7-26-2009

Camera-Based Ballot Counter

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Submitted to ICDAR 2009, Barcelona, Spain

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Abstract

Portable ballot counters using camera technology and manual paper feed are potentially more reliable and less expensive than scanner-based systems. We show that the spatial sampling rate, geometric linearity, point-spread function, and photometric transfer function of off-the shelf consumer cameras are acceptable for ballot imaging. However, scanner illumination is much more uniform than can be economically accomplished for variable size ballots. Therefore flat-field compensation must be designed into the image processing software. We illustrate the mechanical design of a prototype camera-based ballot scanner based on our comparative observations.

1. Introduction

Technical requirements for counting votes are different in the United States than in most other countries. Elections are organized, conducted and supervised by political parties rather than government officials. Citizens vote for many elective positions (town attorney, judge, tax assessor, town engineer, school board, sheriff …), that in other nations are held by appointed civil servants, therefore voters may have to make dozens of choices in any given election. The slate of candidates, and therefore the ballot, is different in every election district, so provisions must be made for tallying ballots in several thousand different sizes and formats. Furthermore, the definition of a valid vote, the rules for casting or cancelling votes, and the mechanisms used for counting, recounting and auditing votes, all differ from election district to election district [1,2,3].

The diversity and length of ballots requires flexible methods of assessing the vote, and the lack of trusted supervision has led to demands for reliable and verifiable mechanisms. According to the Voluntary Voting System Guidelines of 2005, "the system shall achieve a target error rate of no more than one in 10,000,000 ballot positions." Requirements for election technology are compounded by the constitutional guarantee of privacy (i.e., anonymous voting), access for handicapped (blind, paraplegic) voters, and proscription of giving voters any proof of their vote that could result in buying verifiable votes.

In the wake of the 2000 and 2004 US federal elections, there has been a groundswell of support towards paper-based systems. Many scientists and civic activists believe that Direct Recording Electronic (DRE) touch-screen systems are intrinsically untrustworthy because digital records can be automatically modified en masse. Undetectable wholesale modification of hardcopy ballots is considerably more difficult. Paper based voting leaves a permanent record, subject to human or automated audit and recount. Evaluation and improvement of paper-based election technologies are the overall objectives of our NSF Cyber Trust research project [4].

Although counting ballots in a central location is more efficient, new laws (HAVA §301) mandate that ballots also be checked at the polling precinct. An immediate tally allows the voter to be notified that the votes for the chosen candidates will be counted rather than invalidated because of an improperly marked vote or an accidental overvote. Thus there is a need for many low-cost ballot reading devices.

Most commercial systems for reading paper ballots are based on desktop scanner or fax scanner hardware. Optical scanners are, however, prone to paper jams, how they work is not obvious to either lay voters or lay election monitors, and they are fairly expensive. Problems with scanner-based op-scan devices reported in recent elections include inconsistent results

DOI: 10.1109/ICDAR.2009.43

tentatively linked to dust build up [5], and to jamming caused by ballots moistened by rain-soaked voters [6].

We therefore examine the pros and cons of camerabased precinct (portable) and election-district portable ballot counting devices. Cameras have been used with increasing success in other document image analysis tasks [7,8,9]. Widespread familiarity with digital cameras should inspire even more confidence in camera-based voting systems.

We compare scanner and camera characteristics in Section 2, describe the proposed camera-based ballot counter in Section 3, and discuss its putative advantages in Section 4.

2. Camera Performance

As a preliminary step to the design of a prototype camera-based ballot counter (Section 3), we list briefly our comparative observations on a flatbed scanner (Epson Perfection 3170 Photo scanner) and a high-end consumer camera (Cannon G10 Powershot) at RPI DocLab. We evaluate their geometric linearity, point spread function, photometric response, and flatness of field.

Spatial Sampling Rate. Current scanners digitize an A4 page at 600 dpi without interpolation. Our 15 Megapixel Canon camera can space pixels at about half that rate. The only items that need to be recovered from a preprinted ballot (Figure 1) are the voters' marks. Our experiments indicate that valid voter marks (filled-in ovals, connections in a broken line, check marks or X's) from the preprinted background can be readily discriminated from the background at 200 dpi.

