Computer Vision-based Object Recognition for the Visually Impaired Using Visual Tags

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Abstract: *Recognizing generic objects in the surrounding environment is a major challenge for the visually impaired for which few assistive technological solutions have been devised to date. Nevertheless, in recent years, several computer vision-based strategies have emerged for this task which utilize visual tags affixed to objects for identification. These approaches are distinguished by their reliance on commercial off-the-shelf components and mobile technologies rendering them cost-effective, portable, intuitive and thus, compelling solutions to an urgent problem. The objective of this paper is to provide an overview of the state of the art in this area, highlighting the advantages offered by as well as the challenges faced by such systems, and to inspire and facilitate further exploration of this avenue of research.*

Keywords: visually impaired, assistive technologies, object recognition, computer vision, visual tags, review

1. Introduction

According to recent estimates by the World Health Organization (WHO), 285 million people worldwide are visually impaired [1]. Of these, 39 million are blind while 246 million have low vision. Without additional interventions, these numbers are predicted to significantly increase by the year 2020 [2]. Even though 80% of visual impairments are avoidable or curable, however, the unfortunate fact is that 90% of the visually impaired live in developing countries which do not have sufficient treatment and support options in place to deal with this disability. Moreover, 65% of the visually impaired are aged 50 years or older and this number is projected to increase [3]. Most commercial assistive products are beyond the financial reach of this population while many new-fangled technologies are hard, especially for the elderly, to grasp. These facts delineate an urgent need to develop solutions which are cost-effective, intuitive and make use of commonly available technologies. Computer vision-based techniques fit the bill perfectly: Generally, these methods do not require retrofitting the environment with special infrastructure or transmitters (unlike other technologies such as those that utilize RFID or infrared waves). Moreover, many of these solutions can be installed on mobile computing devices that the user already owns (e.g., cell phones and tablet computing devices) utilizing the built-in cameras and other pre-existing functions available therein. This also eliminates the need to carry around a separate gadget for recognizing objects. For solutions that do come with their own apparatus, the majority consist of lightweight equipment that the user can easily carry or wear. Also, unlike visual prosthetics devices, these systems are not dependent upon any part of the human vision system being intact.

A particular class of computer vision based approaches requires unique visual tags to be placed on all objects that need to be recognized. Rather than exploiting the object's physical features such as color, shape, texture, etc., these systems identify an object by capturing an image of the tag placed on it, extracting the tag and deciphering it.

Tag-based systems offer several advantages over their non-tag-based counterparts: Since the only piece of visual data that these systems extract, store and compare for each object is its tag, the computational power and storage space required for these systems is much less than that for non-tag-based systems which deal with much more detailed information, such as shape, size, color, etc., for each object. These solutions are also ideal for tasks that require differentiating among a group of objects which feel the same but have different visual encoding and contents, e.g., searching for a particular DVD in one's DVD collection, locating boxes during a move, or picking the right jelly jar from the refrigerator [4].The need for this differentiation becomes even more vital for the visually impaired when the contents of the object are hazardous, e.g., a tube of glue versus a tube of eye drops [5]. Moreover, many of these approaches do not require tags to be explicitly placed on store-bought products since these objects already have unique visual tags in the form of product barcodes. Furthermore, visual tags can be conveniently generated and printed out utilizing free online software thus, avoiding the hassle and cost involved in the purchase of non-visual tags such as RFID or infra-red ones.

Computer vision-based techniques that utilize visual tags to recognize objects have only recently begun to be employed in the domain of assistive technologies for the visually impaired; however, the results reported so far are very promising and clearly demonstrate the potential of such systems. A survey of such solutions has therefore, been undertaken in this paper. The objective is to provide an overview of the state of the art in this area, highlighting the advantages offered by as well as the challenges faced by such systems, and to inspire and facilitate further exploration of this avenue of research.

The rest of this paper is organized as follows: Section 2 describes other technologies that are currently being utilized for developing devices to assist the visually impaired in recognizing generic objects. Section 3 provides a review and analysis of computer vision-based object recognition solutions for the visually impaired that use visual tags. Section 4 concludes the paper with a discussion of issues related to these technologies and the identification of some directions for future research.

