be achieved by using two webcams (one of them modified to an infrared camera) and record two images simultaneously. The cameras will be installed very closely together to reduce perspective misalignments.

2.2. Infrared capabilities of the webcam

The proposed approach is designed to make use of a conventional webcam to record infrared information. Therefor the infrared filter that is installed within the webcam has to be removed and replaced by a visible light filter to produce an “infrared camera”.

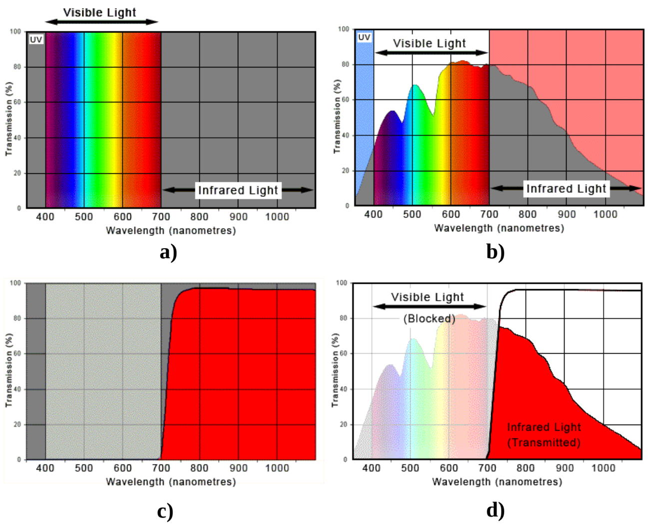


Figure 2: a) shows ultraviolet, visible and infrared light; b) shows the response curve of a CCD sensor and the visible light; c) show the transmittance of a visible light filter; d) shows the transmittance of light applied to a visible light filter [15]

A common webcam is equipped with a CCD-sensor. The spectral response curve of a CCD covers a range from ~350nm to ~1200nm (see Figure 2b gray curve) [5]. In almost every customary camera the sensor is covered by an infrared filter to cut off information that cannot be seen by the human eyes. The infrared information would only disturb the image corresponding to the human visible system. To create an infrared camera that can record near infrared images the visible light has to be blocked. This can be achieved by a visible light filter (see Figure 2c). The resulted information is only infrared light (see Figure 2d).

2.3. Realization of the modification

The camera used in this setup is a *Microsoft LifeCam Cinema HD* it is capable to record a video stream with a resolution of 1280 by 720 pixels at a rate of 30 frames per second [6]. The specifications of the sensor can be found at [7].

To reach and remove the internal infrared filter, the webcam had to be disassembled completely. Figure 3 and Figure 4 show some parts of this process. Detailed instructions on how to disassemble the device can be found at [8] [9]. Figure 5 shows the removed infrared filter that has been cracked to be removed.

Figure 3: The removed front panel

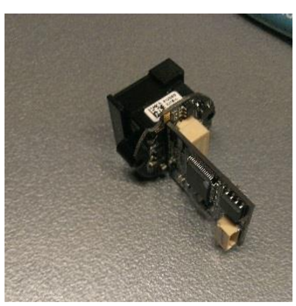


Figure 4: The interior of the webcam

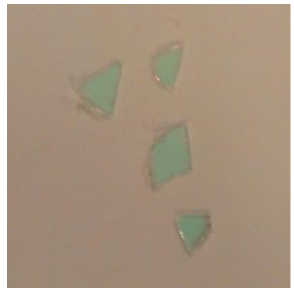


Figure 5: The cracked infrared filter

Figure 6: The cameras screwed together

During the disassembling the original moveable mount of the webcam was removed. Instead the two cameras were screwed onto small rack to eliminate separate movements. This fixation made sure that the cameras are always in the same relative position to each other (see Figure 6).

At first a piece of floppy disc was inserted in front of the optical system to work as a visible light filter. It turned out that the floppy disc is not a satisfying infrared filter, as it blocks most of the infrared light, too. Furthermore its cutoff curve is not very steep. Dark acrylic plastic turned out to be a much better infrared filter as its cutoff curve is much steeper and it transmits more infrared light (see Figure 7) [10].

