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Full Length Research Paper

Potato surface defect detection in machine vision system

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Potato is cultivated as a major food resource in some countries that have moderate climate. Potato is sensitive to many diseases. Sorting is necessary for decreasing the transfer rate of diseases and preparing favourite conditions. Grading with workers has disadvantages such as: instability, time needed and its expensive, to solve these problems, use of machine vision system is necessary. 90 Agria potatoes were prepared. The potatoes were graded to 6 classes with 15 samples that they were: healthy, cracked, rhizoctonia fouled, cutting, rotting and greening. The samples were placed in lighting chamber and images of them were captured by means of a CCD camera. The images were transferred to a personal computer by a frame grabber. These images were analyzed by MATLAB software. For different defect sorting had been used a compound of colour and physical properties of defects. Sorting accuracy was 97.67%.

Key words: Colour analysis, physical properties, potatoes, sorting, surface defects.

INTRODUCTION

The potato (*Solanum tuberosum*) is an herbaceous annual that grows up to 100 cm (40 inches) tall and produces a tuber - also called potato - so rich in starch that it ranks as the world's fourth most important food crop, after maize, wheat and rice. The potato belongs to the Solanaceae - or "nightshade"- family of flowering plants, and shares the genus Solanum with at least 1,000 other species, including tomato and eggplant. *S. tuberosum* is divided into two, only slightly different, subspecies: andigena, which is adapted to short day conditions and is mainly grown in the Andes, and tuberosum, the potato now cultivated around the world, which is believed to be descended from a small introduction to Europe of andigena potatoes that later adapted to longer day lengths (FAO, 2008).

The cultivated potato originated about 8 000 years ago in the Andean range of South America and by the nineteenth century had spread to almost all continents. In fact, Charles Darwin, the greatest naturalist of that time, encountered the potato everywhere, from the sterile mountains of Central Chile where a drop of rain does not fall for more than six months, to the damp forests of the southern islands.

Among the Near East Asian countries, Iran is the world's number thirteen potato producer and the third in Asia, after China and India. In 2006, the country achieved an all-time record harvest of 4.8 million MT, with per hectare yields averaging more than 25 tons (Pandey, 2008).

Potatoes are grown in almost all provinces of Iran, a country of great climatic extremes from deserts to the humid Caspian littoral (Avval, 1977; Askari, 1975). However, there are three major potato regions:

The Elburz Mountains form a narrow band around the southern shore of the Caspian Sea. Potatoes are a major crop here, grown from Tabriz in the northwest to Mashhad in the northeast. Other centres of production in the Elburz include Ardabil, Zanjan, and Gorgan. Potatoes are also an important crop in the Zagros Mountains, which trend south-eastward from the western portion of the Elburz range toward the centre of Iran. Important areas are Hamadan, Arak, Faridan, and Isfahan. Potato

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production in both southern and northern highlands generally occurs at elevations between 1000 and 2000 masl probably and accounts for more than 90% of the area grown (George, 1978).Some scattered production also occurs in the arid lowlands of southern Iran near the Persian Gulf, especially in Fars, the area around Bandar Abbas, and parts of Baluchistan, Khuzestan, and Shiraz (Schmiediche et al., 1986; Fisher, 1986).

Potato is sensitive to the large number of diseases. The agents of these diseases are bacteria, fungi, viruses, micro plasma, Viroids and Nematodes. Another group which is named noncontiguous disease is the deformity of inappropriate climate conditions, food element shortage or other not living factors. In the herbal disease list in the united state national, almost 160 potato diseases and deformities are recorded. Potato is reproduced in asexual way by means of cultivating a part of tuber or a complete one. In this way of reproduction, the pathogen transferring and their wintering in the reproducing tubers are evitable. For decreasing these risks, separating of infected tubers from healthy ones is necessary (Ghafarpur, 1991) potato grading has been determined as one of the qualitative factors which are considered by sellers and purchasers. Grading is usually done by workers and observing the tuber surface. Potato grading by workers include some disadvantages such as: lack of stability, time and cost consuming.

