ARRAY

TP 13283E

X-ARRAY Field Trial Report

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X-Array Field Trial Report

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Un sommaire français se trouve avant la table des matières.

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16. Abstract

This report describes the results of the first field trial of the X-Array automatic threat identification system. The field trial took place at the Lester B. Pearson International Airport in Toronto and provided an opportunity to gather vital data for further development of the X-Array product:

- A large number of images from travellers' carry-on luggage were gathered. Array used this data to enhance the system's performance by reducing the number of false alarms.
- Operator responses were collected; they indicated that the X-Array would be a useful addition to the airport's X-ray security systems.

After the field trial, Array completed several post trial modifications to the software to enhance the system's performance and 'ported' the software to a Windows NT platform.

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16. Résumé

Ce rapport rend compte de la première mise en service expérimental du système X-Array, un dispositif de détection automatique d'articles suspects. Mené à l'aéroport international Lester B. Pearson de Toronto, cet essai a été l'occasion de colliger des données essentielles pour parfaire le système.

- Un vaste échantillon d'images de bagages à main a été réuni. Array a utilisé ces images pour améliorer les performances de son système, notamment pour réduire le nombre de fausses alarmes.
- Les opérateurs ont réagi favorablement au système, voyant dans le X-Array un complément utile aux appareils radioscopiques actuellement en service.

Par suite de la mise en service expérimental, Array a apporté plusieurs modifications au logiciel du système; celui-ci a notamment été adapté à la plate-forme Windows NT, ce qui améliore grandement ses performances.

17. Mots clés

Sécurité des aéroports, détecteur aux rayons X assisté par ordinateur (CAXSS), traitement d'images, réseau neuronal, ordinateur personnel (PC), unité de traitement parallèle, détection d'articles suspects, rayons X

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Executive Summary

The field trial took place at Lester B. Pearson International Airport from December 1 to December 12, 1997. It had five major objectives:

- To determine false alarm rates
- To perform detection tests using real threats
- To collect reliability data
- To obtain operator feedback
- To collect sample bag images for future use

The X-Array system scanned passengers' carry-on baggage after it had been scanned by a standard airport X-ray system. Eight registered airport X-ray scanner personnel were trained to use the X-Array system, and they were the sole operators throughout the trial period.

Detection tests performed by Transport Canada and the Federal Aviation Administration using real threats demonstrated that the system performed as expected (95%+ identification rate) for identifying real threats.

Results of the false alarm rate tests showed a high number of false alarms. The high number of false alarms was principally a result of false knife detections. The carry-on bag mix and the number of potential threats that would normally require screening were largely responsible for the higher than anticipated number of false alarms. However, the trial also provided a significant sample set to be collected, from which modifications of the detection algorithms could be tested to improve the false alarm rate. These improvements were substantial and led to a reduction in false alarm rate from 85% to 34.6% when only the gun and knife detectors were active.

The reliability of the X-Array in the trial environment was also lower than anticipated, although the system could sustain 24-hour runs without failure while at Array. There are many possible explanations for this low reliability including shipping damage or electromagnetic interference at the airport installation site. Investigations suggested that the problem was most probably caused by communication errors across the interface between the personal computer (PC) and the parallel processing unit (PPU). This interface is being phased out as a result of a 'port' of the software to Windows NT.

Operator feedback indicated that the X-Array system was useful in assisting operators in detecting potential threats in carry-on bags. However, the X-ray scanner used by X-Array was outdated, and did not provide the high resolution that the operators are accustomed to seeing on newer machines. The operators felt that the automatic recognition was an enhancement to their current methodology, but they were not willing to give up the easy-to-use interface found on current systems.

Over the trial period, X-Array saved 3,221 images of passengers' carry-on luggage. This data has already been put to use in making further improvements to the detection algorithms. In work carried out under company funding, Array completed a 'port' of the X-Array software to a Windows NT platform operating in near real time on a Pentium II processor. This 'port' has eliminated the need for the PPU and therefore has significantly increased the reliability and reduced the recurring costs.

The X-Array product is nearing commercial availability; porting the X-Array to new X-ray scanner technology with further fine-tuning of the knife detector should permit Array to complete the commercialization.

Sommaire

La mise en service expérimental a eu lieu à l'aéroport international Lester B. Pearson, du 1er au 12 décembre 1997. Cinq grands objectifs étaient alors poursuivis :

- déterminer les taux de fausses alarmes;
- effectuer des essais de détection de bagages contenant des menaces réelles;
- rassembler des données de fiabilité;
- obtenir les commentaires des opérateurs;
- échantillonner des images de bagages pour usage futur.

L'essai consistait à soumettre au système X-Array des bagages à main qui avaient déjà été contrôlés au moyen d'un appareil radioscopique classique. Huit opérateurs qualifiés de détecteurs aux rayons X ont reçu une formation sur l'exploitation du système X-Array. Ils ont été les seuls à utiliser le système pendant toute la durée de l'essai.

Des essais de détection réalisés par Transports Canada et la Federal Aviation Administration sur des bagages contenant des menaces réelles ont révélé un taux de détection conforme aux attentes, soit d'au moins 95 p. 100.

Les résultats au chapitre du taux de fausses alarmes se sont révélés moins satisfaisants. Un nombre plus élevé que prévu de fausses alarmes a en effet été enregistré, et celles-ci résultaient principalement de la détection de couteaux. Ce résultat a été attribué en grande partie à la nature hétéroclite de l'échantillon de bagages, dans lequel se retrouvaient un nombre élevé de menaces potentielles. Mais l'essai fut en même temps l'occasion de rassembler un vaste échantillon d'images sur lesquelles essayer les algorithmes de détection, en vue d'améliorer le taux de fausses alarmes. Cette amélioration a été marquante, faisant passer de 85 p. 100 à 34,6 p. 100 le taux de fausses alarmes, lorsque seuls les détecteurs d'armes à feu et d'armes blanches étaient actifs.

Pour ce qui est de la fiabilité, l'X-Array a déçu les attentes. Même si, chez Array, il pouvait fonctionner 24 heures sans défaillance, tel n'était pas le cas dans un contexte de service réel. Une foule de motifs peuvent expliquer cette piètre fiabilité, y compris la possibilité que le système ait été endommagé pendant le transport, ou l'interférence électromagnétique avec d'autres appareils à l'aéroport. Après examen de la question, les chercheurs tendent à imputer le problème à de mauvaises transmissions (via interface) entre le PC et l'unité de traitement parallèle. Mais cette interface est sur le point d'être éliminée avec l'adaptation du logiciel à la plate-forme Windows NT.

Les opérateurs qui ont participé à l'essai considèrent l'X-Array comme une aide utile pour détecter la présence d'articles potentiellement dangereux dans les bagages à main. Il convient toutefois de préciser que l'X-Array mis en service utilisait un appareil radioscopique dépassé, qui ne procurait pas le degré de résolution élevé auquel sont habitués les opérateurs qui travaillent avec des appareils modernes. Ils estiment que la détection automatique représente une amélioration par rapport à la technique actuelle, mais ils ne sont pas prêts à renoncer à l'interface conviviale qui équipe les systèmes existants.

Au cours de la période d’essai, l’X-Array a enregistré 3 221 images de bagages à main. Ces données ont d’ores et déjà servi à parfaire les algorithmes de détection. L’entreprise a financé elle-même les travaux qui ont mené à l’adaptation du logiciel à la plate-forme Windows NT tournant sous un processeur Pentium II en temps quasi réel. Cette liaison a rendu superflue l’unité de traitement parallèle et a donc considérablement accru la fiabilité du système et réduit les coûts récurrents.

Le produit X-Array est sur le point d’être mis en marché; il reste à Array à adapter son système à une nouvelle technologie de radioscopie permettant un réglage fin du détecteur de couteaux pour le rendre tout à fait commercialisable.

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1 INTRODUCTION

This report describes the work completed during the X-Array Field Trial Project. The purpose of the Field Trial was to generate data to determine the effectiveness of X-Array (a Computer Assisted X-ray Screening System or CAXSS), in an operational environment.

Over the past six years, Array Systems Computing has worked on various phases of a research and development contract to develop the X-Array. The previous phase of the project (completed in November 1997) improved the reliability of the X-Array system.

The Field Trial had five objectives:

1. To determine false alarm rates
2. To perform penetration tests using real threats
3. To collect reliability data
4. To obtain operator feedback
5. To collect sample bag images for future use

1.1 Background

This section describes the status of the X-Array before the start of the field trial.

Enhancements to the X-Array reliability allowed the system to run continuously during 24-hour tests without failing. Reliability improvements were confined to modifying the underlying user interface system to make it more robust. The software user interface and the system configuration were identical to those described in earlier documents.

Before the Field Trial, Array performed a preliminary analysis of false alarm and detection rates using in-house test data. These were used to ensure that modifications to the underlying user interface code did not affect the detection characteristics of the X-Array system. At the time, Array lacked an adequate number of representative images to perform accurate measurements of false alarm or detection rates. Transport Canada performed such analysis during earlier trials.

