Australian Currency Note Identifier for the Vision Impaired : Part I – Hardware Description

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Polymer notes recently replaced Australia's decimal paper currency. The denominations of the new notes, while very distinctive in their colour and design, are very difficult to differentiate for a vision impaired person. All notes are of equal width and increase only slightly in length with increasing value. This is the first of a pair of papers that describe the design and development of a prototype device to identify Australian polymer banknotes, which indicates the denomination to a vision impaired person using a digitally recorded voice output. Use is made of a charge-coupled device (CCD) linear array and a Digital Signal Processing (DSP) chip. Identification is explained in detail in Part II of this work [2] and is performed by imaging and recognising the contents of the clear window found near the lower corner of each note which is unique for each denomination. This development is of significance in Australia to people who suffer a large degree of vision impairment, and possibly also to the vision impaired population of the European Union, which may also plan to adopt polymer note technology.

1 Introduction and Background

Polymer notes recently replaced Australia's decimal paper currency, in use since 1966. The impetus behind this move was to increase the overall quality and longevity of the huge number of notes in circulation whilst simultaneously lowering costs. The new notes are difficult to counterfeit, resistant to tearing and other abuse, and are completely recyclable.

The denominations of the new notes are very different in their colour and design, but it is difficult for a blind person to discriminate between them. This is because all notes are of equal width and the length difference between succeeding denominations is only 5mm nominally. The older notes, however, could be distinguished using a simple template because they varied by a larger amount in both length and width.

Vision impaired people currently use various methods to identify currency notes. For a person with partial loss of sight, close-up examination of colour and features can still suffice. For those with greater loss, friends or relatives can identify notes. Some people fold notes in particular ways to identify them later, while some use a wallet with many compartments to store the different values in known locations. Some use the CashTest Australia note identifier. To use CashTest, the note to be identified is folded over the device and the length is compared with graduating marks, which are identified with Braille. This device requires considerable manipulation of the note and very small differences in note length to be discerned. This device is difficult to use by those who are arthritic or have low tactile sensitivity, particularly when the notes are creased. The high level of dexterity required makes the device slow and inaccurate, and is inconvenient in everyday money-changing situations.

A need therefore exists for an improved device that can identify Australian currency notes. This would give the vision impaired an extra degree of independence and confidence when handling cash. The ideal device would be cheap, accurate, and not require a large amount of dexterity to use. Currently, no hand-held electronic device exists to identify Australian banknotes [1].

The concept of the currency note identifier is that of a battery-operated device, which is held in one hand, while holding the note to be identified in the other, and swiping it with arbitrary speed and orientation through a slot. The note passes over a 512 element CCD linear array, which is able to image a single line. A complete image can be built up from the single lines as the note is moved across the array. The image is then processed, leading to unambiguous identification of the particular note. The arbitrary swipe motion of the note is an important attribute, as it makes the device easy to use as well as not requiring any moving parts. The absence of moving parts makes the device easy to manufacture, lowers costs and reduces maintenance.

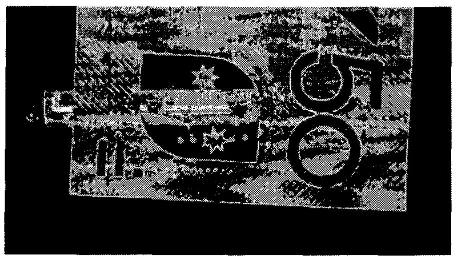


Figure 1: Swipe Action of Note over the CCD Linear Array

In this work, the prototype of a portable device was designed and built to indicate the denomination of an Australian polymer banknote to a vision impaired person, using a recorded voice. Recognition of the particular note is by making use of the characteristic features of the clear window and its contents, which appears near the lower corner of all Australian currency notes. The swiping action of the window across the imaging device is shown in Figure 1. The clear windows were chosen as the method of distinguishing between the various notes because they are different sizes for different denominations, as well as having great variation in internal detail. For reference, some of the Australian series of banknotes are shown Appendix I. In Appendix II, examples of two badly worn notes are shown. They show that the window has a high wear resistance in comparison to other features of the note. Finally, Appendix III shows a photo of the prototype.

2 Imaging System Design

This section describes the key design concepts of the complete imaging system, beginning with a description of the imaging device [1].