Applying machine vision system has removed these disadvantages. Many scholars have worked on separating the defected fruits and vegetables from the healthy ones.Tao et al. (1995), proposed one method in grading green and good potatoes. In this system colour properties were classified into good and green groups. In the first step potatoes were graded by inspectors and workers. In training phase, all 40 of good potatoes (100%) and 38 of green ones (95%) and in testing phase all 20 of good potatoes (100%) and 18 of 20 green potatoes (90%) were classified correctly.Zhou et al. (1998) evaluated weight, cross-sectional diameter, shape, and colour of three cultivars of potato using a computer vision system which was able to classify 50 potato images per second. An ellipse was used as the shape descriptor for potato shape inspection and colour thresholding was performed in the hue-saturation-value (HSV) colour space to detect green colour defects. The average success rate was 91.2% for weight inspection and 88.7% for diameter inspection. The shape and colour inspection algorithms achieved 85.5 and 78.0% success rates, respectively.

The overall success rate, combining all of the above criteria, was 86.5%.Noordam et al. (2000) suggested a method in grading of potatoes based on machine vision system. In this method, the potatoes were graded based on size, shape, surface defects such as: greening, mechanical damages, usual diseases and crack. For grading the potatoes, the statistical technique [Linear Discriminate Analysis (LDA)] and Multi- Layer Feed Forward Neural Networks (MLF-NN) were used and 1100 images from 6 varieties were captured. The grading results based on colour for LDA and MLF-NN was respectively: 86.8 to 98.6% and 88.1 to 99.2%. Rios-Cabrera et al. (2008) determined potato quality evaluating physical properties using Artificial Neural Networks (ANN's) to find misshapen potatoes. The results showed that FuzzyARTMAP outperformed the other models due to its stability and convergence speed with times as low as 1 ms per pattern which demonstrates its suitability for real-time inspection. Several algorithms to determine potato defects such as greening, scab, cracks were proposed. Barns et al. (2009) introduced novel methods for detecting blemishes in potatoes using machine vision.

The results show that the method is able to build “minimalist” classifiers that optimize detection performance at low computational cost. In experiments, minimalist blemish detectors were trained for both white and red potato varieties, achieving 89.6 and 89.5% accuracy, respectively.Jin et al. (2009), reported a novel inspection approach to external defects of potato in three potato cultivars. Adaptive Intensity Interception (AII) and Fixed Intensity Interception (FII) methods proposed to extract the suspect defects. The correct classification rate of defects, the correct recognition rate of defects and the correct inspection rate of potatoes based on FII were 92.1, 91.4 and 100%, respectively.

The experimental image acquisition setup by Ebrahimi et al. (2011) was consisted of an image capturing box equipped with lighting system, a colour CCD camera, and a capturing card. The data set consisted of 25 images of potatoes with physiological skin greening blemishes. Image pre-preprocessing has been carried out to modify the non-uniform distribution of background light intensity. Since potatoes have bright skin, the CCD was saturated in a small part of each image. These parts were eliminated from the images using a relation found between RGB and HSI spaces.

The difference between red and green components of RGB space for green parts of potatoes was lower than that of other parts. Finally, the $1.02R - G$ relation was found to be suitable for detection of green parts of potato tubers.

The average of error between actual green parts area and estimated green parts area for 25 images was 5.26%.

In this research, we had some purposes which are:

1. Evaluation of quantity transforming functions and the best transforming function selection.
2. Evaluation of colour spaces and the best colour space selection.
3. Evaluation of various potato surface defects and their quantitative and colour properties selection.
4. Applying the algorithm and colour threshold extents and evaluation of grading accuracy in to healthy and

Figure 1. The hardware system.

defect classes and separating various defects from each other.

MATERIALS AND METHODS

The use of a lighting chamber and proper lighting sources is the first step in designing a machine vision system. Camera selection and capturing proper images is the second step. Extracting corresponding properties from images is the third step. Finally an algorithm is applied to grade potatoes.

Grading system scheme

In this research, our grading system was contained in two schemes:
Hardware system
Software system

The hardware system

The hardware of this system included these elements:

Lighting chamber
Lighting source
CCD camera
Personal computer

Lighting is a key factor in machine vision system and affects the quality of captured images. The type of lighting source and the way of lighting are the main factors that affect the later image processing and their results. The weak lighting may create dummy effects such as shadows in images and can make an error in image processing. Whereas in steady lighting, the contrast between object and background is easily obtained. Natural light is changed meaningfully by climate conditions, view sight, day hour and geographical locations. For quality light standardization and its reservation, the artificial light was used. The lighting chamber which was used in this research is illustrated in Figure 1.