2. Related work

Non-visual tag-based computer vision approaches for the visually impaired perform object recognition based either on 3D model matching [6, 7] or on features extracted from 2D intensity images of objects. Approaches that adopt the latter strategy predominantly employ SIFT [8] and SURF [9] features for recognition since these descriptors have been shown to be invariant to image translation, scaling, and rotation, and are partially invariant to illumination changes and affine or 3D projection. Also SURF features can be computed very fast compared to other descriptors enabling real-time computation requirements to be met [9, 10] (See [11, 12] and [13-15] for examples of SIFT and SURF-based systems, respectively). However, since both SIFT and SURF do not take color information into account, some other strategies have opted to utilize color and edge detection for recognition [16, 17]. Another set of image-based approaches perform recognition by doing a raw translation of the image data into sound patterns [18] [19] or tactile stimulation on the tongue [20], torso [21, 22] or back [23]. However, these methods require a steep learning curve and it is not obvious how easy or intuitive it is for people to interpret these cues to form a mental representation of the visual scene.

Some other solutions have employed alternate sensing technologies, such as RFID [24, 25], sonar [26] and infrared [27] for this task, thus, avoiding some of the inherent drawbacks associated with image data-based strategies; however, these technologies suffer from limitations of their own., e.g., they all require special sensing equipment while infrared and RFID require specific tags; also, sonar and infrared are not very effective in indoors environments since such surroundings tend to be cluttered and the obstacles present therein may cause the reflected echoes to become distorted resulting in unreliable information being conveyed to the user.

3. Overview of computer vision-based object recognition approaches for the visually impaired which use visual tags

We now present an overview of some innovative computer vision-based systems developed in recent years to assist the visually impaired in recognizing generic objects by utilizing visual tags affixed to them. A summary and comparison of all the approaches discussed in this section is provided in Table 1.

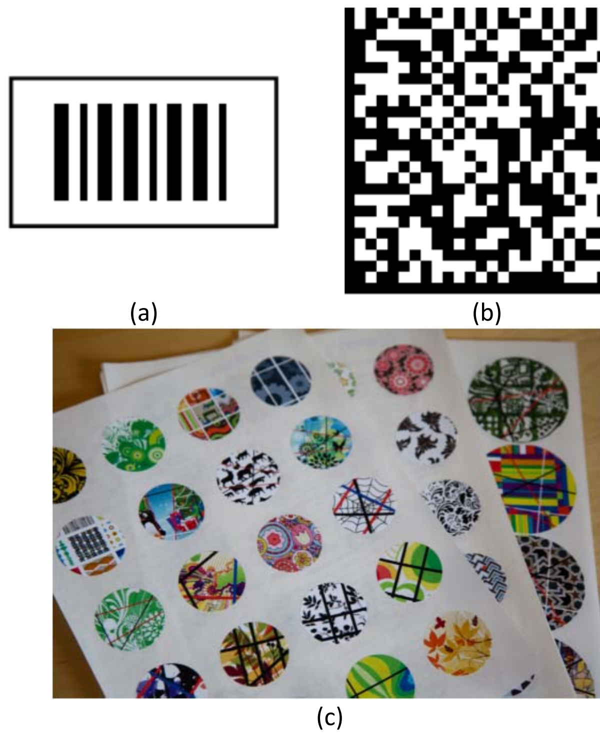

Figure 1. Visual tags for various tag-based systems: (a) Marker with 1D barcode (Badge3D[28]), (b) Semacode (Gude et al.[29]), (c) Printed vinyl stickers (LookTel[11] (©2011 IEEE))

3.1 Badge3D

Badge3D [28] is a relatively recent example of a tag-based system for the visually impaired that provides object recognition and obstacle detection capabilities. The tag in this case is a rectangular-shaped marker with a fixed, black band external boundary surrounding a single one dimensional barcode interior (Figure 1a). The system locates a tag in a captured image by detecting the outer black band using a Canny edge detector[29], extracts the barcode in its interior by applying various image processing techniques and identifies the object based on this barcode. This outer black band is also utilized for tracking the object and estimating its orientation relative to the camera.