2.1 CCD linear array

The Texas Instruments TSL218 linear array was chosen to image the window because of its long length, adequate resolution, ease of use and its low cost in comparison to other imaging devices. The TSL218 requires a single 5V supply and two signals in order to function. These are the Clock Signal and the Serial Input. The TSL218 has two outputs. These are Serial Output and the Analogue Output.

An output sequence begins when a serial input (SI) pulse is correctly presented at the SI input during a rising clock edge. This sets the first bit of a 512 bit shift register and closes the internal switch to transfer the accumulated charge from the first pixel well to the sense node. The differential amplifier outputs a voltage representing the difference between the sense node and a reference dark pixel. This is then held, under the control of the clock signal. Just before the end of each pixel transfer, the sense node is reset to the dark level by closing a switch connecting it to the dark pixel reference, under the control of a non-overlapping clock generator. This sequence then repeats for all pixels as the first bit of the shift register set by the SI pulse propagates through its entire length. The serial output (SO) pulse is generated when this bit reaches the end of the shift register, as the last pixel is output. After the output sequence is complete, a new sequence can begin on the 514^{th} clock, or later, if the integration period needs to be extended. In this case, it is possible for the clock to be disabled until the next SI pulse is due, as no activity need occur within the device [2].

2.2 Illumination – Infrared LED

Illumination of the linear array is by means of a wide-angle infrared light emitting diode (LED). Parallel rays striking at normal incidence across the length of the array would provide the ideal illumination. An approximation to this can be more practically obtained by a point source, provided it is located a large distance from the array. The LED in the prototype is located approximately 65mm from the array. This is a compromise between the conflicting requirements of adequate intensity, evenness of spread and the approximation to an ideal parallel light source. The angle of the illuminating rays distorts the image slightly towards the ends of the array. This is because of the gap between the face of the covering glass and the actual array pixels underneath. In any case, it is expected that the note will be drawn across the array slightly above the glass to avoid grime build-up. Although distorting the image even more, its effect is discounted, as the correlation process is tolerant of some image perturbation.

In the prototype, the infrared LED is mounted on a bracket above the array so the light is spread across its entire length. A photo of the arrangement is shown in Figure 2. The emission from the LED, however, is not even. It is concentrated in the centre and tapers off radially. This is shown in the scan of Figure 3. Also evident in the scan is the unevenness in the response from of the eight segments of the array. The response variation can be up to 20%. Even with an attenuation of about 50% by the window features, it is difficult to set a single threshold that produces a clean binary image in all cases.

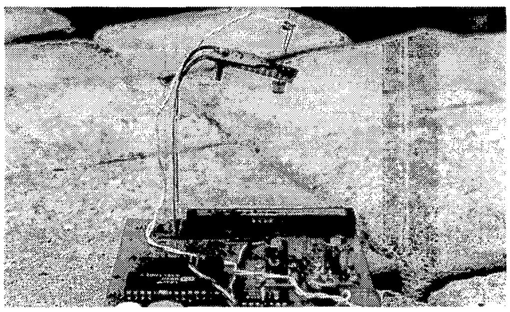


Figure 2: Photo of LED Arrangement

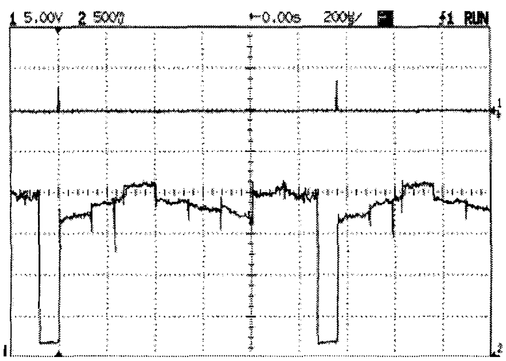


Figure 3: Scan Illuminated by LED

Almost all of the emitted light is wasted with the simple arrangement used. Therefore, a major improvement would be to concentrate the light in an even manner onto the array. This will be essential for a battery-driven device to conserve power. A lens arrangement was tried utilising a narrow beam LED spread along one axis by a cylindrical rod. In this case, the evenness problem still persisted. A clear acrylic block was also tried to guide the light onto the array. This did provide a very even illumination. However, the light rays emanating from the end of the block were spread in all directions, no longer approximating a point source.