The structure of this chamber was an obstacle to outer light. In this chamber four florescent lamps were used. Every 2 of these lamps were positioned in 45°. On the top of the chamber a hole was improvised for camera lens. The camera was a CCD camera of Proline UK model. The samples were positioned in the centre of the chamber which the camera lens was on the top of the samples and the light sources were on the left and right of them. For transferring the pictures to the computer memory a frame grabber of CHATEAU model was used.

The software system

For image processing, MATLAB software version 7.6.0 was used.

Sample preparation

The variety of these samples was Agria. We obtained a large number of tubers from Bostanabad Agricultural research centre of Tabriz and the samples of healthy, cracked, greening and rhizooctonia were separated in 15 groups. Since as the potatoes were stored in appropriate conditions of temperature, moisture and light, the samples of Fetidness group were not available. So we prepared this group by providing appropriate temperature and moisture to tubers putrefied. In this stage we controlled the temperature, moisture and period of time conditions and prepared 15 numbers of potatoes by different percent of fetidness. Also, the skin cutting class was provided in different percent by cutting the skin and simulating the skin cutting in real conditions.

Finally, 90 Agria potatoes were prepared. The samples were graded to six groups: healthy, cracked, rhizooctonia disease, greening, infected and skin cutting.

Sorting algorithm

For grading of these defects, in the first step value transformation functions and various colour spaces were evaluated and the best combination of these functions and colour spaces was selected.

Value transformation functions

By using these functions, values in the first image are transformed to values in the second image. The values between minimum and maximum points in the first image are transformed to the points between minimum and maximum in the second image.

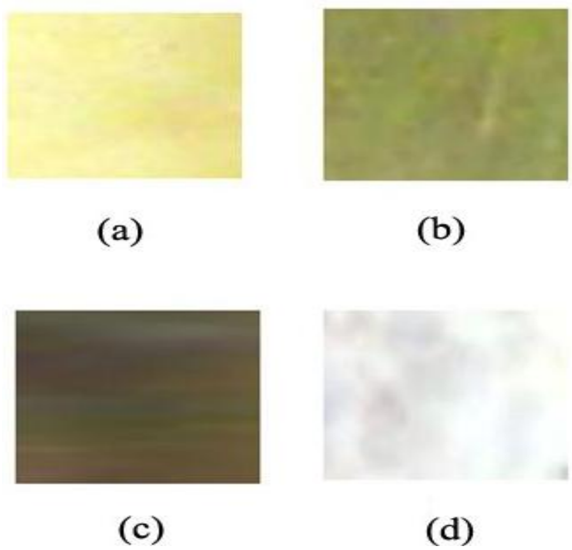

Figure 2. Representative windows of a) skin cutting, b) Greening; c) crack; and d) fetidness classes.

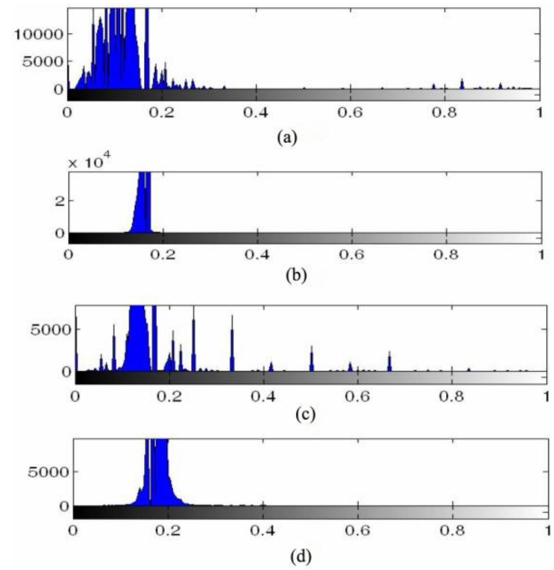

Figure 3. Hue element in a) crack; b) skin cutting; c) fetidness; and d) greening (Horizontal Axis: Hue value-Vertical Axis: Number of pixels).

