Improving Independence in Money Recognition for Blind Brazilians

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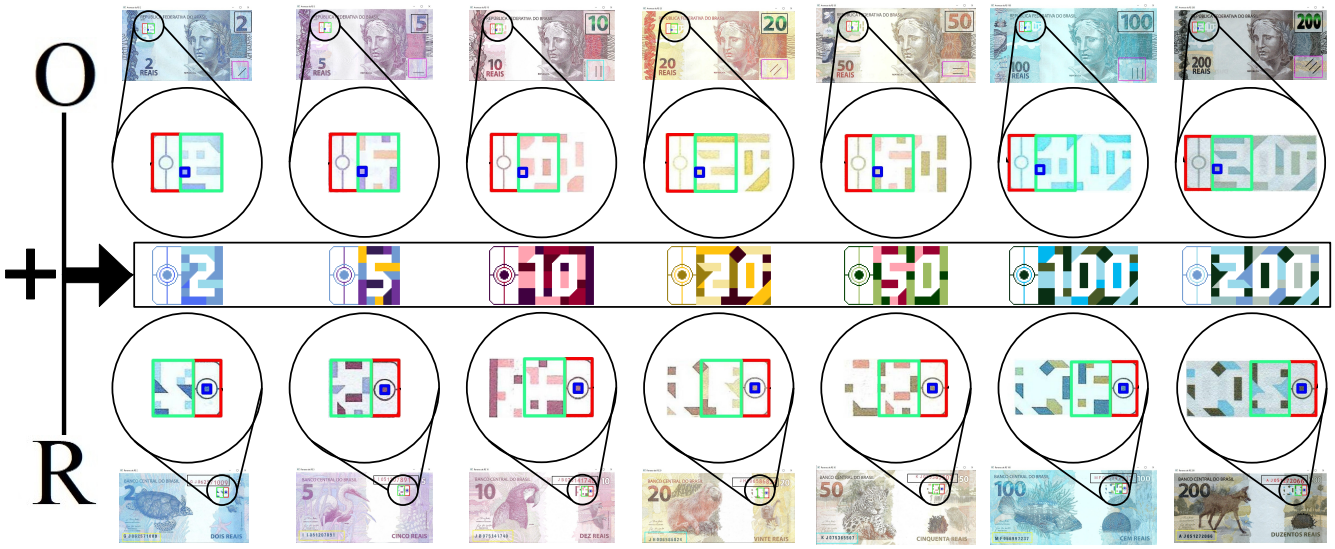

Figure 1: Puzzles on each face of Brazilian banknotes and their appearance when seem jointly by frontal side.

Abstract

This paper aims to propose of an assistive technology taking advantage of using the traditional technique Template Matching combined with color recognition in the domain of HSV color space through of the development of a mobile application to recognition Brazilian banknotes provided by the segmentation of security items named Puzzles that belong to the Second Series of Real. The predominant hue, as the Puzzles, is another one of a several security items of the Second Series of Real and it is possible to classify both verses of the seven types of Brazilian banknotes using this feature. Template Matching is used to turn viable the predictions by the predominant hue extracted from homogeneous, standardized and unique location and at the same time the predominant hue is used to confirm predictions of the Template Matching. Both techniques are available in the OpenCV library which allows the viability of a prospectus to build a smartphone application which can promote the improving independence of visual impaired people in their monetary exchanges dealing with the Second Series of Real banknotes.

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CCS Concepts

• **Human-centered computing** → **Accessibility technologies**; **Accessibility systems and tools**; **Smartphones**; **Graph drawings**; *Visualization application domains*; *Visual analytics*; *Visualization toolkits.*

Keywords

Accessibility, Assistive Technology, Brazilian Banknotes, Second Series of Real, Puzzle, Template Matching, HSV Space Color

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1 Introduction

The money bills are material representations of monetary values that the humanity had created to facilitate the commercial services exchanges among persons without any type of relation (like friendship, family or work), but with a common interest to buy, sell or when there are values left in the exchange on one of the parties involved [9, 18].