The user wears a head-mounted video camera and sends queries to the system by speaking into a microphone while the system provides output to the user in the form of synthetic speech transmitted through headphones. When the user enters a new environment, the visual data from the video camera is used to determine which objects are in the user's surroundings based on their barcode tags. The user can query the system about a particular object and it can then guide him towards that object. Furthermore, untagged objects in the environment (which are considered obstacles in this case) can be detected by an ultrasound-based device mounted on the user's belt.

3.2 Shoptalk and ShopMobile

Nicholson et al. [30] have created a system called ShopTalk to allow visually impaired individuals to shop independently by scanning MSI barcodes on shelves to find product locations and UPC barcodes on products to identify them. This system utilizes a hand-held barcode scanner, a shoulder-mounted keypad and headphones connected to an ultra-portable OQO computer. A new version of this system, called ShopMobile [31, 32], reduces the system's hardware complexity by porting all of ShopTalk's software to a camera-equipped smartphone. The need for a barcode scanner is also obliterated since the system now relies exclusively on computer vision techniques to recognize barcodes (A detailed description of the barcode localization and decoding algorithm can be found in [33]). This system is still under development: it will consist of a camera-equipped smartphone enclosed in a hard case with two plastic stabilizers (≈ 10 cm long) inserted in to a small pocket at the back of the case (Figure 8). It will also have a screen reader and a screen magnifier as well as a wireless over-the-ear headpiece. In a supermarket aisle, the user will place the stabilizers on the lip of the shelf to align the phone's camera with it. The barcode scanning algorithm will find any barcodes in the camera images. If only a part of the barcode is visible, the system will ask the user to move the phone accordingly. Once the whole barcode is visible, it will be recognized and the product's identity would be transmitted to the user via the headpiece.

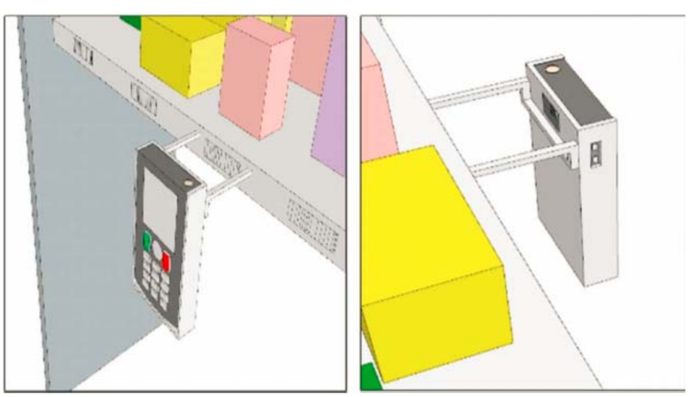

Figure 2. ShopMobile system consisting of a camera-equipped smart phone in a hard case with two plastic stabilizers [33]. (With kind permission of the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA))

3.3 Trinetra

Lanigan et al. [5] have developed Trinetra, a system that assists the blind in identifying products in a grocery store. A product's barcode is scanned using a barcode scanning pencil and then sent via Bluetooth to a module on the user's mobile phone. This module checks a cache onboard the mobile phone and if a match for the product is not found, it communicates with a remote server which retrieves the product information either from a local cache or the online UPC database and sends it back to the mobile phone. A text-to-speech software on the phone converts the product information into speech which is relayed unobtrusively to the user via a Bluetooth headset. Their system's strength lies in that it is comprised entirely of commercial off-the-shelf (COTS) components and is thus, cost-effective and accessible.

