Performance of a System to Locate Address Blocks on Mail Pieces[1]

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Abstract

The objective of an Address Block Location System (ABLS) is to determine the position and orientation of a destination address block in a mail piece image of either a letter, magazine, or parcel. The corresponding sub-image can then be presented to either a human or machine reader (OCR) to direct the mail piece to the appropriate sort category based on the ZIP code. ABLS is capable of dealing with a wide range of environments from those having a high degree of global spatial structure to those with no structure. The system consists of several specialized tools and a control structure so that the tools are opportunistically invoked and coordinated. Its performance on a training and testing image database of difficult cases is described.

1. Introduction

Machines for automatically sorting letter mail have existed for several years. Present machines can only correctly process about 55% of the letter mail presented to them [HKP84,USP84]. The reasons for this relatively poor performance have been determined to be in the areas of address block location as well as locating and reading the ZIP code within the address block. Either a standard address location is assumed or a few features such as window reflectivity and high edge density are used to locate a block of data likely to contain the *destination address*. Therefore, current automatic letter mail sorting machines can be easily confused by extraneous data on the face of an envelope, which is frequently present in third class mail. Flats (e.g., magazines) and irregular parcels and pieces (IPP) are not presently sorted automatically.

In a previous paper [WaS86], we introduced the general problem. This paper describes a refinement of the architecture of ABLS and performance with an image database consisting of many difficult cases. Described is a solution methodology (Section 2), the software and hardware implementation (Section 3), a description of experimental results and analysis (Section 4), and the main research contributions of this system (Section 5).

2. Solution Methodology

ABLS inputs several types of images (photopic, RGB, infra-red, and color under ultraviolet illumination) of a single mail piece, and produces one or more candidate blocks, their orientation(s) and confidence values associated with being the destination address block (DAB).

2.1. Components of ABLS

ABLS is composed of six major components: a mail statistical database, a rule-based inference engine, a control mechanism, a control data, a blackboard, and a tool box.

The mail statistical database [GTR86][SHP86] contains the statistics of the geometric features of all meaningful information blocks on many samples of mail pieces. This includes the probability that a destination address block and a return address block are in a particular location in a 3 by 3 grid on the image, the average and standard deviation of the aspect ratio, number of text lines, and the address block length of a typical hand and machine generated destination address block.

The rule-based inference engine performs forward reasoning on various rule modules which are stored with each tool. The inference engine acts as the interpreter of all the rules.

The control mechanism is responsible for checking the termination condition, selecting a tool, combining new evidence, and updating the context. Tool selection is based on the benefit/cost estimation of each tool. The control mechanism estimates the utility of each tool in the current context using the tool's utility module. The tool with the maximum utility is chosen as the tool to be applied next and its utility is reset to zero before it is applied.

The control data provides information for the control mechanism about the interdependency between the tools, and the criteria for accepting a block as a destination address candidate. The *dependency graph* (Figure 1) is a directed graph to specify the temporal sequence of applying tools as well as to minimize continuously re-estimating the utility of each tool. A node in a dependency graph is triggered if one of the arcs entering the node is activated. Each node in the dependency graph represents whether the utility of the associated tool should be re-evaluated during tool selection. The control mechanism will not invoke the utility rule module of a tool unless its associated node in the dependency graph is triggered.

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[1] This work was supported by the Office of Advanced Technology of the USPS Under Task Order 104230-85-M3349.

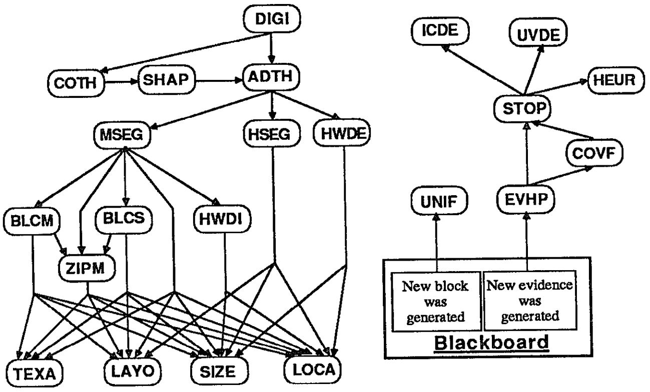

Figure 1. Dependency graph for specifying the temporal sequence of applying specialized tools.

