Estimating Soil Moisture from Images

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***Abstract*—This paper proposes a method to obtain information on the moisture level in soil using images of the soil contrasted by a white background and uniform lighting. The proposed method begins by balancing the colour of the image, using the Simplest Colour Balance algorithm which helped to standardise the images. A mask for the image which isolated the soil pixels was then generated by converting the image to greyscale, before using a grey threshold to create a binary image. Dilation was completed to fill in any holes in the mask, and then erosion was used to ensure only soil pixels were isolated. The average pixel value of the soil was then computed in RGB colour space. Soil samples at different known moisture levels were used to calibrate the 'wet', 'damp' and 'dry' thresholds for the soil type, enabling further samples to be categorised appropriately. This method resulted in further samples of the same type being correctly categorised 93% of the time. This method automatically categorises soil based on its moisture content which builds on previous research which required manual image processing. Prior research also focused on modelling the RGB channel response to changing soil moisture rather than categorisation of samples.**

Keywords—soil moisture, moisture categorisation, image segmentation

I. Background

Detection of soil moisture is vital in improving efficiency in agriculture, particularly when irrigating large areas. Water overuse is typical in irrigation practices which do not use feedback control [1]. The impacts of this are widespread, decreasing production and increasing costs for farms, as well as having a negative impact on the environment [2]. Irrigation projects which are not correctly controlled can result in extensive damage to the soil profile, with changing water table levels, increased erosion, deterioration of water quality and other problems such as unbalanced salinity and intrusion of pollutants in the water supply [3]. Current soil moisture testing can require extensive installation [4], so having another option for testing soil moisture would be beneficial for the sector. The proposed method is designed to be a proof of concept for alternative soil testing methods which use images of soil.

A. Previous Research

One paper aimed to model the response of colour space information from soil samples rather than categorising samples and used known gravimetric soil moisture values and a clay based soil [5]. The results from this paper indicated that their model would only fit soil of the same type as what they used. The colours of the images were also manually balanced before the average pixel values were found, meaning the process was more labour intensive than an automatic process would be. Manual cropping was also used in this study, allowing them to have an image entirely comprising of the soil, with no background.

Another paper which had a similar methodology to the previous paper discussed used soil samples which fell under several different textural classes [6]. This confirmed that one model is not able to be used for multiple textural classes. It also noted that standardisation of the photographs was important, so they should be taken under similar conditions and be colour corrected before analysed. To isolate the soil from the rest of the image, each image was manually cropped to ensure the entire image was of the soil. The soil was also sieved to remove all lumps larger than two millimetres, which indicates the high level of uniformity used in this study.

B. Relevant Algorithms

Simplest Colour Balance (RGB)

Colour balancing the images prior to analyses is important for standardisation of the images. The 'Simplest Colour Balance' algorithm does this by stretching each of the Red-Green-Blue (RGB) channel histograms over the entire range using an affine transform [7]. This preserves the original proportions of the histograms, only stretching the values [8]. An example of this can be seen in Fig. 1 and Fig. 2.

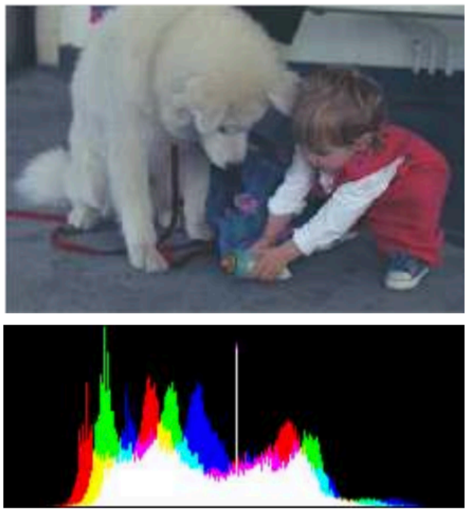

Fig. 1. An image and its RGB histogram prior to colour balancing [7].

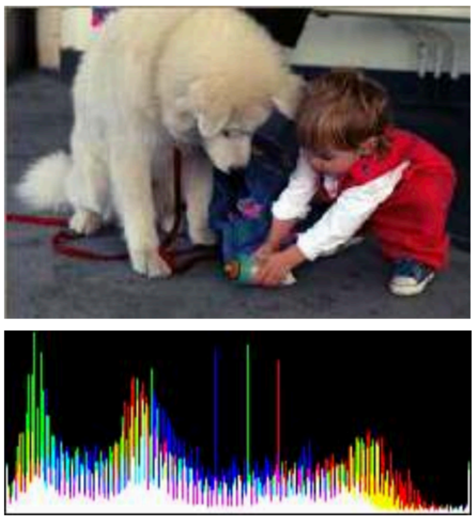

Fig. 2. An image and its RGB histogram after colour balancing [7].