1.2 Reference Documentation

The following references were used in preparing this report:

Operational Trial and Evaluation Protocol, Array CAXSS Lester B. Pearson International Airport, December 1997, Transport Canada, Revision 97-11-19.

Airport Pre-Board Passenger Screener Course, Transport Canada, TP 8697, 31 May 1997.

Functional Specification, Tests and Evaluation Procedure for Array Systems Computing Inc. Computer Assisted X-ray Screening Systems, J. Le Saulnier, ABCE, Transport Canada, June 1996.

1.3 Document Overview

The document is divided into the following sections:

- Approach and Procedures
- Apparatus
- Tests
- Results
- Analysis of Results
- Conclusions and Recommendations

2 APPROACH AND PROCEDURES

Array divided the project into five phases:

1. Factory Acceptance Test (FAT)
2. Operator Training
3. Site Installation and Site Acceptance Test
4. Field Trial
5. Evaluation

2.1 Factory Acceptance Test

Before delivering the system to the field trial site, Array conducted a FAT to confirm that the software and hardware were operating correctly. The FAT tested the automatic and manual operations of the X-Array and the X-ray scanner. Transport Canada personnel witnessed the test.

2.2 Operator Training

2.2.1 Preparation of Training Course and Course Materials

Training course preparation involved three stages:

- Training the course instructor on the use of X-Array.
- Designing and creating overhead transparencies to introduce digital imaging and basic image analysis.
- Designing assessment questionnaires and logging sheets.

2.2.2 Presentation of the Training Course

The operator training course took place over two days at the Array office in Downsview. There were six participants each day. The training course presented an introduction to image analysis and the X-Array, followed by a demonstration and a "hands-on" session. Students were encouraged to ask questions and discuss their previous experiences with airport security systems. The instructor also explained what information was required on the logging sheets and the student assessment questionnaires.

During the practical sessions every student had plenty of opportunity to control the X-Array and examine the types of images created with different types of potential threats. Some students brought their own threat objects to use in the system.

3 APPARATUS

The system hardware consists of an IBM PC compatible computer, and an off-the-shelf PPU. The computer is referred to here as the Personal Computer Unit (PCU). Figure 1 shows the configuration of the current X-Array system.

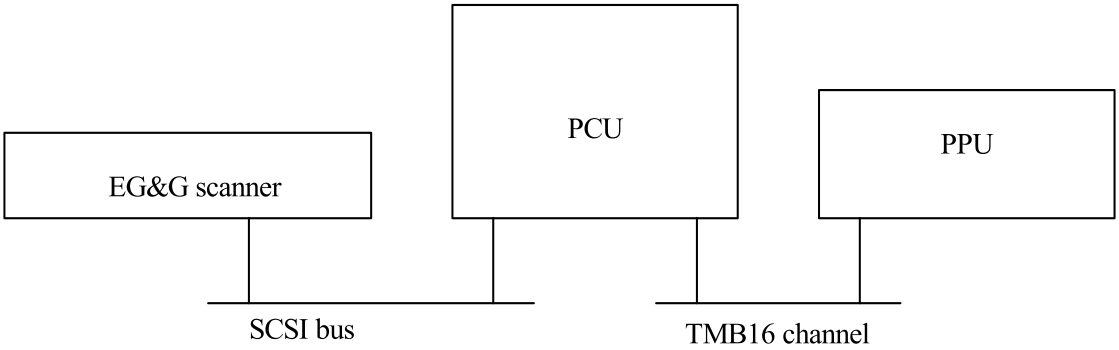

Figure 1. Overview of X-Array System

3.1 PCU Hardware

The PCU contains an Intel Pentium 133MHz CPU, 16 MB RAM, 1.9 GB SCSI hard drive, a Matrox local bus graphics accelerator (Impression), and a TMB16 interface card to facilitate communication with the PPU. The motherboard of the PCU has a VESA local bus for the graphics card and a SCSI card to interface the PCU to the EG&G Linescan.

3.2 PPU Hardware

The PPU is housed in a “pizza-box” unit called the Transtech Parastation. This contains a Transtech Motherboard (TMB24) onto which up to four Transtech Transputer Module (TTM200) daughter-boards can be fitted. The TTM 200s consist of a 50 MHz i860 CPU, a T805 transputer and 20 MB RAM. Figure 2 shows the logical organization of the components of a TTM200.

The RAM in the TTM200 is organized such that the T805 transputer has access to the whole memory address space. The i860 CPU, however, has access to only 16 megabytes of this address space. Each transputer has four serial communication links which can be connected to other transputers on adjacent TTM200s. Each transputer acts as a communications processor and data manager for its local i860. Data is transferred between the T805 and the i860 by the use of the shared memory. Data access control is handled through the use of semaphores and triggers.

The transputer in the PPU that is directly connected to the TMB16 interface card in the PCU is referred to as the global master processor. The global master processor is directly connected to the other two TTM200 transputers in the PPU.

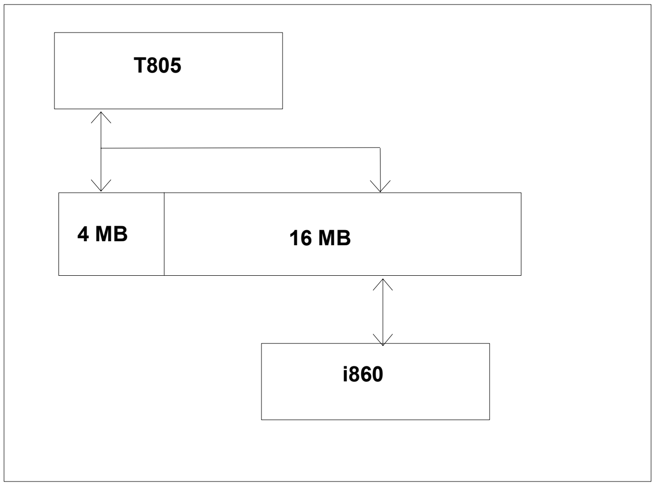

Figure 2. Logical Representation of a TTM200 Module.

3.3 Site Installation and Site Acceptance Test

The development equipment was used during the field trial. The EG&G Linescan 110 X-ray machine was partially disassembled, then the PPU Parastation and the PCU were moved from Array to the airport location. At the trial site the system was connected to a dedicated electric circuit to ensure sufficient power.

The system was installed behind the International Departures checkpoint in Terminal 3 at Lester B. Pearson Airport. This checkpoint normally uses three separate X-ray systems. The X-Array was installed in tandem with one of the three existing X-ray systems. Figure 3 shows the installation plan.

Passengers were asked to voluntarily have their luggage re-scanned using the X-Array system, after being told that it was a trial of a new device. We were able to sample a significant fraction of the luggage passing through the International Departures gate during the trial.

The trial lasted ten working days, from Monday December 1, 1997, to Friday December 12, 1997.

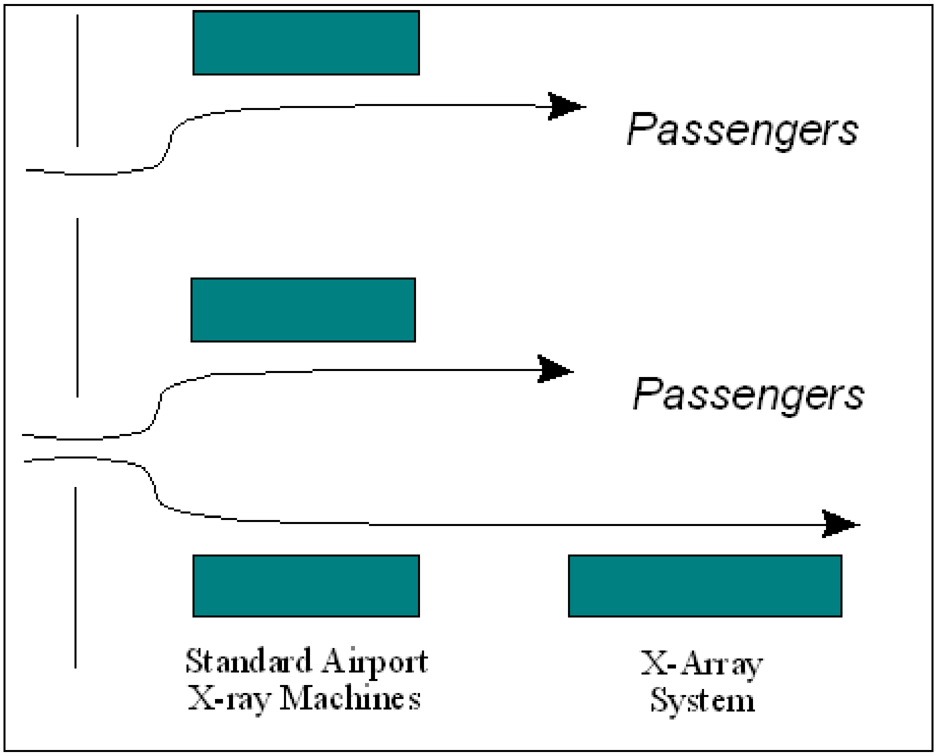

Figure 3. X-Array Installation and Passenger Flow

4 TESTS AND RESULTS

4.1 Factory Acceptance Tests and Results

The Factory Acceptance Test took place on November 17, 1997 at the Array office. The test used a system configuration identical to that proposed for the field trial and included a period of 12 hours continuous operation. Array developed an automated testing utility to simulate button presses and reversing the belt direction. Before the extended test, personnel from Transport Canada operated the system, then introduced real threats and typical carry-on baggage. These tests exercised major features of the X-Array system.