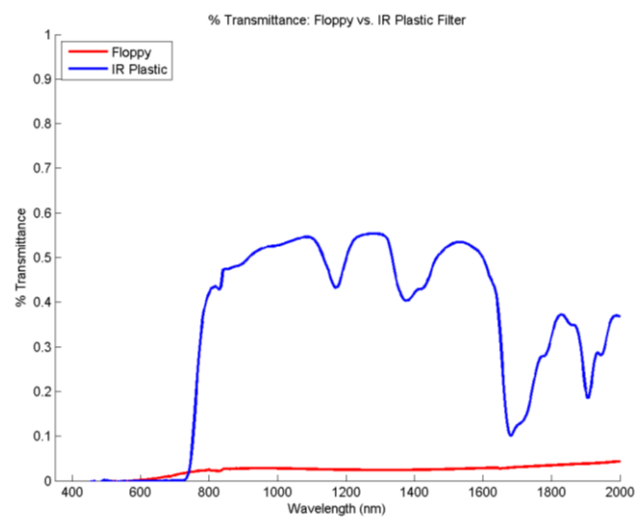


Figure 7: The filter transmittances

2.4. The recording Setup

In the first approach for the setup the samples were placed on a surface in a 45 degree angle. The cameras where installed on a tripod in front of the holding. In this scenario *50W 7000K DC power supply Xenon light sources* were used as they radiate infrared light as well (see Figure 8).

Figure 8: The first setup of the experiment

The general lighting situation of this setup turned out to be unsatisfying. The different leaves were barely visible (see Figure 9). Furthermore these lights had a very strong focusing point and did not enlighten the samples evenly.

Figure 9: Recordings from the first setup

The second scenario was set up in a Spectralight III Light Booth [11]. The leaves were placed on the ground of the light booth and the camera was installed on a tripod as well and was facing the leaves by almost zero degrees (see Figure 10) The Spectralight III Light Booth is able to simulate daylight which provides a very natural and uniform lighting situation.

Figure 10: The second setup

3. SOFTWARE

To achieve the spatial alignment of the images and calculate the NDVI a small software solution was implemented in *python* [12]. The program makes use of *OpenCV* to the image processing. Furthermore *OpenCV* is also able to capture the camera images as well as to save and load images [13].

The software basically consist of three different tasks that had to be addressed. These are the parallel recording of the images, the alignment of the images and the calculation of the *NDVI*.

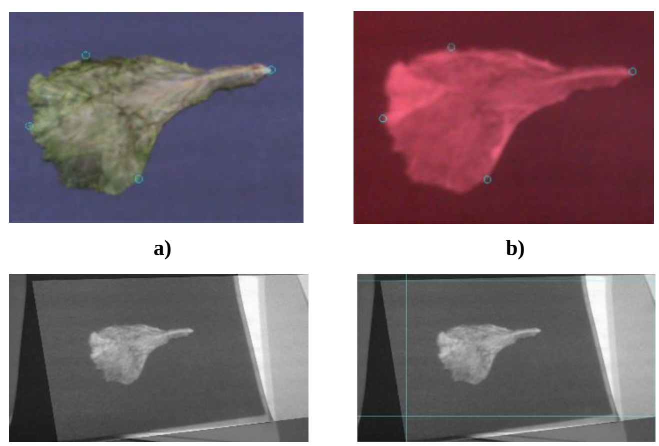
The whole software project can be found at *GitHub* [14].

3.1. Image recording

To record two sample images the program *save2Images.py* is used. It opens up a connection to the two camera devices and saves the images to the disc if the *space* button is pressed. The files will be named after date and time of the recording.