3 Testing of the Imaging System

Running the scanning software and gradually increasing the flash period of the LED until the whole array was lit above the comparator threshold tested the imaging system. This was done by setting the time the data port was held high within the Serial Output ISR [4,5].

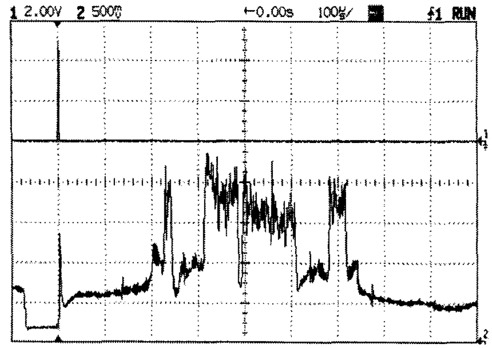


Figure 4: Analogue Image Through Fifty Dollar Note.

Figure 4 shows the analogue CCD output obtained for a scan through the window of a fifty-dollar note. The top trace is the SI signal at the end of the scan, preceded on the bottom trace by a short blank period during which the LED is flashed. The two large dips in the waveform were caused by the two large stars across the centre of the window. The tip of the small star caused the small dip in the centre.

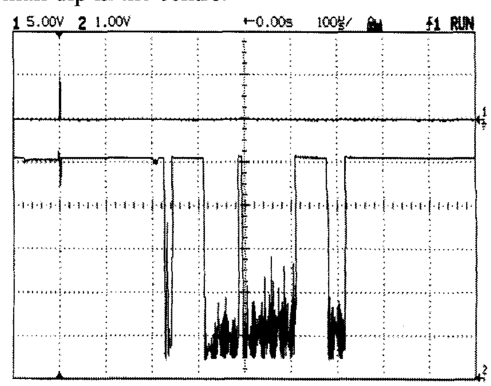


Figure 5: Thresholded Image Through Fifty Dollar Note

Figure 5 shows the image after thresholding and inverting with the comparator. With a carefully selected threshold and even illumination, a clean binary image of each banknote's window can be obtained. Without even illumination, a more complicated scheme of digital conversion employing more thresholds will be necessary, with more interfacing and processing overhead [3].

This would be costly and difficult to implement due to the time restrictions of the pixel sample and store routine [2].

4 Voice Output Design

4.1 Voice recorder chip

A voice recorder chip was used to provide announcement of the denomination. The voice chip provided a quick and easy solution for the prototype, but it is not envisaged to use it for a completed product. For this, digitised announcements will be stored in a low cost EPROM, since a recording facility is not necessary.

4.1.1 Voice recorder chip operation

The device used in the prototype was the ISD1210. This has 10 seconds of recording time addressable to a resolution of 125ms. The digitised voice sampled at 6.4 kHz is stored in non-volatile electrically erasable programmable read only memory (EEPROM), allowing retention with zero power. The device has several operational modes including message cueing, consecutive playback and message looping. These were not utilised. Instead, each message was directly addressed using the address pins. The two most significant bits (MSBs) were tied low to disable the aforementioned modes. The two least significant bits were also tied low as addressing to a high resolution was not required. The four remaining address bits (A2-A5) allow direct addressing of the start of a message in the first eight seconds of the message space, with half a second resolution. The messages that were recorded and their locations are shown Table 1.

Table 1: Locations of Recorded Messages

Recorded Message	Start Location (s)	Binary Address (A2-A5)	Hex Address (A2-A5)
Ready	0	0000	E1
5 Dollars	1	0010	E5
10 Dollars	2	0100	E9
20 Dollars	3	0110	ED
50 Dollars	4	1000	F1
100 Dollars	5.5	1010	F5
Failed	6.5	1101	FB

Edge activated playback was used to initiate the playing of recorded messages. To play a message, the address of the message is put onto the address lines for 300ns and the edge-activated playback pin is brought low. The falling edge latches the address and initiates playback. Once started, the message plays to completion with no other intervention required.

Although the voice recorder chip has a speaker output, this was found to produce inadequate volume. As the completed product will be used in public places, many of which are noisy, a much louder output is necessary. A small integrated circuit (IC) power amplifier was used to provide the louder output. The LM386 has a maximum power output of approximately 140 mW from a 5V supply into an 8-ohm speaker. It also has a low quiescent power drain of 18mW at this supply voltage.