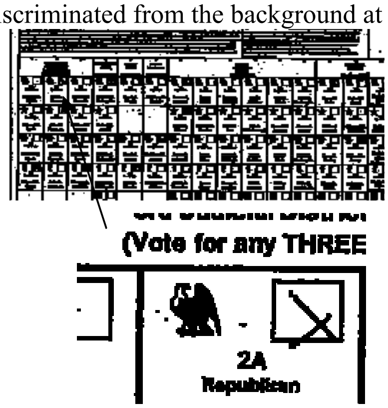

Figure 1. Top: fragment of a scanned 2005 New York State write-in ballot; Bottom: a smaller fragment from the ballot image captured with a 4 Megapixel point-and-shoot camera.

Geometric Linearity. Improvements in lens design have significantly improved linearity. The deviation of the digitized diagonal line from a line segment connecting the corners of the letter-sized test chart in Figure 2 is only 3 pixels. Geometric linearity is important for global registration against a blank ballot to locate targets (ovals or squares) and extract voter marks [10,11].

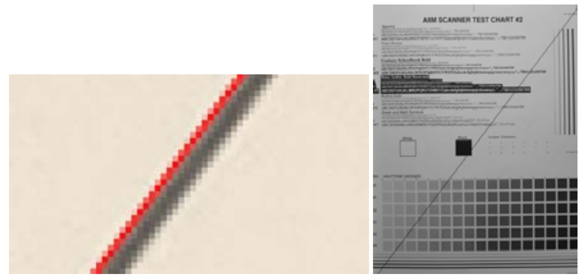

Figure 2. Geometric Linearity of the Canon G10 with an AIIM Scanner Test Chart #2. The red line segment is superimposed on the bitmap.

Point Spread Function. The edge spread function (ESF) of the camera is about twice as wide as that of the scanner. Figure 2 shows several transitions across a sharp white-to-black edge. The edge spread functions are not symmetric. The influence of the edge can be detected in the camera image as far as 3 pixels away in contrast to an average of 1.5 pixels in the scanner image. This may require correction (e.g., deconvolution) at the image processing stage.

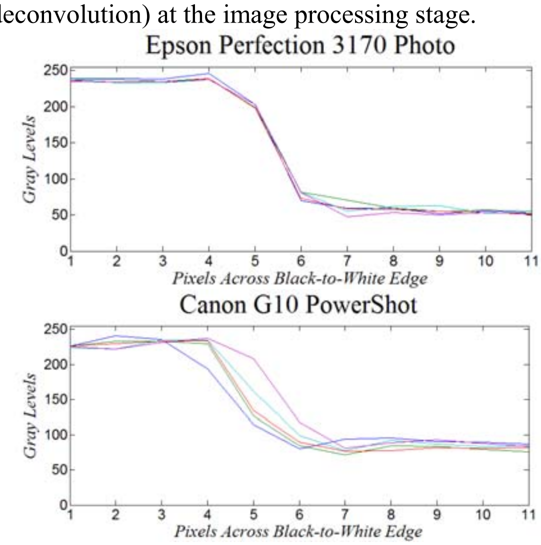

Figure 3. Edge step response of scanner and camera at 262 dpi at five different locations of a sharp white-to-black edge on an AIIM Scanner Test Chart #2.

Photometric response. The mapping of reflectance to gray levels for both devices is shown in Figure 4. Both were measured in several positions with a Kodak Q13 grayscale reflectance step chart, with gray values

DOI: 10.1109/ICDAR.2009.43

averaged over 80x80 pixels for the scanner and 50x50 pixels for the camera. Either the reflectance or the reflective optical density can be readily mapped to a linear scale. Reliable estimates of the reflectance of the preprinted marks, rulings and text can be exploited by image processing algorithms to resolve marks that overlap the target. A pencil mark over the target is usually lighter than the target, while a ball-point pen tends to be darker. Fortunately voters seldom change their writing instrument while marking a ballot.

Our recent image processing experiments that show the effect of the contrast between the marks and ballot backgrounds were reported in [10,11,12]. The mathematical foundations and preliminary experiments for taking into account voter consistency are discussed in [13,14,15].