3.2. Image Alignment

The function *cropAndAlign()* in the file *NDVI.py* warps two input images in a way that their region of interests overlap and there are no empty borders.
To achieve this the user has to select four reference points in both images manually (see Figure 11a and b). With these four references *OpenCV* can determine the perspective transformation between the two images. In the next step the infrared image is warped into the coordinate system of the visible image (see Figure 11c). After that the greatest rectangle that covers both of the images is calculated and the images are cropped to achieve an optimal overlapping see (Figure 11d). These images are then written to the disc to achieve some intermediate information.



a) b) c) d)

Figure 11: a) References in the visible image b) References in the infrared image c) warped infrared image blended onto the visible image d) Rectangle that will be cut out

3.3. NDVI Calculation

To perform the final calculation the function *calculateNDVI()* will convolute the red channels of the two recorded and already aligned input images. First the images are transformed to floating point values to achieve a higher precision. After that the equation mentioned above is applied to create the final result.

$$NDVI = \frac{NIR - R}{NIR + R}$$

Because the resulting image of this convolution will be in a range from *-1* to *1* the image will be scaled to the range from *0* to *1* to be written to the disc as a grayscale image (see Figure 12). To increase the visibility of the resulting image a color grading can be applied to the *NDVI* value. Figure 13 and Figure 14 show two very common color gradients for the use of the *NDVI*.

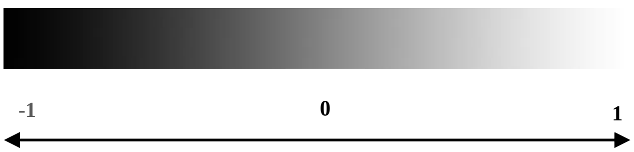


Figure 12: Grayscale gradient

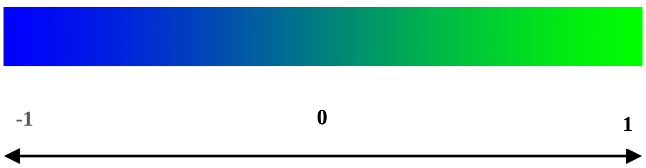


Figure 13: Blue to green gradient

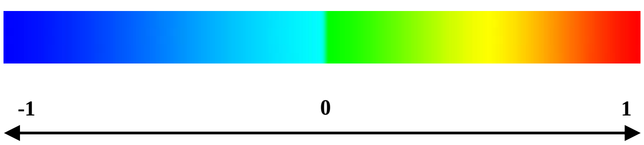


Figure 14: Blue to cyan for negative values and green via yellow to red for positive values

4. RESULTS

During the measurements several different leaf samples were recorded. The samples were three leaves of lattice that were taken of its head one, two and three days before the measurements. Then there are seven older leave samples that were taken from outside and two fake leaves. The expected result would be, that the lettuce leaves show a regression of the *NDVI* value depending on the time they were ripped off. There should also be a very clear difference between the three fresh and the seven older leaves. Furthermore the fake leaves should clearly outstand to be identified as fake leaves.

4.1. Calculations

Figure 15 and Figure 16 show the original recordings. The spatial distance in x-direction is clearly visible.

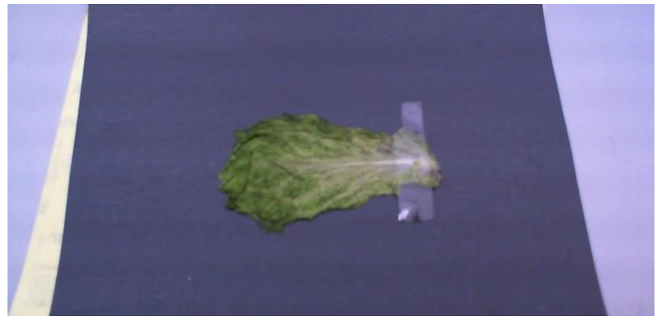


Figure 15: Visible recording of sample

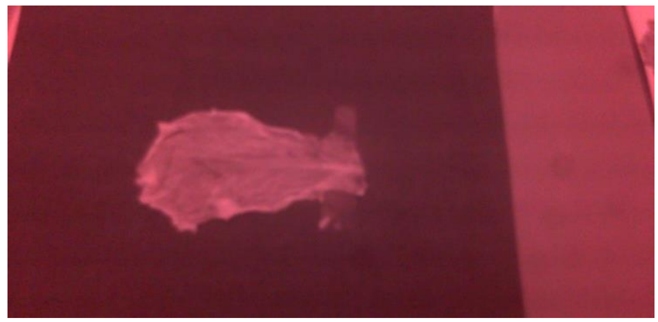


Figure 16: Infrared recording of a sample

The next step is the alignment of the images. As explained above this has been realized by warping on image onto another one withanually selected reference points. The aligned and already separated red channels are shown in Figure 17 and

.