The design of ABLS consists of many specialized tools that are appropriately deployed. An effective method for integrating knowledge from various sources is the blackboard model of problem solving [EHL80, Nii86]. The blackboard model divides a complex problem into loosely coupled subtasks, and each subtask is attacked by a specialized tool. The ultimate goal is to integrate knowledge from various sources to achieve a common goal. The blackboard contains the current context, the confidence values of labeling hypotheses, and the geometric attributes of blocks extracted from low-level image processing.

The tool box contains a collection of tools, many of which are image analysis related. The tools in ABLS can be divided into three categories based on their purpose: (i) destination address candidate generation tools for generating destination address candidates from the mail piece images, (ii) destination address candidate discrimination tools for distinguishing the actual destination address from the destination address candidates, and (iii) control mechanism tools for unifying the block features between overlapping blocks, combining evidence and initiating new hypotheses, and determining when to halt the processing. Table I lists all the tools in ABLS. Each tool contains rules for estimating the benefit and cost of using it, selecting parameters, and evaluating and interpreting results.

2.2. Control Strategy

The control strategy of ABLS is an integration of both bottom-up and top-down processing. For the bottom-up processing, initially, one of the thresholding tools is chosen and applied to the entire mail piece image. The thresholded image is then segmented, bottom-up, into blocks using a segmenter tool. The physical attributes of a segmented block are then interpreted to generate evidence either supporting or refuting a block as being the destination address. In addition to using bottom-up processing, ABLS occasionally will use top-down processing to search for the address block on a particular portion of the mail piece image.

The *global orientation* of a mail piece represents the rotation needed (in 90 degree increments) to correctly orient the assumed destination address. Initially, mail piece orientation is unknown to ABLS but the location of the postage or meter mark may be able to help determine the correct global orientation of a mail piece. If the correct orientation cannot be determined prior to the interpretation of segmented blocks, ABLS will interpret each segmented block in all four global orientations with the correct global orientation assumed to be the one which obtains the maximum degree of support.

2.3. Computation of Utility Value

The strategy of tool selection in ABLS is determined using the dependency graph and the utility value of each tool. The dependency graph specifies the interdependency between tools and dictates which tools are eligible for estimating the utility value. After the utility value estimation, ABLS always chooses the tool with the maximum utility value as the tool to be used next. Through the experimental results on 174 complex training images, the utility value of a tool is computed from the following five measures:

(1) the efficiency of the tool, i.e., the ratio of the number of times the tool is used to the number of times it generates evidence to support the real destination address block as the destination address.

(2) the effectiveness of the tool, i.e., the ratio of the number of pieces of evidence generated by this tool to the number of pieces of evidence that support the real destination address block as the destination address.

(3) the average CPU processing time of the tool.

(4) the percentage of mail population that the tool is designed to deal with. For example, the MSEG tool is designed to segment machine-generated address blocks, while the HSEG tool is for segmenting hand-generated address blocks.

(5) the special situation adjustment, i.e., those occasions which require the immediate attention of the system to invoke a particular tool. For example, whenever there are new pieces of evidence generated, the evidence combination tool (EVHP) will be invoked to combine evidence.

2.4. Confidence Values and Evidence Combination

ABLS can utilize one of several tools at any different time while processing an input mail piece image. When several tools are used, it is necessary to combine evidence gathered from the application of each tool. Each new

TABLE I
Functional Descriptions of Knowledge Sources.

Category	Tool	Descriptions
Destination Address Candidate Generation Tools	**DIGI**	produces digitized images (RGB and gray-level) of the original picture.
	ADTH	adaptive thresholding to convert a gray-level image into a binary image using local contrast.
	COTH	color thresholding to extract regions of specified color in RGB images.
	SHAP	measures the degree of rectangularity of a blob.
	MSEG	bottom-up segmenter to group machine-generated characters into words, lines and blocks.
	HSEG	bottom-up segmenter to group hand-generated thin strokes into lines and blocks.
	HWDE	regularity analyzer to detect the likely regions of hand-generated text.
	ZIPM	merge zip code block in lower right of a destination address candidate.
	BLCS	splits a too high or too wide machine-generated text block into several smaller text blocks.
	BLCM	merges machine-generated text blocks which are parallel and close in proximity.
Destination Address Candidate Discrimination Tools	**HWDI**	regularity analyzer for distinguishing machine-generated versus hand-generated address block.
	TEXA	texture discriminator for address block type characters and non-address block type characters.
	ICDE	postal icon detector to detect rectangular postal icons.
	UVDE	postage detector to detect the postage locations (stamp, meter-mark) on UV illuminated image.
	SIZE	uses block features, e.g., aspect ratio, length, height, number of text lines, and number of components, etc., to classify how likely a block is a destination address, return address, or advertising text.
	LAYO	examines the layout of text lines in a block.
	LOCA	uses the location of a block to determine the likelihood of this block being the destination address, return address, or postage.
	HEUR	uses spatial heuristics or rule-of-thumb to guess the destination address from a list of candidates.
	COVF	verifies the consistency of labeling hypotheses among neighboring blocks.
Control Mechanism Tools	**UNIF**	unifies the block features between blocks generated by different tools.
	EVHP	pools together the evidence generated by various tools and generates labeling hypotheses.
	STOP	decides whether to halt processing or not.