The test results produced no major concerns and Transport Canada gave approval to proceed with the field trial. By mutual agreement, the electronics detection algorithm was disabled during the trial.

4.2 Site Acceptance Tests and Results

The Site Acceptance Test consisted of two tests to check the system performance before starting the field trial. A few test bags were scanned in the system and the results were compared (qualitatively) to results obtained with scans of the same bags taken at Array. Passing the same bag through the X-ray machine repeatedly (using an automated process to repeatedly reverse the direction of the belt) became a short endurance test.

The Site Acceptance Test was performed on the morning of Monday, December 1, 1997. The X-Array scanned a sample bag for 30 minutes continuously without failing, and its identification of possible threats was consistent with threats identified in the development environment at Array.

4.3 Field Trial Tests and Results

The ten-day field trial produced a large volume of data about the functionality of the X-Array system. X-Array saved the scanned image of each bag and data on the objects that the system identified as potential threats. The operators kept a written log in which they described items that the X-Array identified as threats. In this way, data could be analysed later to determine exactly what types of objects X-Array flagged as false alarms and the image data would be available to test future algorithms.

One immediate concern during the field trial was the system's poor reliability. During the field trial the system failed completely, necessitating a system reset. This was a persistent problem during the trials, and varied in frequency from once every five minutes to once every hour. On Tuesday, December 2, the X-ray machine itself failed and took several hours to repair.
Threat bags were also introduced to provide basic feedback on detection performance. These tests

did not use a full range of potential threats, so the result of the test should not be taken as an indication of the true threat detection capability of the system.

The trial produced the following data regarding false alarm rates. All invalid bag images have been removed from these statistics.

The following data were gathered regarding the false alarm rates on the bag images gathered during the trial. All invalid bag images have been removed from these statistics.

Table 1 shows the results with all five detectors active and no thresholding.
Table 2 shows the results with only gun and blade detectors active, without thresholding.
Table 3 shows the results with only gun and blade detectors active, using thresholding.[1]

False Alarm Rates (without thresholding)												
Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total #**	**%**
# Bags	110	166	376	362	380	404	433	413	460	117	**3221**	**100**
# of bags with Threats	102	141	306	314	345	359	375	364	410	106	**2822**	**88**
# of bags with Opaques	60	73	182	165	213	208	217	209	242	46	**1615**	**50**
# of bags with Grenades	42	38	89	86	102	113	117	105	132	35	**859**	**27**
# of bags with Bombs	6	6	17	16	16	18	21	16	16	4	**136**	**4**
# of bags with Guns	79	95	212	211	234	256	254	254	291	78	**1964**	**61**
# of bags with Blades	51	68	180	145	158	187	190	185	202	57	**1423**	**44**

Table 1. Field Trial Results - false alarm rates without thresholding

False Alarm Rates, Gun and Blade detectors only (without thresholding)												
Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total #**	**%**
# Bags	110	166	376	362	380	404	433	413	460	117	**3221**	**100**
# of bags with Guns or Blades	93	120	269	271	289	330	324	322	361	99	**2478**	**77**

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[1] Array implemented a thresholding algorithm to reduce false alarm rates. However, this algorithm was implemented too strictly at the time of the field trial, resulting in a loss of detection of 40% of threat items tested during the field trial. See Appendix A for a later reworking of this algorithm.

False Alarm Rates, Gun and Blade detectors only (without thresholding)												
Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total #**	**%**
# of bags with Gun threats	82	98	216	219	243	261	262	265	310	79	**2035**	**63**
# of bags with Blade threats	55	73	184	143	167	192	195	188	211	60	**1468**	**46**

Table 2. Field Trial Results - False Alarm Rates without Thresholding. Gun and Blade Detectors Active Only.

False Alarm Rates, Gun and Blade detectors only (with thresholding)												
Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total #**	**%**
# Bags	110	166	376	362	380	404	433	413	460	117	**3221**	**100**
# of bags with Guns or Blades	47	50	157	118	143	167	164	155	179	48	**1228**	**38**
# of bags with Guns	11	9	31	34	40	37	29	38	41	9	**279**	**9**
# of bags with Blades	38	46	141	92	113	144	145	131	152	44	**1046**	**32**

Table 3. Field Trial Results - with Thresholding

The trial met its final objective by capturing 3,221 images of typical carry-on baggage. This was not as high as expected, owing to the downtime caused by system problems. However, the number of images is sufficiently high to provide valid statistical results of false alarm rates produced by current and new algorithms. The new bag images are significantly more representative of actual airport carry-on luggage than the images previously available to the X-Array development team. For example, the images show a much higher proportion of electronic equipment than was found in previously sampled bags. This will lead to better theoretical measurements of false alarm rates and will provide a source of data for further research in reducing false alarm rates.

Table 4 shows the types of threats identified by the X-Array system. Note that an average of 2.1 potential threats were found per alarmed bag.

Sources of False Alarms						
Potential Threat Log Sheets for Dec. 1-12, 1997						
	Visual Clear	Manual Inspect	Both	Frequency	Manual Inspect Required	Restricted on Board
Guns	0	6	6	0.1%	6	6
Knife/Scissors	49	49	98	2.1%	98	98
Electronics/Adapters/Cell-Phones	157	214	371	7.8%	287	
Food	107	76	183	3.8%		
Pen/Gauge/Thermometer/Lighter	129	55	184	3.9%		
Umbrella	54	23	77	1.6%	77	
Edge of Bag	209	49	258	5.4%		
Bottle/Perfume	230	90	320	6.7%		
Camera/Video/Binoculars	282	171	453	9.5%	453	
Coins	320	105	425	8.9%		
Batteries/Film/Videotape	234	133	367	7.7%		
Binders/Books/Paper	184	77	261	5.5%	261	
Keys	143	57	200	4.2%		
Watch/Jewellery/Nail Clippers	133	123	256	5.5%		
Purse/Briefcase Latch/Lock	112	63	175	3.7%		
Cosmetics/Toiletries	177	207	384	8.0%		
Shaver	31	37	68	1.4%	68	
Tin Box/Can	53	39	92	1.9%	92	
PC/Fax Machine	91	29	120	2.5%	120	
Aerosol Cans/Lighter Fluid	15	11	26	0.5%	26	
Shoes/Boots	93	14	107	2.2%		
Sundries	131	121	252	5.3%		
Various Homemaking Tools	54	40	94	2.0%		
POTENTIAL THREATS	2988	1789	4777	100%	1482	130
BAGS WITH POTENTIAL THREAT	2227	69%				
BAG OPENINGS	851	26%				
BAGS WITH NO THREATS	994	31%				
TOTAL NUMBER OF BAGS	3221	100%				

Table 4. Sources of False Alarms

4.4 Human Factors Tests and Results

The X-Array system kept a log of every user action performed during the trial. Table 5 shows the operator’s response to the questionnaires (a sample questionnaire appears in Appendix C).

X-Array Field Trial Responses											
Scores											
Least Favourable <-------------	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Most Favourable ---------------->**
Q1 - Easy to use?					2			3	1	2	
Q2 - Opinion on resolution?		1	1	2	2			2			
Q3 - Screen layout?				1		3	1	1	1	1	
Q4 - Job easier?	1	1	1	1	1	1			1	1	
Q5 - Slow down?			1	1			1	3		2	
Q6 - More efficient?			1			2	3	1	1		
Q7 - More or fewer bags?							1	3	1	3	

Table 5. Response to X-Array Questionnaire

Table 6 shows the relative rates of user actions taken by the operators during the field trial period.

The buttons are listed in the order in which they appear on the X-Array screen. The ‘Divert’ button is deliberately excluded as it had no function during the trial.