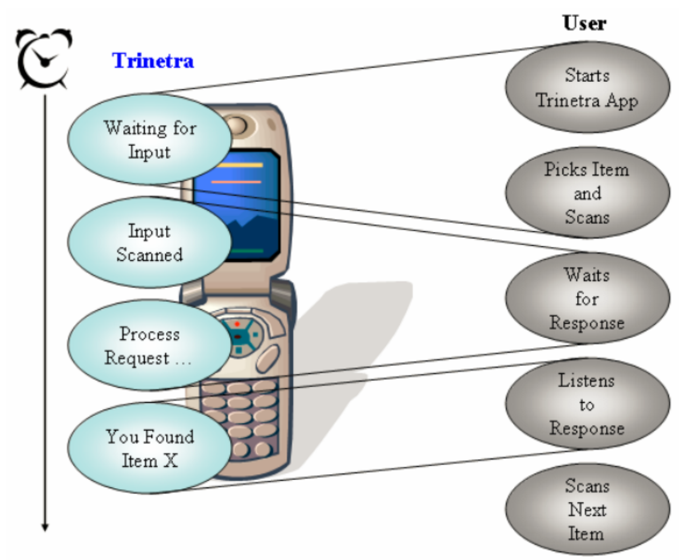

Figure 3. Mapping user actions to Trinetra [35]. (With kind permission of The Biological and Artificial Intelligence Foundation (BAIF))

3.4 Gude et al.'s approach

Gude et al. [34] have developed a prototype system for object recognition and navigation based on two-dimensional barcodes called Semacodes [35] (Figure 1b). The input to the system consists of video streams obtained through two video cameras, one embedded into the user's cane to detect tags placed on or near ground-level, and the other into the user's glasses to detect tags well above the ground-level. The Semacode reader may either be embedded into these cameras or it may be installed on a computer connected wirelessly to the cameras. The system provides output to the user via a tactile braille device mounted onto his cane. As the user walks around, video captured through the cameras is constantly processed and if any tags are

Table 1. Summary of computer vision-based object recognition approaches that use visual tags

Approach	Type of tag	Input device	Output device	User interface to enter queries/ preferences
Badge3D [28]	1D barcode with black rectangular boundary	Head-mounted video camera	Headphones	Microphone
ShopMobile [32, 33]	MSI and UPC barcodes	Smartphone camera	Wireless over-the-ear headpiece	Smartphone touchscreen
Trinetra [5]	UPC barcodes	Barcode scanning pencil	Bluetooth headset	Smartphone touchscreen
Gude et al. [29]	Semacodes	Head-mounted and cane-mounted video cameras	Cane-mounted tactile Braille device	-
Al-Khalifa [37]	QR codes	QR reader-equipped Mobile phone camera	Mobile phone speakers	-
LookTel [11]	1.5” or 3” round, re-stickable vinyl stickers with printed images	Smart phone camera	Open ear, sports-designed headset	Smartphone touchscreen
Tekin et al. [38]	UPC-A barcodes	Mobile phone video camera	Mobile phone speakers	-
TalkingTag™ LV (Low Vision) [40]	2D barcode	iPhone camera	iPhone speakers	iPhone touchscreen

detected, they are decoded by the software and the identity of the object is relayed to the user via the Braille device. Only a crude prototype of this system has been tested so far, which does not include the camera-embedded glasses. Furthermore, though they have suggested that the system can also be used for navigation purposes provided that the software is extended so that it also specifies the distance to the recognized objects, however, this capability has not been added to the system yet. Some preliminary tests showed that a camera embedded with a Semacode reader worked almost as well as a web camera connected to a laptop computer; this indicates the feasibility of utilizing cameras embedded with tag recognition software.

3.5 Al-Khalifa’s approach

Al-Khalifa [36] proposes affixing QR codes (two-dimensional barcodes) to objects which can then be scanned using a mobile phone equipped with QR reader software. The reader decodes the barcode to a URL and directs the phone’s browser to fetch an audio file containing a verbal description of the object from the internet which is then relayed to the user. The proposed system has not been implemented yet.