evidence generated by the application of a specialized tool is associated a *confidence value* to represent the degree to which it supports or refutes a particular labeling hypothesis. An example of a rule with a confidence value is:

IF aspect ratio(A) = x and size(A) = y
THEN A is the DAB confidence z

where A is a particular block being tested, x and y are rule parameter, and z is the probability associated with the confidence of the rule results. The confidence value z represents the a posteriori probability $P(h_i \mid e)$, where e is the evidence (i.e., the condition or "IF" part of a rule), and h_i is the labeling hypothesized to be associated with the block (i.e., destination address, return address, postage, advertising text, and graphics). In other words, $P(h_i \mid e)$ represents the probability of assigning label h_i to block A given evidence e. In the above example, evidence e is the aspect ratio and size testing portion of the rule while label h_i is the DAB label.

There are several ways to estimate the a posteriori probability $P(h_i \mid e)$. The approach we have taken is to use the available statistics from the mail statistics database plus subjective estimation and then use the experimental results (from the image database) to fine tune the subjective estimation. This approach is by no means complete, or statistically sound, but it represents the best possible from the available information.

The scheme to combine confidence values of evidence is based on Dempster-Shafer theory of evidence combination [Bar81, Sha76] with a block on a mail piece having one label of the following five-label set: destination address, return address, postage, advertising or miscellaneous text, and graphics.

3. Implementation

In terms of the implementation running on a single CPU system (SUN-3), the tools in ABLS can be divided into two categories. The first category of tools is primarily implemented in C (10,000 lines) with some additional knowledge rules and Lisp functions (7,000 lines) to do the interface between the control structure and these tools. Tools falling into the first category are the ADTH, COTH, MSEG, HSEG, HWDE, HWDI TEXA, SHAP, and ICDE tools. The detailed descriptions of tools in the first category can be found in [SWP87]. Tools in the second category are basically coded in knowledge rules with some additional Lisp functions to implement those tasks not easily coded in the knowledge rules. Tools belonging to the second category include the BLCM, BLCS, ZIPM, LAYO, LOCA, SIZE, UVDE, COVF, HEUR, UNIF, EVHP, and STOP tools.

4. Experimental Results and Analysis

In order to test the performance of ABLS, experiments were conducted using an image database consisting of 174 complex training mail pieces images. The current training image database consists of four categories: letters, flats (e.g., magazines, newspapers), irregular parcels and pieces, and manual letters. The images are not a strict statistical sample but skewed towards cases that would be difficult to handle. All input images in the training image database have been oriented manually to the correct orientation. This manual orientation has not been performed for testing ABLS with 30 USPS testing images which will be described below.

The statistics of performance on 174 training images are shown in Table II. Each testing is classified as a success (S), i.e., the destination address is the highest ranked block, and the segmented destination address contains enough address to correctly sort the mail piece, a partial success (P), i.e., the destination address is the highest ranked block, but the segmented destination address contains insufficient address to correctly sort the mail piece, a reject (R), i.e., system cannot recommend any block as the destination address block because all figures of confidence were too low, or an error (E), i.e., the highest ranked block is not the destination address.

The cause of failure of those pieces not classified as success (Table III) is roughly divided into six categories: hand generated destination address (H), poor image quality (Q), the destination address located in an unusual location (L), the size of destination address is either unusually large or unusually small (S), the destination address near other text blocks which causes an over-segmentation (N), and other text blocks are similar to the destination address and located in the usual location for a destination address (C). Since a failure could be the result of multiple causes, the summation of each category's percentage may be over 100.

TABLE II.
Statistics of Performance.