Number of Button Presses per Day											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**	**%**
Back	27	24	29	133	8	17	11	7	6	7	269	2.8
Stop	145	127	129	163	62	79	76	49	76	22	928	9.7
Forward	148	435	585	767	502	541	605	504	580	156	4853	50.2
Inverse	100	26	135	48	15	26	74	45	72	12	553	5.7
Contrast	109	66	138	112	80	52	54	80	42	22	755	7.8
Color	45	104	210	128	123	101	181	111	73	36	1112	11.6
Zoom	29	21	78	21	15	21	25	22	7	12	251	2.6
Next	18	18	50	53	9	11	33	34	41	16	283	2.9
Reset	31	49	120	90	33	16	35	64	67	18	523	5.4
Recall	7	9	11	20	17	6	13	8	17	5	113	1.2

Table 6. Operator Button Presses per Day

Feedback from the operators confirmed that X-Array may be a useful additional feature of airport security. Operators agreed that it definitely improved their ability to detect potential threats. Table 7 shows the operators’ opinions of the usefulness of the features in the X-Array user interface.

Most Useful Features											
Scores											
Not Useful	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Very Useful**
ZOOM						3	1			4	
RESET					1	2		2	1	2	
RECALL	1					1	3	1		2	
COLOUR	1					3	1	1		1	
INVERT			1		2	3	1			1	
CONTRAST			1		1		2		2	2	

Table 7. Operators' Opinions of the Usefulness of X-Array Features

Many functions available on the new machines were not available to X-Array operators. The keyboard mouse interface was not as intuitive as the simple control panel on standard machines. In short, the UI did not meet the standards of current machines. The operators felt that automatic threat recognition was an enhancement to their current procedures but were not willing to sacrifice the easy-to-use interface found on current machines.

5 ANALYSIS OF RESULTS

5.1 Reliability Testing

The intermittent failure was tracked to the communication interface between the PCU and the PPU. At seemingly random times, the PPU data would become corrupted and cause a system failure. Shortening the communication cable (under the assumption that environmental noise was the cause of the failure) appeared to reduce the failure rate. With the problem reduced to an hourly issue, continuing the field trial was feasible.

Since the PPU is being phased out of the system by switching to a Windows NT environment, it was not considered necessary to search for a way of eliminating the problem after the field trial. Possible causes include damage during transportation, power fluctuations at the airport, or electromagnetic interference from the surrounding airport machinery. There is a series of large-scale DC motors powering the airport luggage conveyor system directly below the location chosen for the trial. These may have generated interference.

Additionally, there were three other X-ray scanners in the immediate area and two metal detectors. Operation of these systems may have caused electromagnetic interference with the unshielded communication cable between the PC and the PPU or between the PPU and the X-ray scanner. Eliminating these components by phasing out the PPU and embedding the PC inside the X-ray scanner should eliminate performance issues related to electromagnetic interference.

5.2 Analysis of Field Trial Results

Modified threshold levels significantly reduced the false alarm rate for guns and blades. However, the initial settings of the modified threshold limits allowed the detector to miss a significant number of threat items (such as non-flat guns). It is recommended that the thresholding limits be modified to still give a significant false alarm reduction but not eliminate true threats.

Many bags examined in the international departures environment were densely packed, biasing results. Consequently, the test environment created a scenario for assessing the X-Array's performance which gave a broad distribution of classes of false alarms.

The results show that the false alarm rate with all five detectors active is significant. It is recommended that the gun and blade detectors be used exclusively, and that they be further optimized before the X-Array system becomes a commercial product.

Transport Canada personnel introduced a limited number of real threats during the trial. Table 8 presents a summary of these results.

Penetration Test Results

Penetration Test Results			
	Guns	**Knives**	**Both**
Detections	20	9	29
Missed Detections	1	12	13
Detection Performance	95%	43%	69%

Table 8. Results of Penetration Tests

Conclusions about the functionality of the X-Array during the field trial:

System reliability was low. The cause was traced to the Parastation PPU. This unit is being phased out of the project.

The simplistic thresholding approach implemented to reduce the false alarm rate had a significant effect on the detection rate and needs to be re-analysed to find a more suitable threshold value.

The false alarm rate (with or without thresholding) was too high for a commercial product. More analysis of the algorithms and detection systems is needed to reduce the false alarm rate without changing the detection rate.

5.3 Post Field Trial Work

After the field trial, the amassed bag data was used to enhance the pattern recognition algorithm to improve the false alarm rate (see Appendix A for details).

First, the thresholding algorithm was modified to not eliminate the true threat items that it was classifying as non-threat items. This consisted of relaxing the bounds on certain features, and led to none of the known threat items being eliminated by the thresholding. The set of threat images used to define these thresholds consisted of 63 guns and 41 knives.

Second, two new features extractors were defined to further improve the false alarm rate. These features were a gradient analysis and a perpendicular roll-off measurement. These two features were only used by the blade detector to reduce its false alarm rate. Again, the use of these new features did not eliminate any of the true threats from being identified by X-Array.

These two additions to the algorithm reduced the false alarm rate on the complete set of images captured over the time of the trial to 34.6%. Appendix A contains further details of these improvements.

5.4 Human Factors

The skill level of the operators seemed dependent on their familiarity with computers in general. This is most likely owing to use of a mouse interface in the trial. Operators who were not familiar with mouse manipulation had to learn the skill before becoming proficient with the system.
An effective human factors test could not be performed during the trial because external influences

may have biased the operators' performance:

- Operators could be 'cued' to expect a potential threat by the behaviour of operators processing a bag at the permanent X-ray system.

- Monitoring and supervision by personnel from Array, Transport Canada and the FAA may have influenced operators to be more diligent than would be the case under normal circumstances.

Many functions available on the new machines were not available to X-Array operators. The keyboard mouse interface was not as intuitive as the simple control panel on standard machines. In short the UI did not meet the standards of current machines. The operators felt that automatic threat recognition was an enhancement to their current methodology, but were not willing to sacrifice the easy-to-use interface found on current machines. Also, the operators commented that they found two monitors to be a more effective configuration of the system, because it allowed a non-occluded view and a more flexible viewing range, allowing the operators to view the scanned image while opening the bags. Another feature that could be useful would be the ability to remove the threat outlines from the image.

From the number of times each button was pushed during trial it is evident that operators used most of the features. The only feature not used very often (1%) was Recall, for viewing previous bags. The Zoom and Next buttons were not frequently used either (2-3%).

6 CONCLUSIONS AND RECOMMENDATIONS

The December 1-12 Field Trials at Pearson International Airport were the first in an operational setting. The trial achieved its objectives of acquiring a large set of data from typical carry-on baggage and assessing operator interest in the automatic recognition system.

Gun detection rates were high, but false alarm rates were initially unacceptable. Recent efforts (see Appendix A) have significantly reduced false alarm rates, bringing them into a feasible range (gun and blade detection only).

False alarm rates were higher than expected. Recent efforts (see Appendix A) have significantly reduced false alarm rates. Further, a study was conducted to determine areas for further improvement of the knife detector, which is the major source of false alarms. The study report is included in Appendix B.

Array funded efforts to port to a Windows NT platform have been successful. The NT version is much more stable and removes the need for the PPU.

Based on these promising results, Array recommends interfacing the Windows NT version of X-Array to a more modern X-ray scanner.

Appendix A

Post Field Trial

Improvements to X-Array

I. Introduction

During the period from Dec. 1 through Dec. 12, 1997, field trials at Pearson International Airport, Terminal 3, were conducted on Array's X-Array threat recognition system. The tests were sponsored by the FAA and Transport Canada. The purpose of the trial was to collect data and evaluate the X-Array system in an operational environment. The trials confirmed the X-Array detection performance but generated a false alarm rate greater than had been expected. Subsequent to the trials, a series of improvements were made to the gun and knife algorithms which brought the false alarm rate down to 9% for the gun detector, 29% for the knife detector and 35% for both detectors.

II. Field Trial Results

Over 3000 bags were scanned during the 10 day trial period. Manual data was also collected identifying the types of potential threats being highlighted by X-Array. The test data included a very high percentage of potential threats. Based on the operational guidelines for security personnel, 50%[1] of the potential threats identified by X-Array, would have required manual inspection under normal circumstances.

The X-Array system was installed at the international departures gate just prior to the Christmas holiday season. Therefore, most passengers tended to be carrying densely packed large bags. This environment resulted in a worst case scenario for generating false alarms.

Using the unmodified X-Array software, the results generated, an overall false alarm rate for both the gun and knife detector of 47%[2]. With all detectors active (gun, knife, opaque, grenade and bomb), the false alarm rate approached 80%. Furthermore, reliability issues, caused by the Parallel Processing Unit (PPU) and the SCSI interface, hampered the collection of data during the trials with an average period between crashes of 16 minutes.

However, during penetration tests conducted during the trial, X-Array maintained its superior threat detection performance, as highlighted in Table 1. X-Array achieved a 95% detection rate against guns during these Transport Canada initiated penetration tests[3].

---

[1] Based on the results presented in Table 2, Airport Pre-Board Passenger Screener Course and interviews with Group 4 security supervisors.

[2] Based on data collected during Dec. 2, 3 and 5.

[3] With thresholding off, Array implemented a thresholding algorithm to improve false alarm rate. However, results were unsatisfactory, therefore the feature was switched off for the trial.