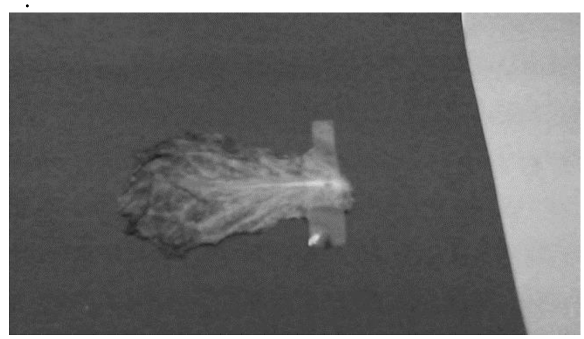


Figure 17: Aligned red channel

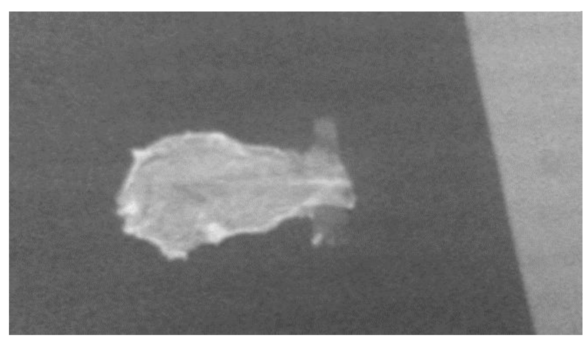


Figure 18: Aligned near-infrared channel

With these aligned images the NDVI can be calculated. Figure 19, Figure 20 and Figure 21 show the calculated NDVI with the three color gradings mentioned above.