Mail Class		S	P	R	E
Flats	Pieces	41	1	3	5
	Percent	82%	2%	6%	10%
Letters	Pieces	46	0	2	2
	Percent	92%	0%	4%	4%
IPPs	Pieces	23	4	3	7
	Percent	62%	11%	8%	19%
Manual Letters	Pieces	30	2	1	4
	Percent	81%	5%	3%	11%
Total	Pieces	140	7	9	18
	Percent	81%	4%	5%	10%

The statistics of performance in Table II show that ABLS achieves an 81% overall success rate. The overall success rate of ABLS can not be higher than the percentage of acceptable segmentations which is 83%. This means that ABLS can achieve a very high success rate (81 / 83 = 98 %) given an acceptable segmentation result. Therefore, the key to substantially enhance the performance of ABLS lies in the improvement of segmentation results. In the early stage of ABLS development, only one bottom-up segmentation tool (MSEG) was used, and it can only achieve about 60% correct segmentation results. However, with the incorporation of more tools using either different methods to segment an address block or to repair the segmentation results, ABLS now can achieve an 83% acceptable segmentation rate.

The experimental statistics (Table II) also show that ABLS achieved a high success rate on letter mail since they are well structured and have the destination address in a standard position. For the other three mail classes, generally speaking, the major cause of failure, besides the segmentation failure, is due to the confusing text blocks which are too close to the destination address. The block splitting tool (BLCS) of ABLS is aimed at solving this kind of failure, and achieves limited success.

The CPU time required by the system for these training images, on average, is 10.4 minutes with 6.3 minutes for letters, 8.2 minutes for manual letters, 7.7 minutes for IPPs, and 18.2 minutes for flats. The long processing time required for flats is mainly because of the large digital image size encountered in this mail stream. The average processing time per invocation of each of the image analysis tools is as follows: TEXA-3 seconds, SHAP-12 seconds, COTH-23 seconds, MSEG-1.5 minutes, HSEG-1.6 minutes, HWDI-2.0 minutes, ICDE-3.1 minutes, ADTH-5.5 minutes, and HWDE-6.3 minutes. The average processing time per invocation of each of the control structure tools is as follows: LAYO-1 second, EVHP-1 second, STOP-1 second, UNIF-1 second, SIZE-1 second, BLCM-2 seconds, LOCA-2 seconds, BLCS-3 second, COVF-4 seconds, HEUR-6 seconds, and ZIPM-9 seconds. We are presently focusing on methods to reduce the processing time per mail piece by several orders of magnitude using several specialized image processing boards. This should produce a system which performs at real-time rates.

This system has also been tested on 30 images that were not part of the training set and are skewed toward more difficult cases. The performance on the 30 test images was: 77% (success with correct global orientation), 0% (success with incorrect global orientation), 23% (P), 0% (R), and 0% (E), which are consistent with the results of the previous experiments. The performance codes for test images are slightly different from the definitions because the definition of the partial success (P) is relaxed to include every test image which does not have a satisfactory segmentation result. Therefore, there is no reject and error because all the failure

TABLE III
Statistics of Cause of Failure.

Mail Class		# of Cases	Cause of Failure					
			H	Q	L	S	N	C
Flats	Pieces	9	2	3	2	1	4	3
	Percent	100%	22%	33%	22%	11%	44%	33%
Letters	Pieces	4	0	4	0	0	1	0
	Percent	100%	0%	100%	0%	0%	25%	0%
IPPs	Pieces	14	1	8	0	4	4	0
	Percent	100%	7%	57%	0%	29%	29%	0%
Manual Letters	Pieces	7	2	2	1	2	2	0
	Percent	100%	29%	29%	14%	29%	29%	0%
Total	Pieces	34	5	17	3	7	11	3
	Percent	100%	18%	50%	9%	21%	32%	9%

cases in test images are due to the the poor segmentation results.

5. Conclusion

A methodology for designing a system to recognize address blocks in an environment that may be structured, partially structured or random has been described. The approach has been to utilize specialized tools to generate several candidates for the destination address block, and to distinguish the destination address from other candidates. The framework is flexible enough to incorporate as many tools as possible into the system if experimental results can establish the usefulness of those tools. Knowledge about the selection and utilization of each tool is kept independently and separately on each tool so that the addition, deletion, or modification of a tool will not cause side effects on other tools.

The experimental results demonstrate that using multiple thresholding tools, segmentation tools, and refined-segmentation tools is a promising direction toward locating address blocks on mail pieces with varying degrees of complexity and quality. Commercial letter mail sorting machines of today largely assume a standard position for the address block and cannot process mail pieces with complex structure. The key set of features which are useful for locating an address block has been identified and the necessary image analysis tools for extracting those features have also been developed and evaluated on an image database. This system shows an interesting and effective method for using blackboards in addition to many image processing routines to locate information in a digital image.

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