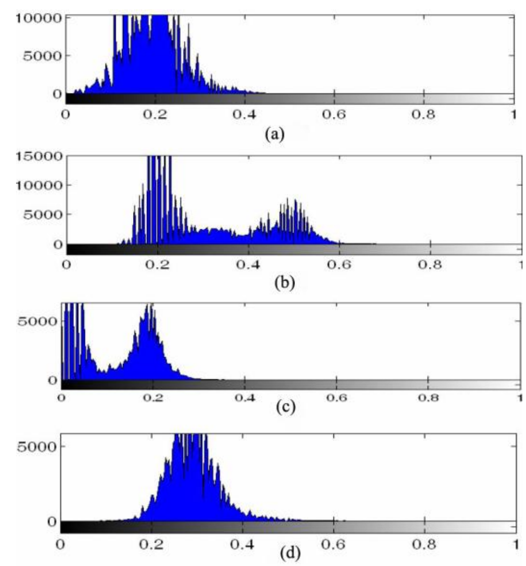

Figure 4. Saturation element in a) crack; b) skin cutting; c) fetidness; and d) Greening (Horizontal Axis: Saturation value-Vertical Axis: Number of pixels).

Contrast traction

A low contrast in image may be a result of low light, low dynamic range in imaging sensor or incorrect adjustment of lens in duration of image capturing. The goal of contrast traction is the increasing of gray level dynamic range in processing image.

Logarithmic transformation

Sometimes, the dynamic range of processed image is over of the displaying power device. In this condition only the lightest parts of image are visible. Image Fourier spectrum displaying is one of the examples of this phenomenon. The dynamic range of pixels is created by transformation function in Equation 1. In this equation, c is fixed and r and s are dependant to intensities before and after the function performance and create the favourite logarithmic function.

$$s = c * \log\left(1 + |r|\right) \tag{1}$$

Colour properties evaluation and pixel classification testing

For the first step, every pixel of image was classified to pre-defined classes. Afterwards, each pixel was graded based on colour properties. For extracting colour threshold of each class, images in every class were divided to learning and testing classes. In training classes, 100 number of 100 by 100 pixel windows were extracted. For pixel classification of images, the extracted windows were introduced in MATLAB software as representative of each class (Figure 2). Reaching the best grading system was obtained by evaluation of RGB, HSI, YC_bC_r and HSV colour spaces. For selection the best combination, correlation coefficient between extracted percent of defects and the actual percent of defects was calculated.

RESULTS

Evaluation of colour based sorting precision

For evaluation of colour based sorting precision, the histograms of Hue (H), Saturation (S) and Intensity (I) were extracted (Figures 3, 4 and 5). As represented, mere colour properties defect sorting isn't applicable because the overlapping between the Crack and Rhizoctonia defects and between Skin cutting and Fetidness are high. By this reason we evaluated surface properties in addition to colour spaces.

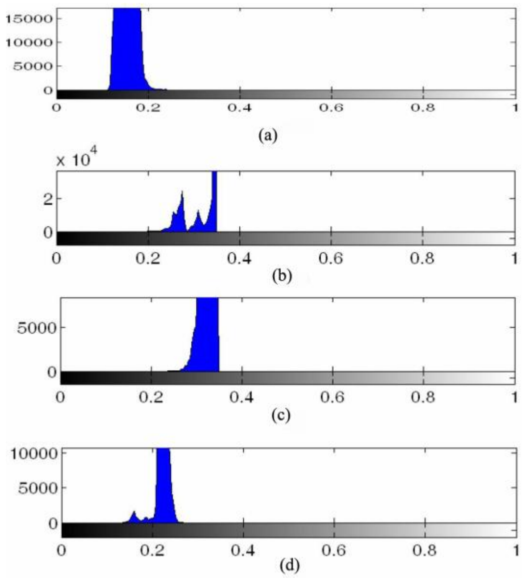

Figure 5. Intensity element in a) crack; b) skin cutting; c) fetidness; and d) greening (Horizontal Axis: Intensity value-Vertical Axis: Number of pixels).

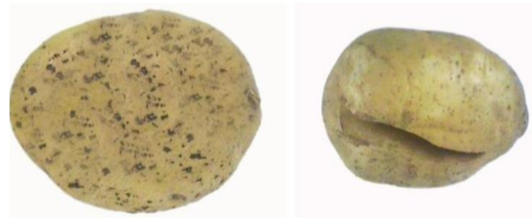

Figure 7. Cyrack(right) comparison with Rhizoctonia (left).