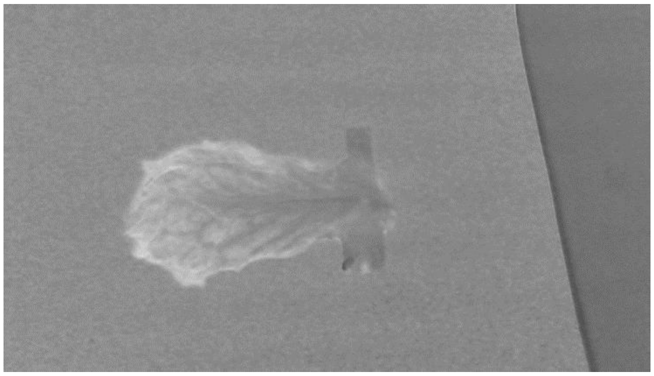


Figure 19: Grayscale NDVI

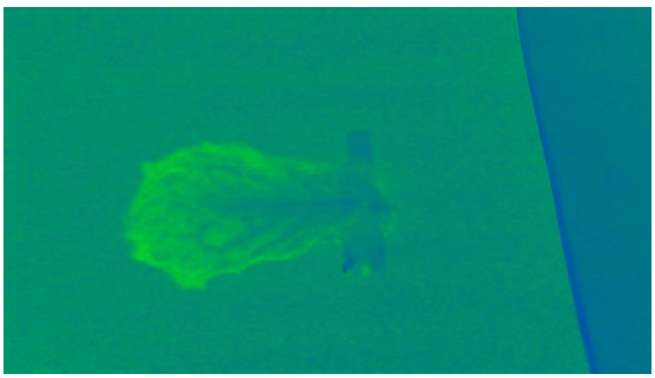


Figure 20: Blue to green NDVI

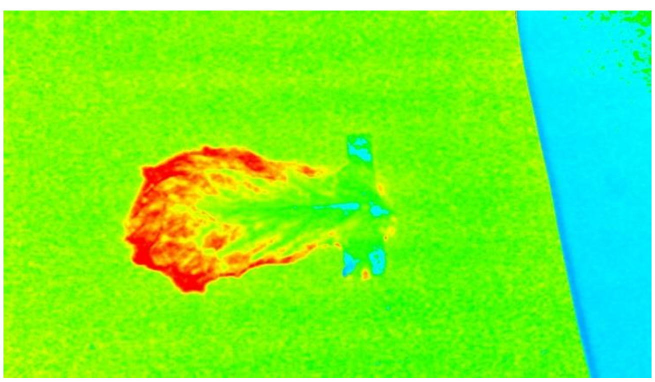


Figure 21: Blue to cyan and green to red NDVI

4.2. Interpretation of the fresh leaves

Unfortunately the visual difference between the differently aged lettuce leaves is not as high as expected. Figure 22, Figure 23 and Figure 24 barely show, the varying NDVI. The only noticeable difference is that the outer left region is redder in the first leaf. The second and the third leaf seem to be almost identically. The blue region in the second leaf is even bigger than in the third leaf. That contradicts the expectation. To examine this more concrete the leaves were cut out of the background (see Figure 25) and the average value was calculated. The first leaf has an average value of *0.41*, the second one has *0.31* and the third one has *0.34.* This approves that that the first leave has a higher *NDVI* but the expected decreasing was not noticeable at all.

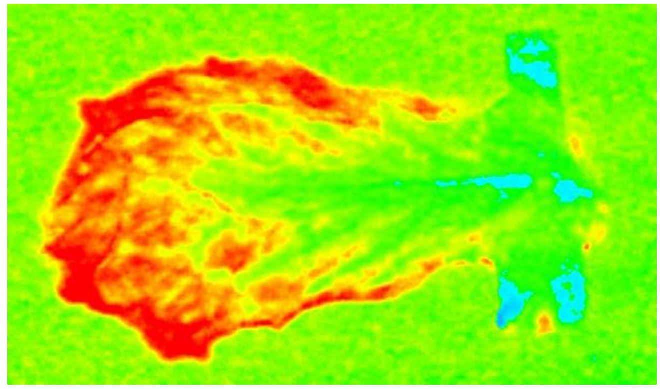


Figure 22: One day old lettuce

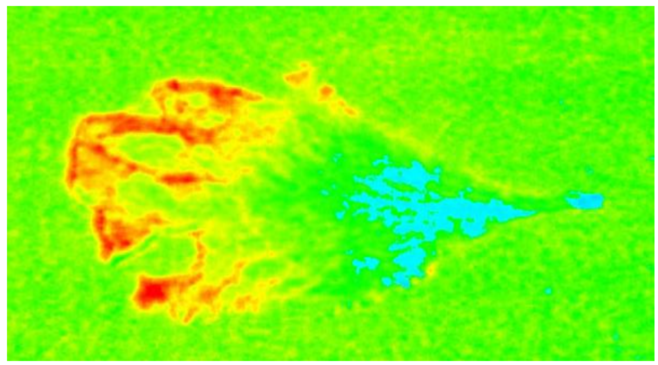


Figure 23: Two days old lettuce

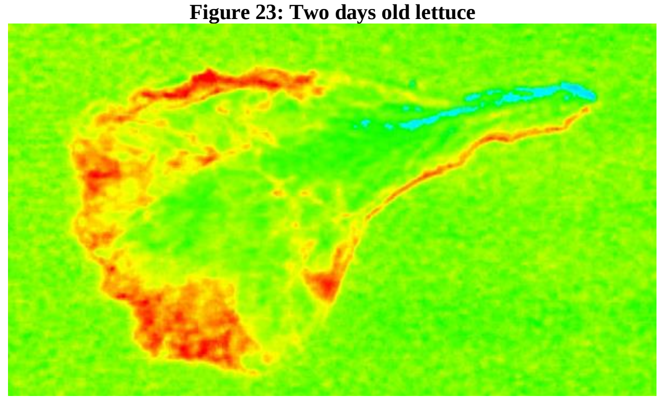


Figure 24: Three days old lettuce

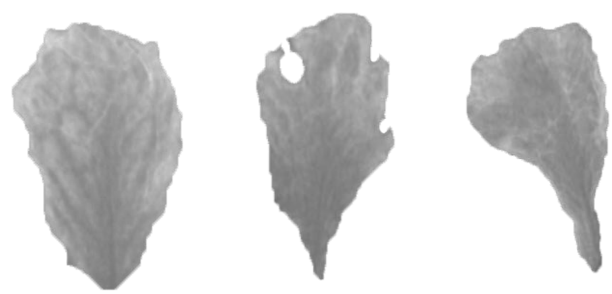


Figure 25: Cut out grayscale NDVI samples

4.3. Interpretation of the old leaves

As mentioned above the older and dry leaves should display a much lower *NDVI* due to their lack of chlorophyll.