Penetration Test Results		X-Array
Detections	**Guns**	20
	Knife	9
	Both	29
Missed Detections	**Guns**	1
	Knife	12
	Both	13
Detection Performance	**Guns**	95%
	Knife	43%
	Both	69%

Table A 1. Penetration Test Results

Potential Threat Log Sheets for Dec 3-12, 1997

	Visual Clear	Manual Inspect	Both	Freq.	Manual Inspect. Required	Restricted On Board
Guns	0	6	6	0.1%	6	6
Knife/Scissors	49	49	98	2.1%	98	98
Electronics/Adapters/C-Phone	157	214	371	7.8%	287	
Food	107	76	183	3.8%		
Pen/Gauge/Thermometer/Lighte	129	55	184	3.9%		
Umbrella	54	23	77	1.6%	77	
Edge of Bag	209	49	258	5.4%		
Bottle/perfume	230	90	320	6.7%		
Camera/Video/Binoculars	282	171	453	9.5%	453	
Coins	320	105	425	8.9%		
Batteries/film/Video tape	234	133	367	7.7%		
Binders/Book/Paper	184	77	261	5.5%	261	
Keys	143	57	200	4.2%		
Watch/Jewellery/Nail Clippers	133	123	256	5.4%		
Purse/Briefcase/Latch/Lock	112	63	175	3.7%		
Make-up/toiletries	177	207	384	8.0%		
Shaver	31	37	68	1.4%	68	
Tin box/can	53	39	92	1.9%	92	
PC/Fax machine	91	29	120	2.5%	120	
Aerosol cans/lighter fluid	15	11	26	0.5%	26	26
Shoe/Boots	93	14	107	2.2%		
Sundries	131	121	252	5.3%		
Various homemaking tools	54	40	94	2.0%		
Potential Threats	2988	1789	4777	100.0	1482	130
Bags with pot. threats	2227	69%			50%	4%
Bag Openings	851	26%				
Bags with no threats	994	31%				
Total Number of Bags	3221					

Table A 2. Sources of False Alarms

III. Field Trial Reliability Assessment

Array has been able to conclude with a significant level of confidence that the reliability issues demonstrated during the trials were isolated to the SCSI interface and the Transtech parallel processing unit (PPU). The SCSI implementation by EG&G is single ended and operates at very high data rates. The cable run was probably too long for reliable operation in an electromagnetically harsh environment. The Transtech PPU also suffered from low reliability and required frequent rebooting because of a break in data transfer to the PC. The X-Array code operating on the PC ran bug free.

The SCSI implementation of X-Array is unique to the EG&G Linescan 110 unit. Further, the PPU is not required in the NT version of X-Array. Thus, these reliability issues will not be relevant to future versions of X-Array operating with either the Heimann or the Vivid APS machines.

IV. Post Field Trial False Alarm Improvements

Investigation into the sources of the false alarms provided some immediate clues into possible deficiencies within the detection algorithms. These deficiencies relate to both the gun and knife detector algorithms.

Since the detection performance was very good for the gun and acceptable for the knife, the concentration of effort was on eliminating false positives after detection rather than on improving the algorithms to eliminate the detections in the first place.

The data used for these improvements consisted of the data files collected during the trial. The data sets were split 70% for development data and 30% for test data.

The results of the modifications to both the gun and knife detector are outlined in the following table:

False Alarm Improvement Statistics

Date	Total # of bags	Gun FA # of bags	Gun FA %	Knife FA # of bags	Knife FA %	Gun & Knife FA # of bags	Gun & Knife FA %
1-Dec	110	11	10%	27	25%	37	34%
2-Dec	166	9	5%	42	25%	47	28%
3-Dec	376	31	8%	126	34%	144	38%
4-Dec	362	34	9%	83	23%	110	30%
5-Dec	380	40	11%	99	26%	129	34%
8-Dec	404	37	9%	134	33%	157	39%
9-Dec	434	29	7%	133	31%	152	35%
10-Dec	413	38	9%	113	27%	138	33%
11-Dec	460	41	9%	130	28%	160	35%
12-Dec	116	9	8%	36	31%	42	36%
Totals	**3221**	**279**	**9%**	**923**	**29%**	**1116**	**35%**

Table A 3. Results of Modifications

False Alarm Rate (improvements after algorithm modifications)										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
# Bags	110	166	376	362	380	404	433	413	460	117	**3221**
# of bags with Guns or Blades	37	47	144	110	129	157	152	138	160	42	**1116**
# of bags with Gun threats	11	9	31	34	40	37	29	38	41	9	**279**
# of bags with Blade threats	27	42	126	83	99	134	133	113	130	36	**923**
# Initial Threats	451	640	1382	1246	1331	1698	1587	1588	1742	500	**12165**
# Threats eliminated by thresholding	283	441	883	856	912	1113	1056	1065	1144	343	**8096**
# Threats eliminated by gradient	42	18	50	36	50	50	60	68	78	22	**474**
# Threats eliminated by roll-off	10	18	28	18	18	14	18	16	10	14	**164**
Total # threats eliminated	**329**	**469**	**949**	**906**	**978**	**1175**	**1128**	**1139**	**1228**	**371**	**8672**

Table A 4. False Alarm Rates - After Algorithm Modifications

A. Gun Algorithm

The main source of false alarms with respect to the gun algorithm were generated by the thresholding levels. The gun detector determines the certainty of a threat against approximately 40 different features. Prior to the trials, Array had modified the code to change the threshold level in order to improve the false alarm rate. However, because of the limited data set, the effectiveness could not be certified and as a result, the implementation did not materially decrease the false alarm rate but rather reduced the detection performance.

The larger data set has permitted Array to further investigate these threshold levels with substantially improved results. The modifications to the thresholding eliminated most of the nuisance alarms (objects too small to be a gun, too oddly shaped, or too light). The effective contribution resulted in removal of approximately 30%-35% of the identified false positive threats. On the other hand, these modifications did not remove any confirmed gun threat detections.

B. Knife Algorithm

The knife algorithm was the main contributor to the overall false alarm rate. In general, knife detection algorithms are much more difficult to implement than gun detection algorithms. Nevertheless, analysis of the false alarms suggested several areas which could be addressed while maintaining the detection performance:

1) Area gradient analysis

The area gradient analysis determines the 'complexity' of a threat (how bumpy the surface is) and eliminates many camera/electronic hits, and other objects that are simply too noisy to be a knife.

Contribution: removed approximately 15%-20% of the false positives

2) Slope analysis

Another method implemented by Array included determining the 'smoothness' of the data perpendicular to the major axis of a blade. The change eliminates false positives such as pens and other long straight objects that have a sharp drop-off at the edge (unlike blades, which have a smooth, slower drop-off).

Contribution: removed approximately 12%-17% of the identified threats

Several other modifications were attempted but did not result in any further improvement to the false alarm rate.

C. Future Enhancements

The modifications made to X-Array bring the overall false alarm rate down below 40%, a significant improvement over the results from the field trial. However, further improvements are required in order to bring the results in line with the suggested performance outlined in the Transport Canada draft requirements document. There are three important areas where further performance enhancements can be made:

a) Statistical feature analysis such as graphing techniques
b) Edge detection
c) Handle detection

A subcontract has also been placed with Raman Paranjape to undertake a more fundamental study. His report is due at the end of February.

V. Conclusion

The trial results proved the effectiveness of X-Array in detection performance. Array was also able to collect over 3000 images with a high concentration of potential threat items. Based on Transport Canada guidelines, security personnel would have been expected to manually inspect approximately 50% of these bags[2] based on the specific threats identified by operators.

Regardless, the trial data provided an excellent database to allow Array to make improvements. Since the X-Array algorithms have already been highly refined during previous efforts, relatively minor changes have resulted in relatively significant improvements. A false alarm rate for both the gun and knife detectors of 35% was achieved without impacting the detection performance. Furthermore, the door remains open to additional improvements.

The modifications were made to the Windows NT version of the X-Array source code. The Windows NT version does not require the PPU. The port has therefore greatly enhanced reliability and significantly reduced recurring cost. The Windows NT version runs at very close to real time on a Pentium 133 MHz processor and should be capable of running at real time with a higher speed processor, such as the Pentium II. The results of these post trial improvements are available for demonstration on this platform using the files obtained during the trial. Several examples of the improvements have been included.

Finally, all of the trial results were conducted using the EG&G Linescan 110 X-ray machine. Array's X-Array performance was ultimately limited by its capabilities. A port to either the Heimann or the Vivid APS should of themselves provide a significant improvement which would further enhance performance.

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[2] The "normal" percentage of potential threat in carry-on bags is unknown, however TC suggest manual spot checks of at least 15% of bags.