Figure 8. Skin cutting (right) comparison with fetidness (left).

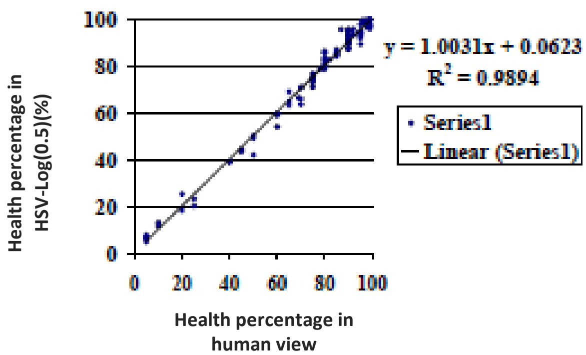

Figure 6. The correlation between health percent of pixels in human view and the color algorithm.

Table 1. Crack and rhizoctonia recognition.

Defect	Gray level	Diameter ratio
Crack	<0.4	>2.5
Rhizoctonia	<0.4	<2.5

Colour spaces and intensity transformation combination evaluation (in health class)

As shown in Figure 6, for only evaluating the accuracy of the colour sorting algorithm, the correlation between percent of health class in each sample estimated by experts and the algorithm percent of health class was calculated. The percent of health class in the same face of each sample in the human viewing was estimated and in the algorithm is defined as dividing the number of pixels in health class to the total number of pixels.

Colour based grading threshold in every class was calculated by selection the best combination of colour spaces and intensity transformation functions. The best combination was logarithmic transformation with 0.5 coefficients in HSV colour space (with correlation coefficient of 0.989).

Sorting of crack and rhizoctonia defects

For grading of these defects we studied their physical properties. Grading of these defects was performed according to Table 1. As represented in Table1, by studying the available cracks, it was found that the ratio of the major to minor diameter is larger than 2.5.

For grading of these defects, the combination of gray level threshold and the major to minor diameter ratio were combined Figure 7.

Sorting of skin cutting and fetidness

Fetidness is mostly scattered region whereas the skin cutting is a continual region and isn't scattered on the potato surface. Therefore these defects were graded based on this physical property and colour specification. The threshold of physical property was extracted and the sorting was performed by combination of colour and physical properties Figure 8.

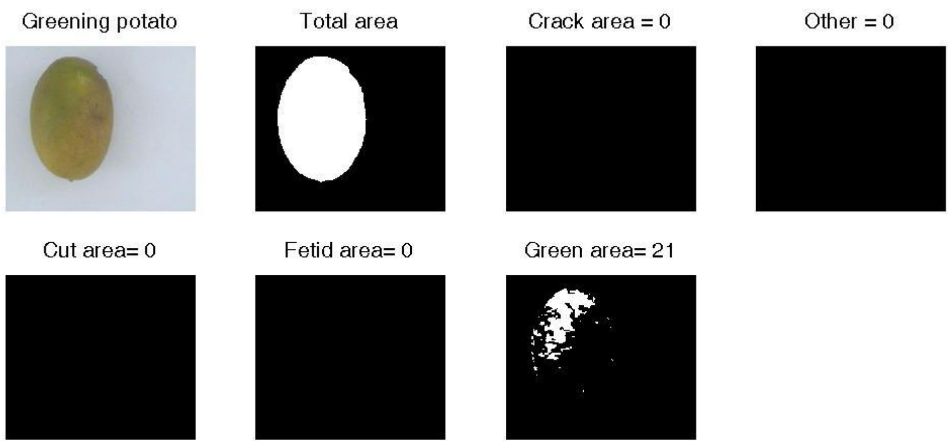

Figure 9. One sample of green potato sorting in MATLAB software.

Table 2. Precision of various defect sorting.

Class	Healthy	Crack	Greening	Fetidness	Skin cutting	Other defects	Precision (%)
Healthy	15	0	0	0	0	0	100
Crack	0	15	0	0	0	0	100
Greening	0	0	15	0	0	0	100
Fetidness	0	0	0	13	2	0	86
Skin cutting	0	0	0	0	15	0	100
Other defects	0	0	0	0	0	15	100
							97.67

Sorting of various defects

For sorting of various defects, we wrote a program in which images were called and existence of crack, rhizoctonia, greening, skin cutting and fetidness were inspected. In the next stage, the percentage of each defect was calculated and the highest of it was selected.