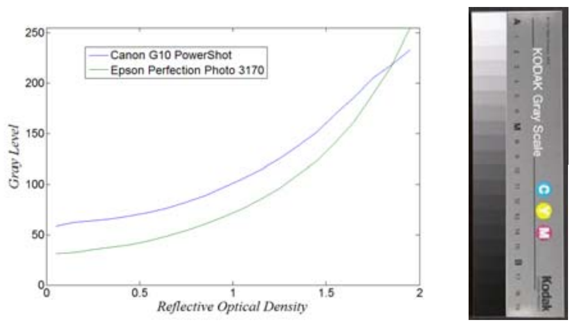

Figure 4. Photometric transfer function (a) scanner (b) camera measured with a Kodak step chart.

Flatness of field. The uniformity of the photometric response of the CCD elements in both scanner and camera is at least an order of magnitude higher than that of the illumination. Nevertheless, it has been shown that with a flatbed scanner, OCR errors are not uniformly distributed across the page [16], which may disadvantage some candidates. Roller feed scanners are subject to uneven paper feed that distorts the image. There is reason to believe that the proposed system will be less prone to positional effects.

It took us quite a while to devise acceptable illumination under the constraints imposed by the physical design of the ballot counter. The design limits the distance of the light source from the ballot to about 30 cm, and it must avoid casting a shadow of the camera support and the camera. We currently illuminate the ballot indirectly with a fluorescent circle light and white LEDs, but will experiment with flashes mounted some distance from the camera. The reflections from our partial light box with a matte white surface produce rays at many angles and therefore avoid highlights (glare).

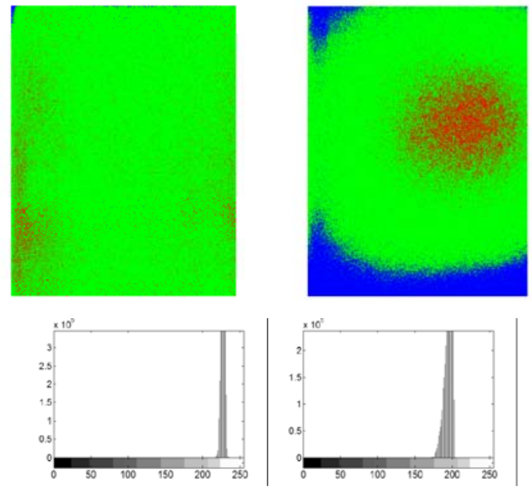

Figure 5. Left: Gray level contours for a uniformly colored document taken with the Epson Perfection 3170 Photo scanner. The highlighted levels are <220 (blue), 220-230 (green), and >230 (red); Right: Gray level contours for the same document taken with the Canon camera. The highlighted levels are <190 (blue), 190-200 (green), and >200 (red).

The relationship between position and gray level for a uniformly colored document is modeled as a quadratic equation. The product of the coefficients of the quadratic terms is a measure of the flatness of field. It is about two orders of magnitude smaller for the scanner than for the camera. The non-uniformity of illumination is therefore compensated by a linear adjustment. The compensated field of flatness of the camera is better than that of the uncompensated scanner, as shown in Figure 5.

Compression. Like most consumer cameras, the Powershot 10 provides RAW output in a proprietary format that can be converted to TIF using Canon software provided with the camera. However, under computer-controlled exposure, the only readily accessible output is JPG. For the AIIM test chart, the JPG files are twice as small as TIF.

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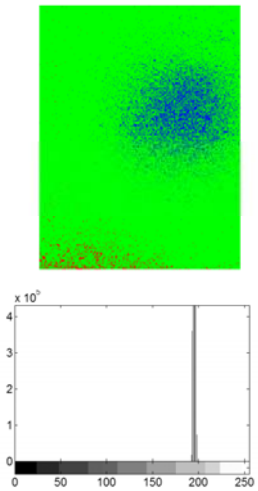

Figure 6. The iso-intensity contour level of the image in figure 5 after linear flattening. The highlighted levels are <194 (blue), 194-197 (green), and >197 (red), which is nearly a tenfold improvement over Figure 5.

To ascertain how much is lost in compression, we obtained TIF and JPG versions of the same ballot image, converted them to gray scale, and compared them pixel by pixel. To our relief, the average difference between the two images was less than 0.5% of the range gray levels in the ballot, and the maximum deviation was 7 gray levels. We conclude provisionally that the current version of JPG can be used safely for high-contrast pictures like ballots.

3. Mechanical and electronic design

In Section 2 we showed current consumer cameras can produce adequate ballot images. However, the mechanical design based on camera imaging differs considerably from that based on a line scanner. Here we describe the configuration of a prototype device.