Greyscale Image Conversion

Converting an image to greyscale improves the ease of colour thresholding and creating a mask for an image. This is done using a linear combination of the RGB channels of each pixel. This combination is shown in Eq. 1 [9].

$$Y = 0.299R + 0.587G + 0.114B \tag{1}$$

Colour Thresholding

Colour thresholding is a method for isolating an object of a known colour from the rest of the image. The result of an image after going through this process is a binary image where the pixels above the threshold are given the value one, with all others being set to zero [10]. A mathematical representation is shown in Eq. 2.

$$dst(x,y) = \begin{cases} 1 & if\ source(x,y) > threshold \\ 0 & if\ source(x,y) < threshold \end{cases} \tag{2}$$

Erosion

Erosion uses a kernel which specifies how many neighbouring pixels are used and their weightings. It performs a transformation on the source image by finding the minimum value of the centre pixel and neighbouring pixels and replacing the centre pixel with this value. Erosion can be performed also be performed for multiple iterations [11]. Erosion results in lighter objects on darker backgrounds being reduced at the edges. It can be useful for noise reduction in the background of images, and for eliminating small objects which are not the main focus of the image [12]. Although it is useful for these purposes, it does also result in the goal object of the image becoming smaller. A mathematical representation of erosion is shown in Eq. 3.

$$dst(x,y) = \min\left(source(x+x', y+y')\right) \tag{3}$$

Dilation

Dilation is similar to erosion in that it makes use of a kernel which specifies how many neighbouring pixels are used and what their weightings are. It performs a transformation on the source image by finding the maximum value of the centre pixel and neighbouring pixels and replacing the centre pixel with this value. Dilation can also be performed for multiple iterations [13]. Dilation results in lighter objects being enlarged against darker backgrounds. It can be useful for filling holes in objects but increases the size of the object itself [14]. A mathematical representation of dilation is shown in Eq. 4.

$$dst(x,y) = \max\left(source(x+x', y+y')\right) \tag{4}$$

II. Proposed Method

A. Hardware and Software Used

OS: MacOS Catalina
Processor: 3 GHz Quad-Core Intel Core i5
IDE: PyCharm
Language: Python
OpenCV Version: 3.4.2
Device: Desktop Computer
Camera: Huawei P20 Pro main camera, 10MP f/1.8 1/1.7" PDAF Laser AF OIS

B. Method

Each of the soil samples must be taken from the same place to ensure they are of consistent soil type. Prior to photographing the samples, they must be completely dried out over a period of 48 hours, turning often to ensure an even soil colour is achieved. The samples are required to be photographed under even lighting on a white background to achieve standardisation. Three images are to be taken of the dry soil under these conditions to ensure accurate readings are being taken by the proposed method. Further samples are to have an incrementally higher moisture level than that of the previous sample. This is to be done using a spray bottle to evenly coat the top surface of the soil from a distance of 15 centimetres. The spray bottle is used to measure the relative moisture level of the soil in comparison to the previous sample. These images then can be used as the test images for the proposed method. Each image will be manually categorised to give a ground truth to compare further results to.

Firstly, each image must be loaded and resized to a standard image size. This is chosen to be 500 x 500 pixels for this paper. Once this is completed, the image will be colour balanced to correct any anomalies that have arisen due to the photographing process. The simplest colour balance algorithm will be used, which spreads each of the RGB channels across the entire spectrum using an affine transform, therefore preserving critical colour information while enabling more consistent pixel readings to be taken.

A mask will then be generated to isolate the soil pixels from the white background of the image. First the colour balanced image must be converted into greyscale, using the greyscale conversion equation shown in Eq. 1. The resulting image can then be colour thresholded to eliminate the background, turning the mask into a binary image. Once this has been generated, dilation will be performed for one iteration to close the gaps in the mask, before erosion is performed for six iterations to completely isolate the main soil sample.

Once the binary mask has been completed, it can be multiplied together with the colour balanced image to produce an image of the soil without any background pixels. This allows the mean pixel value of all non-zero pixels to be calculated.