Figure 26 though, shows that their *NDVI* is quiet high. The color graded leaves appear to be very yellowish. The examination of the averages shows that the *NDVIs* of the old leaves are *0.4, 0.36, 0.37* and *0.42*.

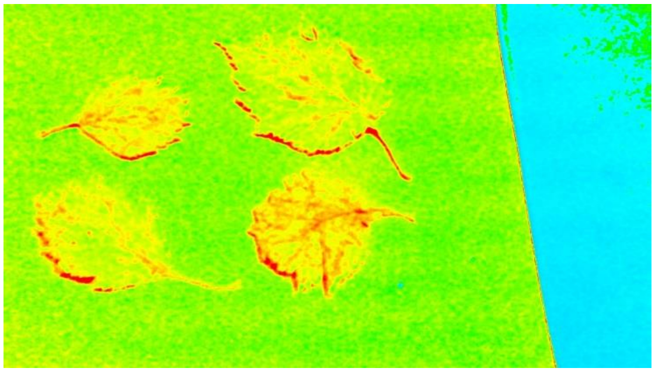


Figure 26: The older leaf samples

4.4. Interpretation of the fake leaves

The fake leaves show surprisingly high *NDVI* values. The color graded results are almost completely red. The averages of the two given samples are *0.7* and *0.47*. This is higher than all the other values.

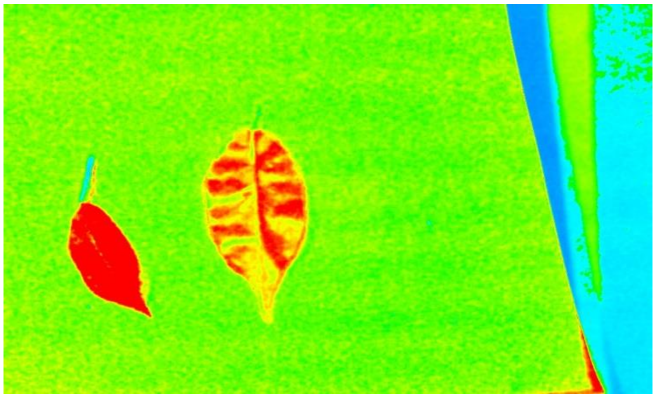


Figure 27: The fake leaf samples

5. CONCLUSION

The assumptions made in the beginning were barely approved. The old leaves had a similar average *NDVI* as the fresher leaves. This has be compared with care, because the leaves are totally different and cannot be compared directly.

The fresh lettuce leaves though, show some form of regression in their average *NDVI*. To determine that exactly, more samples had to be recorded over time. The three samples give evidence that older leaves have a lower *NDVI* but with just three samples the assumption could finally not be approved. Further research should take much more recordings of the same leaves over a long period of time. With those measurements the decreasing amount of chlorophyll could be recorded more correctly.

Also the expectation to distinguish fake leaves was not fulfilled at all. The actual opposite came true. The *NDVI* of the fake leaves was even higher than the real ones. The fake leaves seem to consist of a material that reflects infrared light as well as the visible light in a similar fashion to a plants.

To evaluate the quality of this *low budget* solution the samples have to be recorded with some professional spectral measuring devices, to see if the weak results lead from the quality of the measuring sensor or the lighting conditions or any other circumstances.

5.1. Distraction of the images

Several aspects distracted the recording of the correct values. To improve the results of further research these issues should be addressed.

The given leaf samples were not completely flat so that they casted small shadows at their edges. These shadows appear in the NDVI images very clearly, because they turn out into completely different values. Furthermore the fact that the leaves were not flat caused an uneven lighting because some parts of the leaves were facing the light source more than others. This is clearly visible on the right leaf in Figure 27.

Another disadvantage of the lettuce was the white stem that did not correlate with the green part of the leaf that was to be observed.

6. REFERENCES

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