4.1.2 Testing of voice output

Connecting a microphone and recording several messages tested the voice output circuit. A dip-switch was used to pull the address lines low to set the record and playback addresses. The recording and playback worked as intended, with reasonable speech quality obtainable when speaking loudly into the microphone. The volume was also sufficient. Although distortion was evident with the volume at maximum, this was mainly due to the very small speaker used. Proper mounting of the speaker on a baffle would provide a great improvement in power handling and quality of the voice output.

5 Conclusions and Future Work

A complete description of the software developed for this work is presented in Part II of this two-part paper [1,2]. The prototype recognised 5, 10, 50 and 100 dollar notes when they are swept horizontally over the array, with the motion as shown in Figure 1. This shows the usefulness of the correlation technique as a method for recognising the clear window of Australian notes. A useful device for the vision impaired could stem from the prototype if several problems can be overcome.

5.1 Illumination

The problem of poor evenness and concentration of the illumination needs to be solved. Better concentration is essential for reasonable battery life. The evenness problem may need to be solved using a two-pronged approach. A suitable lens arrangement is needed to concentrate the light in one axis. Then, an analogue to digital converter with more resolution can cope with the drop in intensity towards the ends of the array. This may be as simple as using the other half of the dual comparator to provide another threshold. The output of one comparator could be used across the centre and the other at the ends. On start-up, the processor could enter a control loop in which the illumination is increased while monitoring the thresholds. This would enable the illumination to be brought up to the same level each time, regardless of slight changes in the illumination system. A failure of the LED or partial failure of the array due to grime build-up would be sensed, and an announcement made to the user.

5.2 EPROM voice storage

Because voice recording is not necessary, the voice recorder chip used in the prototype should be dispensed with and an EPROM used to store the digitised voices and tones. This would lower costs.

5.3 Power management

In the prototype, the audio amplifier and the LED are kept running, even when they are not needed. Switching these off when they are not needed would result in useful power savings.

6 References

[1] Siewert, I., "Australian Currency Note Identifier for the Vision Impaired", Final Year Thesis, School of Electrical and Computer Engineering, Curtin University of Technology, 1998

[2] Siewert, I., Murray, I., Dias, T, "*Australian Currency Note Identifier for the Vision Impaired- Part I: Hardware Description*", Submitted ANZIIS 2001

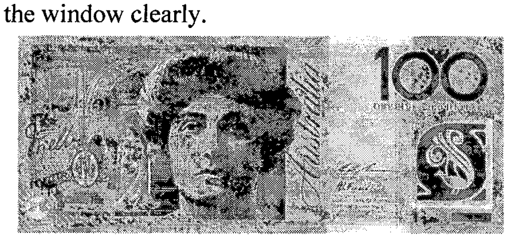
[3] Levaldi, S., Digital Image Analysis, Pitman, 1984

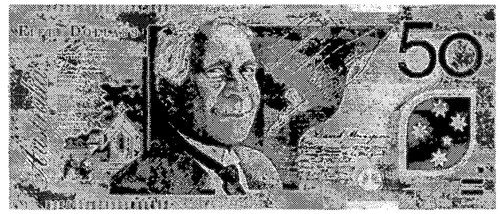
[4] Texas Instruments, TMS320C5x DSP Starter Kit User's Guide, 1996

[5] Texas Instruments, TMS320C5x User's Guide, 1997

Appendix I: AUSTRALIAN POLYMER NOTES

Some examples of the current series of Australian polymer notes is shown below (not actual size). The notes were placed on a blue backing to show the window clearly.

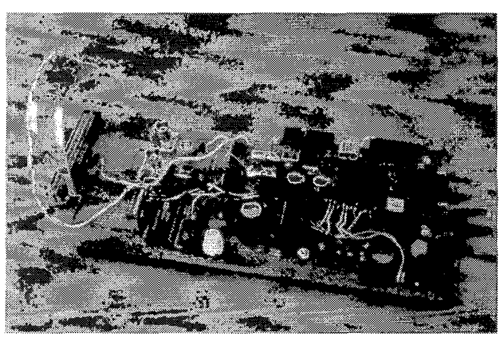




Appendix II: EXAMPLES OF WORN NOTES

Badly worn ten dollar and five dollar notes are shown below (not actual size). The notes were placed on a blue backing to show the window clearly.

Appendix III: PHOTOS OF PROTOTYPE



Completed Prototype. The two push buttons at lower right are for a separate project.