3.6 LookTel

A tagging option for object recognition is also included in LookTel [11] – a portable visual assistance system that allows a user to capture images of objects using a mobile device, such as a cellular phone, which are sent to a remote server where they are recognized based on the SIFT algorithm [8]. However, items with no clear distinguishing features (for example, clear glass jars or Tupperware containers) are not suitable for recognition by SIFT. These objects may be tagged with 1.5” or 3” round, re-stickable vinyl stickers with printed images produced by the developers for this purpose (Figure 1c). New tags with custom images may also be compiled by the users themselves. The system also affords navigation assistance: indoor locations can be added to the system as generic objects and the user can make his way through the environment by moving from one location to the other. Audio output is provided to the user via an open ear, sports-designed headset. A touch-based user interface has also been provided for the user to interact with the system. A major limitation of this system is that the recognition process is not fully automated since a sighted assistant has to help out with the training process.

3.7 Tekin et al.’s approach

Tekin et al. [37] have developed a mobile phone application that utilizes the phone’s video camera to detect a UPC-A barcode in the scene in front of the user and then guides him to the detected barcode by providing audio feedback. The barcode digits are recognized using a Bayesian statistical approach and the resulting barcode is compared against a customizable user database as well as a manufacturers’ database, which are stored on the phone, thus eliminating the need to access a remote server. If a match is found, product information is relayed to the user via the text-to-speech module on the phone. The application was tested on a Nokia N97 camera phone and suffered from the camera's erratic autofocus mechanism and the slow processing speed, problems which the developers assume would be ameliorated if the same application is run on newer generation devices such as the iPhone or Google Nexus One.

3.8 TalkingTag TM LV

We will wrap up our discussion about tag-based systems by mentioning a popular commercial product for recognizing visual tags available for iPhone [38] users: TalkingTag™ LV (Low Vision) [39] enables visually impaired people to label items with special coded stickers. Users can scan each sticker with their iPhone camera and record up to a one minute audio message identifying what is being labeled using the iPhone's VoiceOver feature. The message associated with a sticker can be erased and recorded over.

4. Conclusion

It should be noted that, despite their many merits, tag-based systems suffer from some inherent limitations: They require careful, a-priori selection of significant objects and the correct placement of tags on those objects and their use is restricted to surroundings where objects have been tagged. Also, if an area is heavily populated by tagged items, the user will be overwhelmed by receiving information about all those items simultaneously. Unlike RFID tags, visual tags have to be in line-of-sight of the camera, otherwise, they will not be detected. Furthermore, visual tags cannot be embedded in objects; the visibility of these tags may be unappealing from an aesthetic perspective. These approaches are also subject to the general difficulties faced by computer vision-based techniques in uncontrolled real-world environments due to imaging factors such as motion blur, image resolution, video noise, etc., as well as changes in conditions such as illumination, orientation and scale.

The above shortcomings notwithstanding, the systems described above, several of which are still proof-of-concept, have revealed the potential of utilizing visual tags for object recognition. These systems' universal reliance on commercial off-the-shelf components and mobile technology has rendered them cost-effective, portable, intuitive and thus, compelling solutions to an urgent problem. However, the following issues need to be addressed if these technologies are to be developed into practical solutions which can be used autonomously by the visually impaired: one major concern, which none of the above approaches explicitly addresses, is how to enable a user, who does not have the advantage of sight, to locate the visual tag and align it with the camera. The only exception is Al-Khalifa [36], who suggests putting a Braille marker on the QR code; this solution might work well for a limited number of objects but not, for instance, for general grocery items, unless product manufacturers start putting such markers on the barcodes. ShopMobile [31, 32] partially addresses this issue by providing stabilizers to align the phone's camera with the supermarket shelf while Tekin et al. [37] provide audio feedback to guide a user to a detected barcode; however, the assumption in both cases is that the barcode will be located on the front of the product which is not necessarily true. Also, though the prevalence of 1D and 2D barcodes as a means of identifying commercial products is not likely to diminish in the near future, however, the proliferation of other tags such as RFID tags, which do not suffer from the same limitations as visual tags (i.e., these are omnidirectional, can be embedded in objects, are reprogrammable, hold more product information, etc.) indicates the sagacity of augmenting visual tag-based systems with the capability to recognize these non-visual tags to produce a more robust solution capable of recognizing objects based on both kinds of tags. Some systems such as Trinetra [40] and BlindShopping [41] have already taken a step in this direction by incorporating RFID-based recognition modules into their systems.

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