If a potato had various defects, the sorting was performed based on the highest percentage of defects. A potato which had no defect was identified as healthy potato. A sample of this program output is represented in Figure 9. In this figure a Green potato is sorted and the percentage of this defect is calculated. Based on this percentage, the potato is sorted as Green one. For evaluation of this program, 90 potatoes which contained 15 number of Crack, 15: rhizoctonia, 15: greening, 15: fetidness and 15: healthy. Results of this program testing are represented in Table 2.

DISCUSSION

As mentioned in the result, for sorting of different defects, the colour properties and physical characteristics were extracted. At first, in the colour properties, extraction of 20 of 100 by 100 pixel windows from each image and defected area were extracted. By only implementing the colour spaces (as shown in Figures 3, 4 and 5) the sorting accuracy in detection of different classes from each other was very low because the colour overlapping in classes was (especially between Crack and Skinless classes) high. By this reason we utilize two methods:

1. Performing the best combination of different colour spaces and transformation functions.
2. Performing the combination of colour properties and physical properties of each class.

In the first method Health class was selected for extracting the best combination of colour spaces and transformation functions. At first step the experts determine the percentage of health in each sample and then the images of the same face were transferred to the computer memory. By implementing the algorithm of different combination the percent of number of health pixels to the number of total pixels were displayed. The comparison between two group percentages: human view and algorithm performing, was done. The beat combination in which the percentage were very close was selected. By mere performing this algorithm the sorting algorithm was improved, but still the overlapping was occurred. In the second method defects physical properties and colour specifics were combined. Overlapping in defect identification between crack and rhizoctonia as well as between fetidness and skinless was high. Rhizoctonia is scattered and small area points all over the potato skin. In contrast, crack is continuous line which is larger than area of each point in rhizoctonia. The major axis length to minor axis length in different cracks was calculated and the threshold of 2.5 was extracted. About different fetidness and skinless (Cutting), extracting the appropriate threshold was difficult because Fetidness is a variable defect and its area in the different condition of moisture, temperature and even passed time is changed. So extraction the fixed physical threshold for this defect is difficult. Also The cutting area is variable and is dependant to the condition of harvesting, handling and so on.

Before implementing the sorting algorithm, the experts graded samples based on their major defects and the samples, which have none of the five defects were graded as Health group. The algorithm calculated the percentage of each defect (the number of each defect divided to the total number of pixels) and the greatest was identified as the major defect. The output of program was the same as the defect which sample was graded into that class. From 15 of each class, all defects were graded correctly (compared to pre-graded class) except of fetidness class which 2 pre-graded of this class were graded by program as skinless class incorrectly. Thus the accuracy of all these sorting were 100% except fetidness which was 86% (13 of program sorting to 15 pre-graded samples). The total accuracy was 97.67% which was the average of all sorting accuracy of different classes.

Conclusion

Total precision of potato sorting was 97.67%. This precision with regard to the other studies is acceptable. Tao et al. (1995) operated HSI colour system for sorting of Green potatoes and their sorting precision was 90%. Noordam et al. (2000) sorted potatoes based on LDA and neural network. The sorting precision for LDA technique was 86.8 to 98.6% and for neural network was 88.1 to 99.2%.

Zhou et al. (1998) sorted Green potatoes based on HSV colour space. This system's accuracy was 78.0%.

Barnes et al. (2009) introduced novel method based on "minimalist" classifier for detecting blemishes in potatoes. This research result for white and red potatoes was 89.6 and 89.5%, respectively.

Jin et al. (2009) reported a novel inspection approach to external defects of potato in 3 potato cultivars. AII and FII methods proposed to extract the suspect defects. The correct classification rate of defects, the correct recognition rate of defects and the correct inspection rate of potatoes based on FII were 92.1, 91.4 and 100%, respectively.

We can operate this system on the on-line systems. For operation the on-line sorting system, we must install crop moving distinction equipment, image capturing system and an equipment for crop sorting to various classes.

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