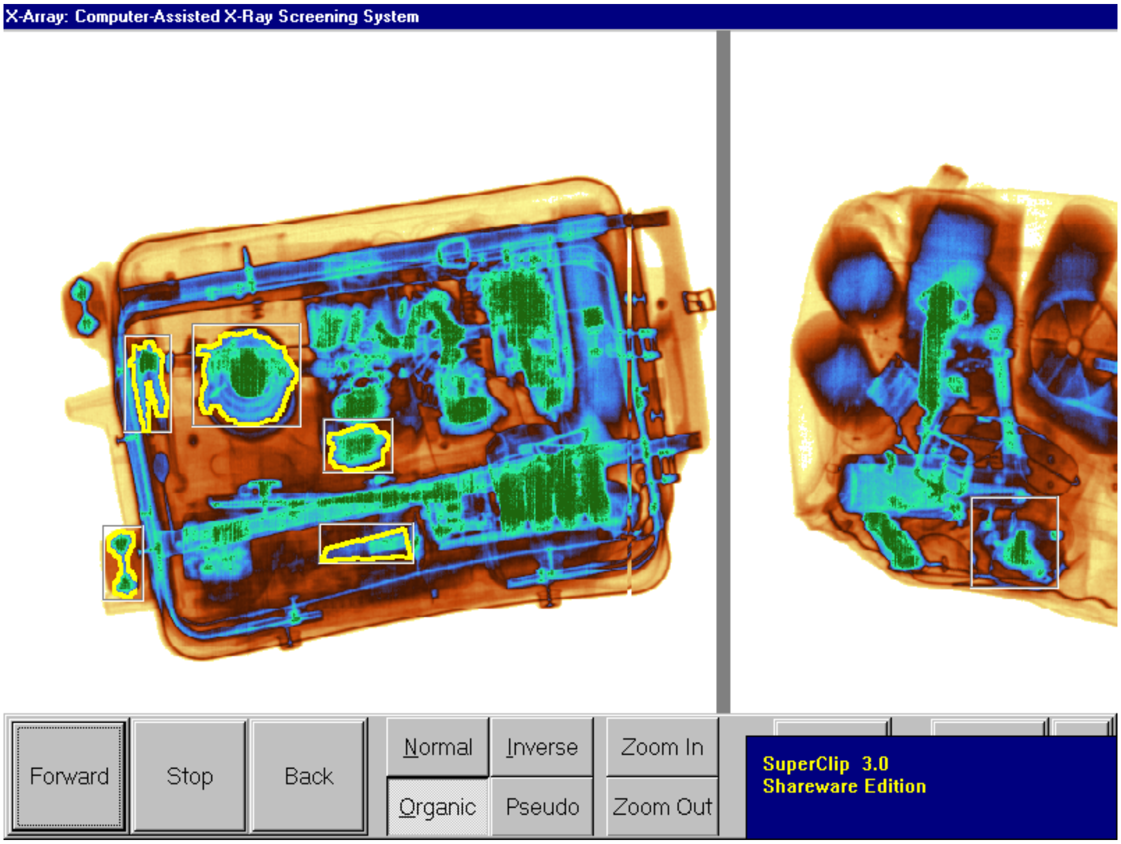

Figure A 1. Before

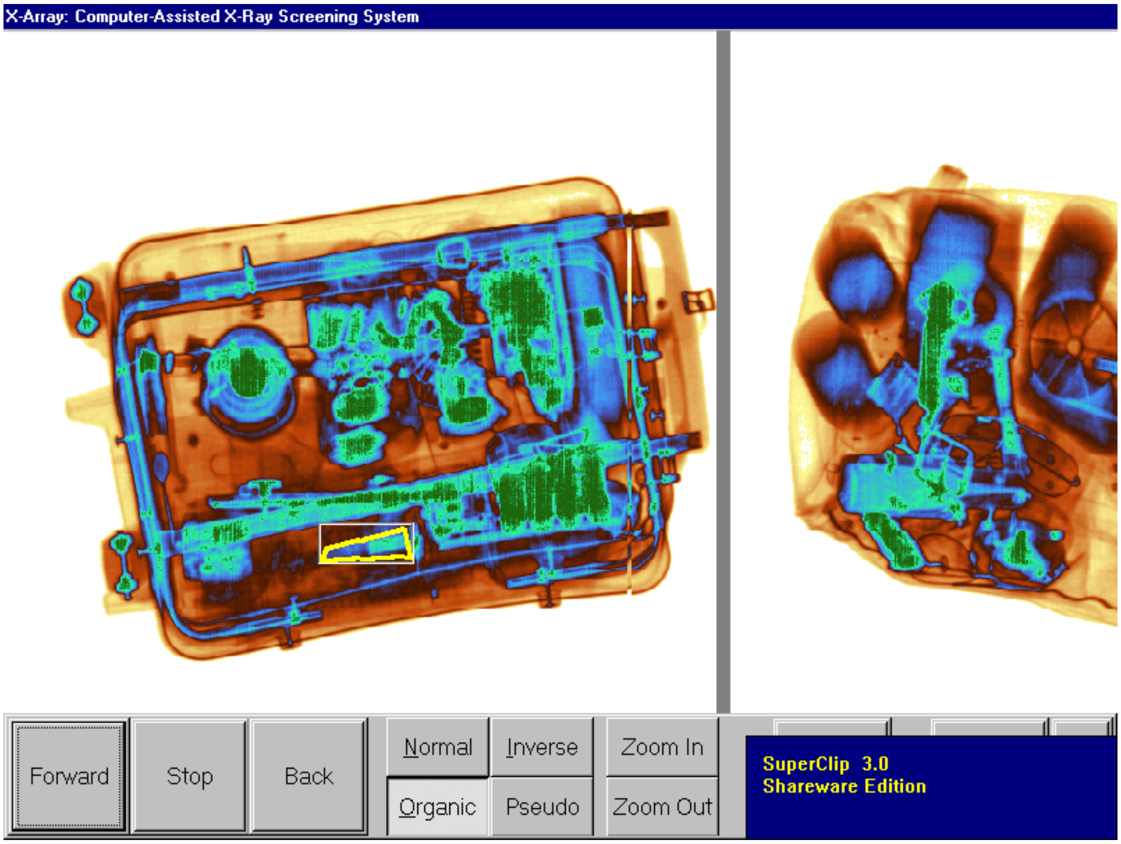

Figure A 2. After

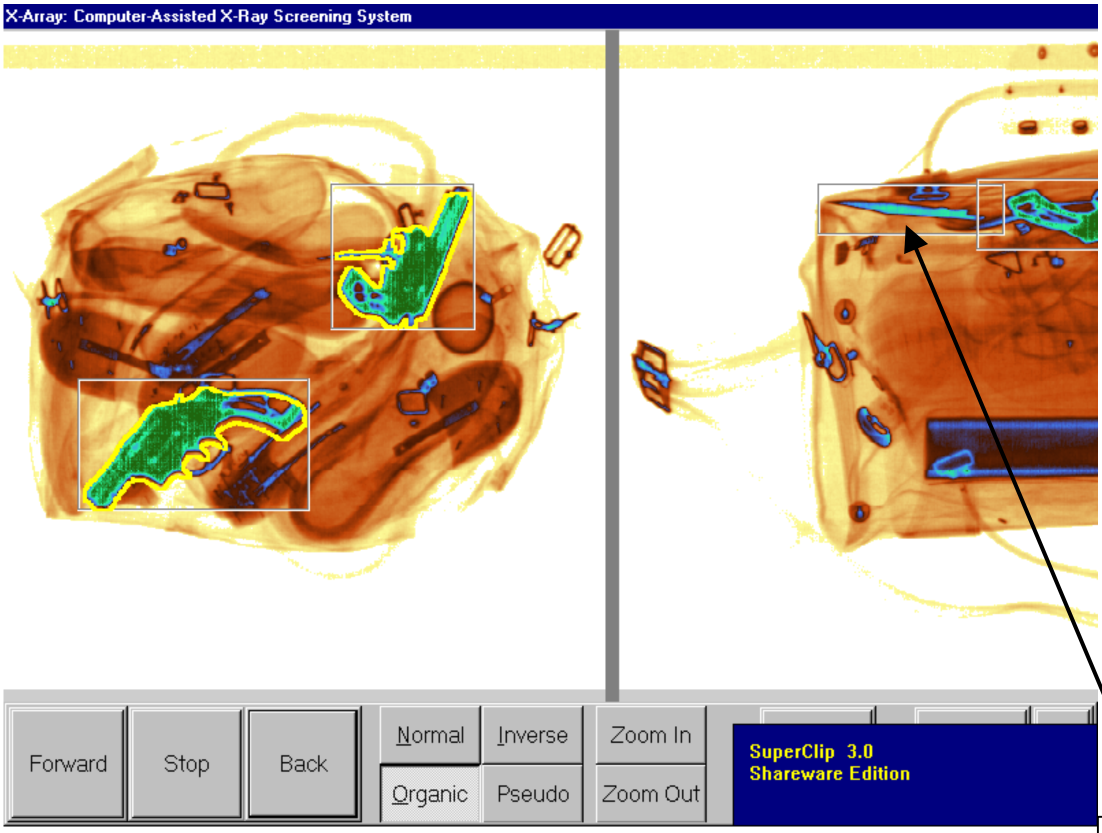

Figure A 3. Before

Actual Knife

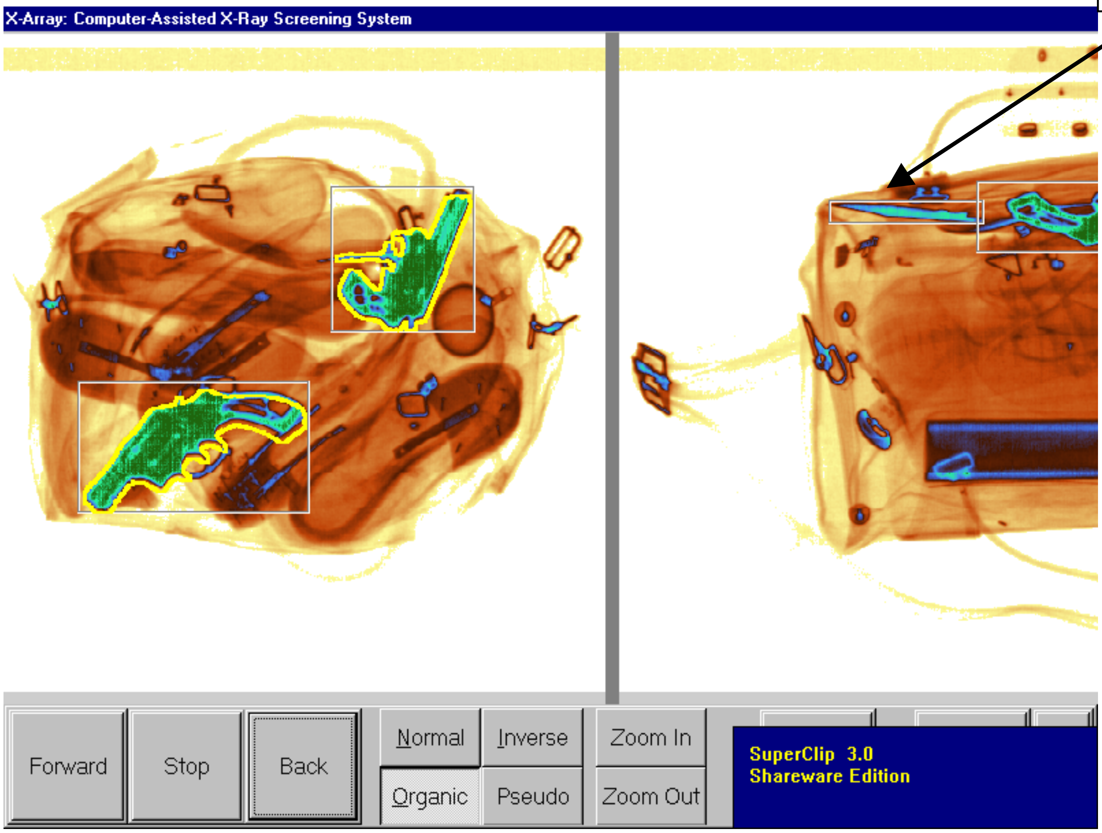

Figure A 4. After

Appendix B

A Review of the X-Array Knife Detector

by
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2 March, 1998

Executive Summary

The X-Array Vision System is a complex computer vision software system designed to analyze X-ray images from EG&G Astrophysics X-ray machines used to scan passenger carry-on baggage in Canadian and International Airports. This report focuses on a significant part of the X-Array – the knife detector.

The knife detector is one of two major classes of detectors in X-Array. Basic knife detector components are also used in the aerosol, electronics and clock face detectors of the X-Array. The knife detector is actually incorrectly named, as it is really only a flat blade detector and does not attempt to detect any part of the knife handle or finger guard.

Any computer vision system can be broken down into three different stages: segmentation, feature extraction and feature analysis. This report follows this basic morphology and further breaks down the structure of the knife detector into additional significant sub-stages within this morphology when appropriate. In addition, with in this morphology a section at the end identified gross limitation and avenues to improve and/or adjust the knife detector.

This report is based entirely on the recollection of the author and is subject to the limitations indicated.

Limitations

This report provides a review of the knife detector of the X-Array Vision System (X-Array). This review is based entirely on the personal recollection of Dr. Paranjape. It is produced without an examination of the original or current code in the X-Array. Dr. Paranjape's involvement with the X-Array project was as the Project Leader and Project Scientist order the period from October 1992 to July 1996. However, the bulk of the work in the project was performed between October 1992 and July 1994.

This report is a review of the principles and concepts behind the X-Array knife detector. No guarantee is explicitly or implicitly provided, however, that the current or previous versions of the X-Array implement these principles accurately and/or faithfully.

Introduction

Any computer vision system can be broken down into three different stages: segmentation, feature extraction and feature analysis. This report will follow this basic morphology and will further break down the structure of the knife detector into additional significant sub-stages as appropriate.

The knife detector is actually a flat blade detector. The knife detector does not detect, identify or analyze the handle or finger guard portions of the knife. The knife detector will not detect knives on end such that the handle and blade are self occluding. Knives in this orientation are difficult for the human observer to identify as the blade is not visible at all. The extent to which the knife detector recognizes knives on edge, is dependent on the amount of blade that is visible, and the extent to which this object can be seen as a flat blade. The knife detectors fundamental components do not adjust or used different procedures to detect knives on edge. The knife detector will not detect knives on edge when they appear as ice picks. The mechanism that is used to allow the knife detector to detect knives at some angle is through the training of neural networks.

Knife Detector Component Review

Segmentation

The knife detector has two possible methods of segmenting out regions of an image as candidate knives.

Light Blade/Dual Energy