In Brazil, the acceptance of cash is mandatory if one of the parties involved so wishes, in these cases the currency circulation is predicted in the law as provides fine punishment to any citizen

who recuses to receive a monetary amount in Brazilian currency [3, 4]. These laws should be seen not as an obstacle, but as an aid to the exchange of smaller amounts by people without access to other forms of payment or receipt even by people who are blind or have reduced vision. The Real was created in 1994 with other aspect that is now named the First Series of Real. In 2010, it was launched the Second Series of Real which substituted and innovated the design but maintain some of visual features like the characteristics colors associated to each value. Among innovations the most significant it is the one that provides help of accessibility for Visual Impaired Persons (VIP): different lengths to distinct values and the inclusion of tactile elements at the corner of the bills as shown at third and sixth columns of Figure 2. In 2020 the Brazilian Central Bank (BACEN) launched the 200 bills with the same dimensions of the 20 bills. This fact turned harder recognition by sizes. Moreover, even before the launched of the 200 bills, most of VIP related difficulties to recognize Brazilian banknotes only handling them [5].

The Second Series of Real presents banknotes that have several security features to prevent counterfeiting, such as colors, dimensions, animals from the Brazilian fauna and items called Puzzles shown in the seventh and eighth columns of Figure 2 [2]. The Puzzles when observed against the light from the Obverse side combined with the opposite side must show the note value. The last column of Figure 2 shows the value of the note based on the image resulting from such a combination. The Figure 1 shows how the Puzzles are placed in each sides of the Brazilian banknotes.

Obverse	Reverse	Dimensions (mm X mm)	Animal	Predominant Hue	Tactile Mark	Puzzle Obverse	Puzzle Reverse	Obverse + Reverse
		121 X 65	Sea Turtle	Navy Blue				
		128 X 65	Heron	Lilac				
		135 X 65	Red Macaw	Red				
		142 X 65	Golden Lion Tamarin	Yellow				
		149 X 70	Jaguar	Beige				
		156 X 70	Grouper	Tourquoise				
		142 X 65	Guara Wolf	Gray and Sepia				

Figure 2: Second Series of Real features [2].

This paper aims to purpose the development of an Assistive Technology through a mobile application using Image Analysis to characterized the values of the Second Series of Real using Template Matching and Color Recognition techniques provided by the *OpenCV* library [13].

2 Related works in Banknote Recognition

A recent survey identify lacks of academic research in investigation of money bills. Its authors verified that the majority of the research with currency paper is done by industrial sector. They described a state of the art of four tracks involving this research around the world. These tracks are: (1) Banknote Recognition, (2) Counterfeit Banknote Detection, (3) Serial Number Recognition and (4) Fitness Classification [12]. This section shows some studies in the first one: Banknote Recognition.

2.1 Image Analysis for Banknote Recognition

The banknote recognition is considered a critical field of pattern recognition [16]. In 2015, several samples of Saudi Arabian banknotes with different usage conditions are considered. Some of them were rotated up to 15°. In addition, dirty or worn-out banknotes were also used. This work used the Radial Basis Function to identify and to classify the banknotes. When a image is provide to the classification system it is calculated all correlations possible. Then a net was training for image classification.

The authors in [14] bring a proposal of recognition of Mexican and Euro banknotes through a robust system using Artificial Neural Network trained with images from banknotes illuminated by natural and artificial lights. The Convolutional Neural Network was used to detection and recognition of objects present in Mexican and Euro banknotes. In this study it's important to note that the characteristic colors obtained from the banknotes increase the recognition accuracy of the same tests performed with only gray scale images. The authors conclude that the color information and some regions of the banknotes are sufficient to get higher percentages of classification and recognition.

The authors in the study [8] shown a paper motivated by design renewal of the Euro banknotes that was programmed to the year 2024. The cell characterization is made by recognition of the fiber that only visible under the ultraviolet light. These fibers are present in the Euro banknotes and they are randomly positioned during the production of Euro cells. The authors point out that the mere presence of fibers with these characteristics does not guarantee the authenticity of the banknote analyzed, due to the wide variety of modern printers that have the capacity to use visible inks that simulate these fibers in the same way when illuminated with ultraviolet light. On the other hand, the random position of these fibers guarantees the uniqueness of their location on each banknote, and this property could be characterized as a security and identification feature of each note, just as fingerprints are unique to each human being. The random position is not the only notable characteristic of these fibers, but also their orientation and inclination. The authors use the HSV color space to develop a software using the *OpenCV* library that uniquely identifies each Euro banknote by the position and inclination of the fibers visible only under ultraviolet light.