The result will be an RGB value which can be compared against other samples to give an estimate of soil moisture. The RGB channel values will then be averaged to give a single number which represents the relative moisture level for that soil type. A full range of samples with varying moistures should be used to determine where the threshold for each discrete moisture level should sit. Once these thresholds are determined, future samples of the same soil type will be able to be categorised.

III. RESULTS

Each of the soil samples were taken from the same raised garden bed to ensure they were of consistent soil type. This soil was of a loamy textural class [15]. Larger particles were separated to increase the uniformity of the soil's appearance, as a uniform texture was desirable for image standardisation. Prior to taking the photos, the soil was dried out for 48 hours, with turning during the day to ensure an even colour was achieved.

Images of the samples were captured on a white background during an overcast day to reduce shadows and give an even lighting effect. This improved the standardisation of the photos. Some samples were also photographed during slightly different lighting conditions which cast shadows on the background. Other samples had larger particles and were also photographed to use as an edge case for the method.

A spray bottle containing water was used at a distance of 15 centimetre directly above the samples to provide a method of incrementally increasing the water content of the samples. Several samples of completely dry soil were photographed as controls to ensure the proposed method provided consistent results for samples of the same moisture. A 'dry' sample can be seen in Fig. 3, with a 'damp' sample shown in Fig. 4, and a 'wet' sample in Fig. 5. These samples were then colour balanced using the simplest colour balance algorithm after being resized to 500 x 500 pixels. An example of the result of this can be seen in Fig. 6.

Fig. 3. An example of a 'dry' sample.

Fig. 4. An example of a 'damp' sample.

Fig. 5. An example of a 'wet' sample.

Fig. 6. The original image (left) compared to the balanced image (right).

The mask which isolates the soil from the image was then generated using the colour balanced image. After it had been converted into a greyscale image, it was then able to be thresholded to give a binary image which isolated the soil particles. This image contained a substantial amount of excess information due to the smaller particles which are present around the outside of the main collection of the sample. The mask itself had holes as well due to small lighter particles in the soil. This can be seen in Fig. 7. Dilation was then performed to close the holes. This was done with a three by three kernel of ones once, the result of which is shown in Fig. 8. Erosion was completed six times with a five by five kernel on the result of the dilated mask, to eliminate excess noise around the main sample of soil. The result of this can be seen in Fig. 9.

Fig. 7. The binary mask image showing considerable noise and holes.

Fig. 8. The binary mask after dilation.

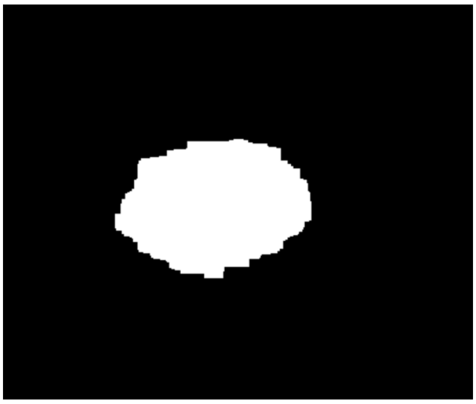

Fig. 9. The binary mask after erosion.

This mask was then multiplied to give the final image, which completely isolate the soil from the white background. In most cases the edges of the soil were also removed, which was desirable as these were often discoloured due to the resizing of the original image. The final image which has the soil isolated from the background can be seen in Fig. 10. This image was then able to have all non-zero pixels averaged to give the average RGB channel values for the soil sample.

Fig. 10. The final image which isolates the desired soil pixels.

The averages of each sample that were to be used for calibration were graphed so the correlation between moisture content and RGB channel values could be observed. In addition to the channel values, the average value was plotted to see if this would be a suitable quantification to use to decide on ‘dry’, ‘damp’, and ‘wet’ thresholds. This graph is shown in Fig. 11.

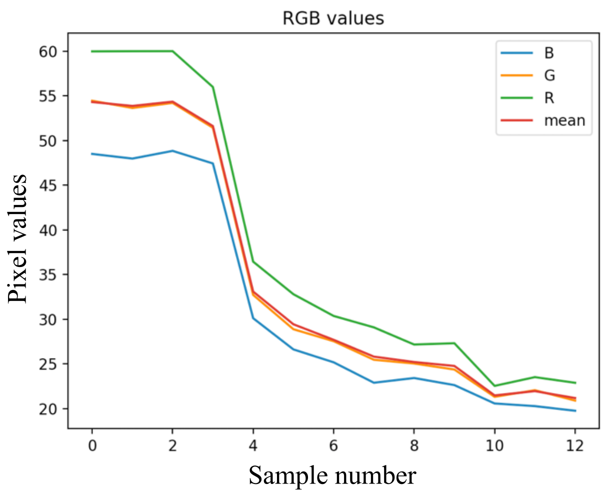

Fig. 11. Calibrating graph of RGB values from range of soil images at increasing moisture levels (sample 0 dry, sample 12 wet).