The Light Blade/Dual Energy segmentation uses a threshold in the difference between the high energy image and the low energy image collected from the X-ray imager. Region growing is done by checking neighbors of included pixels and incorporating them if they meet threshold requirements. A relatively rapid and efficient method of region growing is used in this work. The segment area is labeled as a dark connected region (DCR) in the code.

Dense Blade

The knife detector can be set to detect only heavy hunting type blades. This segmentation uses only the high energy image and an absolute threshold gray level. The region growing algorithm is the same throughout the X-Array but is applied to different types of image data.

Both segmentation methods produce a set of DCRs in the image. These DCRs are analyzed in later parts on the knife detector. A set of DCRs are likely to be produced from most images and the knife detector will attempt to find blades within the segmented DCR. A DCR may contain parts of objects that are not part of the blade detection. This approach was used because knives typically are touching or are seen as overlapping with other same-density objects in the image.

Feature Extraction

The feature extraction is the largest part of the knife detector. A series of stages are executed in order to: first validate areas of the image and then identify key features in validated areas which may be used to perform feature analysis.

Dilate

Algorithm

First there is a double dilation of the image's segmented areas. This dilation is performed in order to ensure that the perimeter of the segmented objects are adequately smooth for the chain code extraction process which follows. That process requires that there be no single-pixel-thick crevasses or holes in the segmented object. Dilation is performed by dragging a 3x3 convolution kernel over the minimum bounding rectangle (MBR) . If there is a hit with the 3x3 convolution kernel at any point, the center pixel is set.

Limitations

There are no limitations on the actual dilation algorithm. However, use of object dilation results in a blurring of edge information which can result in a loss of specificity in the object recognition process. Thus, a very large compromise was made in order to save on the development of a complex chain code algorithm.

Chain Code

Algorithm

The chain code of an object describes the set of moves that are required to follow the perimeter of the object. The moves are quantified using directions as defined by a 3x3 direction matrix. Moves are identified, in up to eight different directions, from the current location in the center of the matrix.

The Chain code algorithm is a very tightly written algorithm. The basic idea behind this algorithm is to start in the upper right hand corner of the MBR and move to the left and down until the first pixel of the DCR is found. Once the first DCR pixel is found, then the next pixel is found by searching to the back and then clockwise up and around. Using this process, and moving forward as the next pixel of the perimeter is found, the DCR is navigated. Once the chain code tracing reaches the start pixel, the DCR chain code is thought to be identified and the DCR is removed from the image.

The chain code algorithm continues to move through the image until no pixels from segmentation remain. For each DCR of size greater than a thresholded, a chain code is produced.

Limitations

Accuracy of the chain code is dependent on the size of the object. Smaller objects are not well represented by the chain code because sampling rate is courser.

Chain Code Smoothing

Algorithm

The chain code that was previously found is then re-represented or converted into a set of 'straight' lines and a set of high curvature points. This is because a string of perimeter points and the direction are an ineffective way of coding or parameterizing the perimeter of the DCR. The chain code consists of a set of sharp discrete moves. These moves are smoothed out, to create a re-representation of the perimeter that more effectively captures the positions of high curvature and more importantly the positions of relatively straight edges.