2.2 Banknote Recognition Apps

The authors in [6] propose a Euro banknote recognition system for blind people to acquire more independence in their purchases. This system uses a credit card microcomputer and a mini electronic camera, both from the *Raspberry Pi* brand. The camera, which has an additional infrared light, is adapted to the lenses of sunglasses. The system is complete when the information collected by the camera and processed by the microcomputer is sent to the smartphone of the user who operates the acquisition system through voice commands. The authors achieved 84% detection of the locations where the banknotes were located and 97% in the recognition stage using the SURF algorithm.

The authors in [11] aim to include Visually Impaired people by developing a mobile application for recognizing Argentine banknotes (Pesos). The application is developed with open source code

so that it can be continuously updated by independent contributors who identify any system failure. The authors draw attention to the subject because, in addition to inclusion, it promotes independence and increases the quality of life of people with some visual impairment in their commercial transactions using physical currency.

2.3 Ideas Correlation

The methodology developed at [20] defines the objective of this paper which is to propose a solution that allows simple monetary exchanges involving amounts of money that a blind Brazilian can carry in everyday-life and using the computational capability of a mobile device with an app without the pretension of confirm the authenticity of the banknotes like in [11]. With this idea, combining two well established techniques, Template Matching and HSV color space, it aims to avoid heavy computational solutions or buying additional equipments that would be necessary to identify the Second Series of Real banknotes.

In this research were used banknotes in several states of deterioration to identify them in real conditions of purchase in a similarly manner as developed at [16]. It was taken advantage of the fact that there is a one-to-one correspondence between each value of Brazilian banknotes and the corresponding predominant hue presented at Figure 2 to identify this feature in the domain of HSV color space which allowed a better characterization of the hue extracted from tiny regions as it used to confirm the predictions by Template Matching and increase the percentage of classification like [8].

The predominant hue obtained from inside the small regions of the puzzles allows the full characterization of Brazilian banknotes and this simple region is sufficient to confirm the verse and the value of the bills which converges to the conclusions of [14] that is not necessary use full image of the banknote to classify it.

With restrictions of the Template Matching technique and using the image of a single Brazilian banknote, digitized each time in a scanner, and isolated by it's edges in [20], it was possible achieve very close to 100% of detection and recognition, which indicates a great potential in a prospect mobile application with natural light.

3 Template Matching and Color Spaces Techniques

According to the considerations in the previous section, this work belongs to the research field of Banknote Recognition, since it also aims to classify the Second Series of Real banknotes according to their verse and value. This research presents the possibility of using the traditional pattern recognition technique ***Template Matching*** in the recognition of security elements called Puzzles to characterize the images of Second Series of Real banknotes that could turns viable a develop a mobile application. Through the applied methodology, it is possible to classify the value attributed to the image using the predominant characteristic hue identified in the HSV color space.

3.1 Template Matching

The pattern recognition technique called *Template Matching* is a traditional technique for recognizing objects present in digital images, i.e., it is the investigation of the location of a pattern that

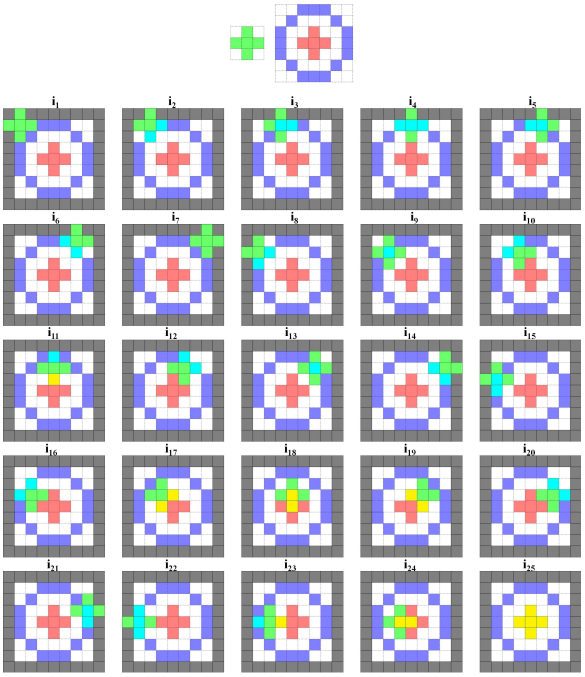

Figure 3: Illustration of an example of the Template Matching algorithm.

is present in a digital image [10]. The input image (*source*) is where we want to locate the exact area that matches with the pattern (*Template*) [7]. The technique is well known, easy to implement and flexible in its use. In addition, it is already implemented in several programming languages [17].