The first four samples shown on this graph were all dry samples. This confirmed that the pixel values were being read consistently as they were all close. It was also observed that the RGB channel values proportionately decreased as moisture levels increased. This meant that the average RGB channel value of each image could be used to set suitable thresholds.

Thresholds were set using the ground truth categorisations of the calibrating samples alongside their mean RGB channel values. The thresholds were set so they fell between the mean RGB values for the samples which were on either side of a category. These thresholds are summarised in Eq. 5.

$$thresholds = \begin{cases} mean > 40 & dry \\ 40 > mean > 25 & damp \\ mean < 25 & wet \end{cases} \tag{5}$$

Once these thresholds were set, further samples were run through the programme to check the accuracy of the method. These samples also had a ground truth category so that the method could be evaluated quantitatively. This testing comprised of a further 15 samples which complied with the initial testing conditions. Of these samples, 14 were correctly allocated to their ground truth category. The one that was incorrectly categorised sat on the boundary between damp and wet.

A. Limitations of the method

Further samples which were taken under different conditions were also tested. This allowed the response of the method to non-ideal images to be tested. Three images for each different condition were tested. The first condition was extremely wet soil. This soil becomes reflective in photographs, and the method struggled to categorise this soil as wet, instead giving it the categorisation ‘damp’. An example of extremely wet soil can be seen in Fig. 12. Uneven lighting conditions were also tested, as was large particles in the soil. Uneven lighting conditions caused the colour balancing to have less effect, making it more difficult to get consistent, standardised images and results. Large particles in the soil changed the mean pixel values slightly, particularly when non-soil objects were present in the sample (for example, a woodchip). An example of a sample with uneven lighting and large particles is shown in Fig. 13. All of these cases substantially reduced the success rate of the method, confirming that image standardisation is vital for the method to have a high success rate.

Fig. 12. An example of extremely wet soil that became reflective.

Fig. 13. An example of a sample with uneven lighting and large particles.

B. Benefits of the method

Although requiring image standardisation is a limit of this method, there are many benefits in comparison to methods used in previous research. The main benefit is that all of the processing of the image is done automatically. In previous research all of the image processing is done manually, whereas in this method the images are resized, colour balanced, and analysed as part of the process. The soil pixels are also isolated automatically regardless of where they are in the image, rather than the image having to be cropped so that only soil pixels are present. The results achieved by this method in comparison to previous methods are comparable, with previous methods focusing on developing a model that fits the samples they had. This resulted in a 100% accuracy when classifying each sample, which is slightly better than the 93% accuracy result achieved by this method. The ease of use of this method is the main benefit, with comparable accuracy meaning that it is an improvement towards a widely usable method.

IV. Conclusions

Each image taken of a soil sample was resized and colour balanced prior to a binary mask being generated so that the soil pixels in the image could be isolated then averaged. This average value was used to categorise each sample as either ‘dry’, ‘damp’, or ‘wet’. The results from this were compared to the ground truth which was marked prior to running the images through the programme. This method resulted in a 93% success rate in classifying the images into the correct category. This is comparable to the results achieved by prior research which managed to get 100% accuracy, although the focus of this research was based on modelling the pixel value response to changing moisture rather than categorising each sample. The main benefits of using this method compared to the methods used in prior research are that it processes the images automatically and can isolate the soil pixels from the background. The limitations of this method are that it struggles to correctly classify soil which is too wet due to it becoming reflective, as well as requiring standardised images which have even lighting on a white background.

A. Further Research

Further research which could be done to improve this method would include developing methods of standardising images that have uneven lighting so conditions do not need to be exactly the same for functionality. Automatic shadow lightening is another improvement that could be made, as although shadows were not commonplace in the samples they were still present and may have altered some of the pixel values. Automatic calibration which would enable the user to pass in images of the soil type they wish to classify would also be highly beneficial to the method. Currently the user has to set the thresholds for the soil by manually comparing the ground truth categories and the mean pixel values. The biggest improvement on this method would be increasing the number of levels it can categorise samples into. It would be more useful, for example, if it was able to give an indication of the percentage of saturation the soil has. This would be a big step towards making the method usable for a wide range of applications.

V. References

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