The galvanized steel enclosure is 50cm x 46cm x 64 cm with an externally accessible ballot chute, an adjustable camera mount, and a manually operated punch that allows invalidating an over-voted, undervoted, or misinterpreted ballot (Figure 7). The lights and the camera are triggered by a photo sensor when the ballot is in place (the light source is not shown in Figure 7.) An Arduino Duemilanove microcontroller with six analog inputs and 14 digital I/O ports, programmed through a USB port in C#, keeps track of the number of ballots, the number of cancelled ballots, and the number of camera images.

It is desirable to avoid the tangle of extension cords usually found at temporary voting locations like churches and schools. The system is therefore designed for alternative battery operation. Two 26 ampere-hour lantern batteries will provide ample 12V power for up to 1000 ballots (1.2 minutes per voter) on Election Day.

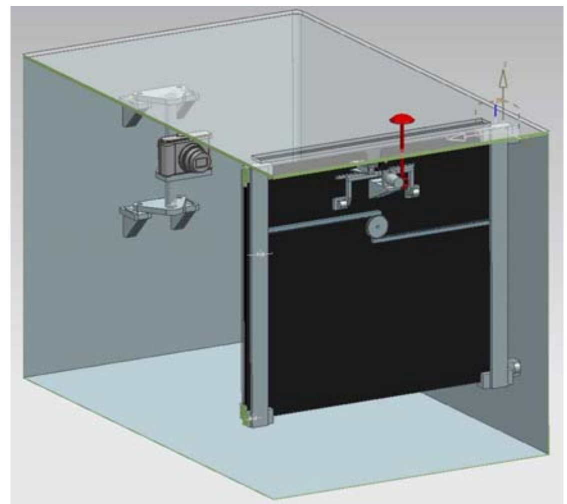

Figure 7. Mechanical design of Portable Ballot Counter.

The actual operation of the device is envisaged as follows. The voter will deposit a filled-out ballot in the chute, which will carry it beyond the voter's reach. The ballot image is captured, retained in a secure write-once memory, and immediately analyzed. The interpretation is then displayed on a screen at the top of box for inspection by the voter. The voter either presses a button to cast the vote, or voids the ballot with the punch. In the latter case, a light signals the cancelled ballot to the election judge, who may then issue a fresh one.

The punch is a temporary expedient: eventually invalidated ballots must be guided to a separate, equally secure, container. During the development phase the images are exported to a laptop for mark extraction and display of the results.

Although the electronics and software are essential components, they need not be absolutely foolproof provided that access to the marked ballots is fully secured by the mechanical design. Subsequent verification can be accomplished by (1) inspection of the ballot images, (2) acquisition and analysis of new images of the ballots with other ballot scanners, and (3) visual inspection of the original ballots.

4. Discussion

We presented our ideas and observations toward the development of a prototype camera-based portable ballot counter. We believe that such a device offers the

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following advantages over traditional roller-feed flatbed scanners:

Transparency. The mechanism should be obvious to an electorate accustomed to cell-phone cameras.

Robust paper transport. Paper jams, such as caused havoc in some precincts during the 2008 elections should be rare, and easily cleared.

Energy efficiency: Power consumption is minimal (no motors), and portability is ensured by the optional dry cell power supply.

Flexible ballot format and design. Only two sliders need to be mechanically adjusted to accommodate ballot formats up to A2 (420 by 594 mm) on a wide variety of stock (paper weight/thickness).

Speed. Operation of the camera is virtually instantaneous, so fewer such devices are required for each polling place. The voter capacity of the device will depend primarily on the time required to verify the displayed interpretation, which in turns depends on the average number of offices voted in the precinct.

Cost. Because of its simplicity and reliance on inexpensive off-the-shelf components, both purchase and maintenance costs should be highly competitive with reported costs ranging from $5500 to $11,000 [2,17,18,19]. We also expect that camera-based systems will require less training for temporary election supervisors without a technological background.

5. Acknowledgments

This material is based upon work supported by the National Science Foundation under grants Nos. CNS-0716647 (EBS), CNS-0716393 (GN), CNS-0716368 (DL), the Rensselaer Open Source Software Foundation, and the NYS/RPI Center for Automation Technologies and Systems. Part of this material was presented (abstract only) at the SPIE 2009 Document Recognition and Retrieval Conference.

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DOI: 10.1109/ICDAR.2009.43