In Figure 5, for example, the technique's algorithm compares the wanted pattern, which is represented by a 3×3 pixels area that aims to describe the green plus sign, to each sector of the same size (in number of pixels) within the input image given by a 7×7 pixels area that aims to represent a blue circle with the red plus sign inside it, which is identical in number of pixels to the green sign. In Figure 5, the scanning iterations that occur between the two images are shown up to iteration i_{25}, which shows the perfect match between the two images. The iterations from i_{26} to i_{49} were not shown, but they are analogous to the twenty-four iterations prior to i_{25}, due to the symmetry of the images. If the reader wants to "see" these iterations, simply rotate the image 180° to see what the iterations up to i_{49} would look like starting from i_{25}.

There are six techniques for calculating the similarity (or difference) between the pattern and a region of the image [7, 17]. The methods are:

- Sum of Squared Differences;
- Normalized Sum of Squared Differences;
- Correlation Coefficient;
- Normalized Correlation Coefficient;
- Cross-Correlation (or Autocorrelation);
- Normalized Cross-Correlation (or Autocorrelation).

In the study [20] the method **Normalized Correlation Coefficient - NCC** was selected as the most efficient method for the

purpose to classify Brazilian banknotes in relation to its verse and value using the Puzzles features. In [19] it was used 656 Brazilian banknotes to obtain the results shown in the Table 1.

Table 1: Performance Comparative [19]

Method	*Index for Evaluation*	*Regular*		*Normalized*	
		Obverse	*Reverse*	*Obverse*	*Reverse*
Sum of Squared Differences	Accuracy	0.84	0.86	0.97	0.98
	Precision	1.00	0.78	1.00	0.97
	Sensibility	0.68	1.00	0.94	1.00
Correlation Coefficient	Accuracy	0.81	0.82	0.99	1.00
	Precision	1.00	0.76	1.00	1.00
	Sensibility	0.62	0.93	0.99	1.00
Cross-Correlation	Accuracy	0.13	0.40	0.98	0.98
	Precision	0.20	0.00	1.00	0.97
	Sensibility	0.26	0.00	0.96	1.00

3.2 Puzzles Segmentation

Choosing a recognition pattern should be simple, however, the use of patterns elaborated in more detail should only be used when the simpler options have already been exhausted [15]. With this idea, after studying and analyzing the several security features against counterfeiting of Real banknotes, the symbols presented in the seventh and eighth columns of Figure 2 stand out for their simplicity [20]. These symbols, called Puzzles, are presented with enlargements in Figure 1.

In Figure 1, line "O" contains the Obverse Puzzles while line "R" contains the Reverse Puzzles. The middle line "O + R" shows the respective banknote values obtained by combining both Puzzles and viewing the Obverse against the light.

Other details and information about the Puzzles:

- The symbols on each side of the same banknote are different from each other and when the banknote is observed against the light from the front side, the two Puzzles combine to form the value of the banknote .
- For each value, the symbol used is standardized and exclusive. Banknotes with the same value have the same symbols.
- The symbols are formed by elementary geometric figures such as straight line segments, triangles, rectangles, squares, rhombuses, trapezoids, circles, circle quadrants, with some of these figures being combined with each other and in different sizes.
- The predominant hues characteristic of each of the notes are present in this region. This characteristic in particular could help in identifying the note by its predominant hue, as shown in the Section 3.3.

According to [20] each note, it is possible to segment the Puzzles into two regions, as shown in Figure 1:

- **General Pattern:** Puzzle Region highlighted by the red rectangle and which appears on the Obverse or Reverse, regardless of the value of the note.
- **Exclusive Pattern:** Puzzle Region highlighted by the green rectangle which appears on the Obverse or Reverse, of the same value, making it Exclusive for a specific value.

After the face is classified, the blue rectangles are positioned in a standardized and unique location in relation to the identification coordinates of the General patterns. In the case of the Obverses, the blue rectangle is positioned inside the Exclusive patterns. In the case of the Reverses, the blue rectangles are positioned inscribed in the circle inside the circumference of the General pattern. The proposed methodology should first verify whether the face of the note is the Obverse or Reverse and its value based on the predominant hue.

In Figure 1, the blue rectangles are positioned in the same reference location in relation to the General pattern of the identified face. These rectangles delimit regions that contain the predominant hues characteristic of each banknote. To classify the predominant hues described in Figure 2 for each of the banknotes, it is possible to use these rectangles to isolate small regions of homogeneous colors. In this way, it is possible to establish the correspondence between the values and the predominant hues that characterize the banknotes of the Second Series of Real.

Using again the *Template Matching* technique with the method selected in [20], after recognizing of the analyzed face, the images categorized for a type of face are reclassified in relation to their value using the Exclusive patterns belonging to the classified face. Furthermore, classifying the value using the Exclusive patterns allows to confirm or refute the prediction by the predominant hue.

Thus, in the case of recognizing Real banknotes, in this two-aspect analysis methodology, there are a mutual benefit from the joint use of both techniques. On the one hand, the *Template Matching* technique enables the location by reference of the blue rectangle over a standardized and homogeneous region, from which the predominant hues characteristic of each value will be extracted. At the same time, it allows the prediction to be ratified by the predominant hue through the use of Exclusive patterns. On the other hand, exclusive identification by *Template Matching* may be insufficient to characterize the image of a banknote, since without the predominant hue characteristic, the prediction may be incorrect. This possibility is related to the observation that the Exclusive Obverse pattern of the R$ 5 banknote is identical to the region surrounded by the green rectangle of the Exclusive Obverse pattern of the R$ 50 banknote. These two regions of Exclusive Obverse patterns only differ in the predominant hue, as we can see in Figure 1.

3.3 Predominant Hues Identification

To determine the predominant hues characteristic of each banknote, histograms extracted from the colors contained within the blue rectangles on the Obverse and Reverse are used, as shown in Figure 4. In the RGB and HSV color spaces, one-dimensional histograms are used that have a single integer data entry, which is the part of the image corresponding to the blue rectangles, that is, this small part of the image described in RGB. The difference between them lies in the variation range, as shown in Figure 4. In the RGB color space, the intensities of each channel vary in the interval [0, 255], while in the HSV color space, the angles in degrees that characterize the hues, represented in the H channel, vary in the interval [0°, 360°].

In the RGB color space, all colors are formed by the contribution of each primary color R, G, and B, and therefore the information from each channel is required to define a color. In the HSV color space, however, the H channel concentrates in itself the complete information about the hue that characterizes the color. The same color described in two different bases is represented by completely

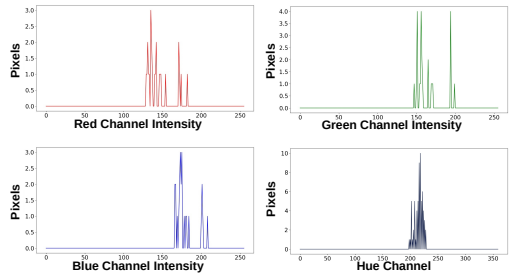

Figure 4: Typical histograms from the R, G, B and H channels obtained from R$ 2 cells.

different triples or sets (*r, g, b*) or (*h, s, v*), although they are analogous colors to the human eye [1].

3.4 Mode Distribution at H channel Histograms

The results obtained in [20] were improved and published at [19] by adjusting the location of the blue rectangle more centrally over the regions from which the predominant hues are extracted. This process allowed capturing more homogeneous colors that made it possible to identify less sparse intervals of hues associated with the Real values. These more accurate results allowed the construction of Table 2 that shows the intervals in degrees of variation of the maximum angles identified in the histograms of the H channel of the HSV color space. As described in Section 3.3, these histograms were extracted from inside the blue rectangle shown in Figure 1. The intervals of variation of the angles in the H channel were constructed by taking the modes of the characteristic histograms that are shown in Figure 4.

Table 2: Interval of angles built with modes from H channel histograms [19].

Value (R$)	*96 DPI*	
	Obverse	*Reverse*
200	[146°, 180°]	[50°, 70°]
100	[186°, 204°]	[184°, 206°]
50	[40°, 70°]	[26°, 80°]
20	[36°, 60°]	[12°, 34°]
10	[340°, 18°]	[336°, 354°]
5	[246°, 312°]	[240°, 340°]
2	[206°, 240°]	[204°, 224°]

4 Conclusions and Future Works

Choosing the Puzzle as the pattern to be found turns easier the recognition work through the *Template Matching* technique associated with the NCC method, since it is a region composed of simple geometric figures present on both verses of the banknotes [20]. In addition, the Puzzles allow classifying the images of the banknotes in relation to their face, using only the General patterns, and also in relation to their value, when using the Exclusive patterns of each face.

Figure 5: Others examples of Segmentation Rectangles.

The development of an assistive technology using a mobile application needs to consider solutions that overcome the limitations of the *Template Matching* technique, such as capturing images of Real banknotes with ambient lighting and possible rotations or inclinations of the notes in relation to the phone camera, since this technique is sensitive to rotation and scale transformations. The decision to use the *Template Matching* method for developing a mobile application instead of other more advanced techniques such as *Deep Learning* is due to the possibility of a solution that is adequate to the computational capacity and faster responses to users.

As observed at [20] and [19], although the *Template Matching* technique allows the identification of the values of the banknotes, the step of extracting the predominant hues that characterize the banknotes is not optional, since each value is uniquely associated with a characteristic predominant hue and, therefore, each banknote can only be associated with the value identified by *Template Matching* if it presents the corresponding predominant hue.

The location of the blue rectangle by reference to the coordinates of the General patterns, together with the use of the HSV Color Space, allowed the identification of the predominant hues that characterize the Real banknotes. It is possible to identify the value of a note by the predominant hue by associating it with one of the spectra of hues identified for each banknote. These spectra shown at Table 2, in fact, contain the predominant hues described in the fifth column of Figure 2 according to the list of colors described by names and available at [21]. It is observed, however, that the predominant hues in the fifth column of Figure 2 are not sufficient to characterize all the banknotes.

The confirmation of value predictions based on the hues identified can be confirmed by using the results of the classification through Exclusive patterns. In this way, the *Template Matching* method, in addition to enabling identification by the predominant hue, allows its confirmation. Similarly, identification by *Template Matching* can only be corroborated by identifying the predominant hues. It is possible to conclude that the isolated classifications by *Template Matching* and by the predominant hue do not allow the banknotes to be characterized completely, however the combination of both techniques can make viable the design of a mobile application for recognizing banknotes of the Second Series of Real.

5 Future Works

In this research, for all banknotes, only the regions of the patterns with the same width in pixels of the R$ 2 and R$ 5 banknotes were used. The complete region of the Exclusive patterns allows the classification of the banknotes by face and value without the need to use the General patterns. Thus, the classifications of face and value using the complete area of the Exclusive patterns constitute an initial proposal for future work.

On the Reverse face, the position of the blue rectangles of the predominant hues of the R$ 50 and R$ 200 banknotes are similar and, to avoid this conflict of classifications by the characteristic predominant hue, it is possible to locate more segmentation rectangles for the colors within the Puzzles.

Thus, the location by reference of other segmentation rectangles represents another possibility for future work to be explored in order to allow the complete characterization of the analyzed banknotes. It is possible to locate other Regions Of Interest that include information, for example, the serial numbers and the number that designates the value of the note. Figure 5 shows the rectangles in black, yellow, magenta and cyan colors surrounding the value designation numbers and tactile identifier on the Obverse and the serial numbers present on the Reverse. Thus, the methodology presented can assist in the stage of detecting serial numbers, facilitating their location in works dedicated to their identification. In addition, the relative positioning of other segmentation rectangles can be performed using the coordinates of the Exclusive patterns with or without their total area.

Another possibility for future work involves combining the presented methodology with character recognition techniques such as the use of the *Tesseract* tool, which is already available in the *OpenCV* library [13].

The location by reference of other segmentation rectangles can facilitate or even make the detection stage of regions with characters unnecessary, and thus efforts can be concentrated on identifying and classifying the characters.

Euro banknotes are similar to Real banknotes in terms of banknote size and different colors. In addition, they have simple patterns that can enable their characterization in a manner analogous to the methodology used with Puzzles.

The limits of the classification method should be tested to evaluate a possible technology through a mobile phone application. Thus, the aim is to investigate the recognition of banknote images obtained mainly by mobile phone cameras with ambient lighting. In addition, it is possible to recognize several banknotes at the same time and in different positions. The possibility of using small regions of the banknotes instead of using the entire area should also be considered. In order to facilitate commercial exchanges involving banknotes, work with Real coins must also be developed to cover all commercial exchanges with physical currency.

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