The mechanism used to perform this smoothing is to travel over the perimeter using a moving average window function. The smoothing function is applied until a large discontinuity in the direction of the chain code is found and maintained. There are threshold values which define the size of the smoothing window and the amount of discontinuity which will cause a new moving average to be started. The basic idea is that the DCR can be represented by a finer direction (more than eight level) and in terms of longer relatively straight lines. The number of times that moving average window is drag around the perimeter is also a very important threshold which determines the amount of smoothing of minor edge discontinuities.

Limitation

In this work, some attention has to be given to the size and shape of the objects that are to be re-represented relative to the amount of noise and the size of the pixel. Too much smoothing will result in a representation which has lost many salient features, and too little smoothing will result in a representation of primarily the noise and minor discontinuities in the perimeter.

Algorithm is quite complex and is likely to have errors. There may be special cases which will not be correctly processed by the algorithm.

Convert Chain Code to Straight Lines

Algorithm

Once the smoothed chain code has been created it is further re-represented as straight lines. The mechanism used is to follow the perimeter and the smoothed chain code and group pixels which are in the same direction (with in a given tolerance) into the same line. An arbitrary tolerance level is used and this will be highly dependent on the size of the object. Large objects will have long straight lines associated with them while small objects will not. The actual value of the threshold is arbitrarily set and will have a big effect on the number of lines found. Another threshold has to do with the length of lines. Lines that are shorter than a particular threshold length are not considered. This length is again set empirically and changes may have a big impact of the algorithm. When a line is found, the average value of the angle of the line is also determined.

Limitations

This algorithm is highly dependent on the previous smoothing of the chain code. It will function very differently if the parameters and thresholds are changed.

Find Parallel Lines

Algorithm

Parallel lines are found by an analysis of the straight line representation of the object perimeter. A simple check is made to see if adjacent lines are in opposite directions. The angles of adjacent lines are compared to see if the average direction of the lines are opposite. A tolerance used on the direction of adjacent lines to identify lines that are opposite. This tolerance is arbitrary and changes in its value will impact the algorithm. If two lines are found to be opposite and parallel, a detailed feature extraction is applied in later sub-stages.

Limitations

The algorithm does not check lines that are not adjacent. This will mean that overlaps on the tip will cause the algorithm to fail. A wide blade or any complex patterning or poor segmentation may affect finding parallel lines. This is potentially a very serious limitation.

Find Tip Point

Algorithm

After the two parallel lines have been found, a tip point is found. The tip point is where the two lines meet, or if the two lines are close to each other at the mid-point between the two lines. If the two lines are far enough apart a search is done of the chain code and the perimeter to find the highest inflection point between the end points of the line. The inflection point on the smoothed chain code can be a good measure of the tip location.

Limitations

Issues with the approach used include a danger that a poor segmentation has been performed and the perimeter is not adequately captured by the chain code. Bounds checks and sanity checks on this would be very useful to ensure that an appropriate tip point is identified. The idea of using the middle point, when lines are close to each other may be a costly short coming. In later sub-stages, a detailed analysis is made of the tip. Shortcuts now may have large consequences later.

Find Blade Points

Algorithm

The tip point and the parallel line are analyzed to define control point for the blade and the tip. The blade and tip are define by five points. Only the tip is finalized until this module. The parallel lines are first extended to ensure that they go back as far as they should. The blade is then defined by extending the edge point out to the edge of the segmented area.

Limitations

The details of this algorithm are not very clear to the author. However, the danger that the incorrect area has been segmented is very great. There is no effort made to ensure that the correct segmentation has occurred by returning to the original input image. All blade control point refinement is done to a post-segmentation image. An arbitrary factor is used to define where to extend the edge of the blade. A blade feature based approach may be more useful.

Get Features

Algorithm

The following features are used in the knife detector. For the Blade: length, width (two points), average greylevel, greylevel variance, area, various ratios between area and dense pixels. For the tip triangle: length of sides, average greylevel, greylevel variance, upper half of tip pixel count, lower half of tip pixel count, various weighted averages of pixel values, ratios of number of pixels to bounding rectangle.

Limitations

A careful analysis has not been done of the features to confirm their value. These were the best of the available features but they may not represent the blade itself well. Segmentation is critical prior to this analysis. There is no explanation why the tip is split into two sections, other than is seems to be a useful indicator.

Feature Analysis

Bounds Check

Algorithm

A bounds check is done to ensure that the features identified are reasonable and within expected tolerances.

Limitations

Limitations are that sanity checks on the ranges themselves have not been done. The ranges were determined only from the available data set and with out a complete review of reasonable values.

Knife Neural Networks

Algorithm

The code for the knife neural networks was automatically generated using the Neuralware Professional II software. The network used is Error-Back Propagation Feed Forward Neural Network. Other networks have been used but no significant improvement in the detection rate was seen. It is expected that the neural network out performs a linear discriminant function by between 5% and 15% in terms of correct classifications. This was not experimentally verified but is extrapolated from the gun detector. Training of the NN was based on using 60-70% of the available data and testing with 30%. The training protocol used to enhance learning was, that after a fixed number of random cycles through the training data (approx. 50K), the miss-classified knives were duplicated in the training data set, reinforcing these feature combinations. Networks for light and dense knives were created.

The output of the NN was two real numbers with values between zero and one. These numbers express the computed probability that the object is a ‘knife’ and the probability that the object is a “non-knife”. The probability that the object is a ‘knife’ must be greater than the probability that it is a “non-knife”. The degree to which the ‘knife’ probability is greater than the ‘non-knife’ probability controls the color of the alarm generated by X-Array.

Limitations

The actual features used are almost certainly not optimal. They were arbitrarily selected. No handle of finger guard information is considered. The coefficient and weights of the NN can be examined to determine the key features for the decision. A conceptual understanding of those features will allow an update of the NN features so that all aspects of the knife are captured.

Conclusions

The knife detector computer vision system is divided by the author into three major activities or stages, segmentation, feature extraction and feature evaluation. Each one of these stages can be examined for modifications and changes which will have a more pronounced and global effect on the knife detector algorithm and performance.

Segmentation

The following recommendations are made with respect to knife segmentation. The knife blade is the trigger for the knife detector. The approach used was to allow the knife to be in contact with other dense objects so that knives do not need to be isolated from other objects to be detected. The limitation to this approach is that no effort was made to separate the complete knife from the background. It is suggested that this is one of the primary causes for the large number of false alarm. Some type of handle or knife base analysis will be useful so that the knife as a whole is segmented from the image. Analysis of the knife as a complete structure can then follow. This will lead to dramatic improvement in detection rates and a reduction in false alarms. A second and fundamental limitation on the segmentation is the use of arbitrary and fixed greylevel thresholds. The knife blade, unlike a dense gun, will appear to have different and varying densities depending on the orientation, angle and the degree of self occlusion of the blade. By using a more dynamic and adaptive thresholding model, in a second order segmentation, a more accurate and complete segmentation will be achieved. This approach will also definitely reduce false alarms and increase detection rates. All subsequent stages of the algorithm will benefit from this detailed analysis-based segmentation.

Feature Extraction

The feature extraction stage of the knife detector algorithm is the most detailed. In general, this stage attempts to capture the essential features of the knife blade such that they can be fed into an inference engine in order to classify the object. The key issue in the feature extraction is confirming that the features are correctly computed. The modules in the feature extraction take in any unpredictable and uncontrolled input from the segmentation stage. The feature extraction has not been aggressively tested to ensure that the feature extraction will function correctly for all inputs. A detailed testing and verification is needed in order to improve and confirm that the modules of this stage can tolerate and process the wide variety of input conditions.

Feature Evaluation

The Feature evaluation is currently limited to doing a bounds check on the extracted features and a neural net analysis of the features. One of the key indicators which will reduce false alarms will be some measure of the background structures that the potential knife object is in contact with. The metal supports in a briefcase are commonly mistaken as knives by the algorithm. It may be easy to determine that there is a briefcase in the image by identifying symmetries in metal supports, in testing for a handle, clasps or hinges. By including this information in the analysis, false alarms will be reduced. The fundamental approach would be to create a network of networks so that other non-candidate object information is considered in the evaluation process.

Appendix C

Operator Questionnaire

X-ARRAY Field Trial

We need to know you opinions about the X-ARRAY system. Please answer the following questions by circling the number that best indicates your response.

1. Did you find the X-ARRAY system easy to use?

Not easy 1 2 3 4 5 6 7 8 9 10 Very easy

2. What is your opinion of X-ARRAY image resolution?

Poor 1 2 3 4 5 6 7 8 9 10 Good

3. What is your opinion of the screen layout?

Cluttered 1 2 3 4 5 6 7 8 9 10 Very Clear

4. Do you think X-ARRAY can make your job easier?

No 1 2 3 4 5 6 7 8 9 10 Yes

5. Did you find the X-ARRAY slowed down your work?

No 1 2 3 4 5 6 7 8 9 10 Yes

6. Do you think the X-ARRAY can make you more effective in screening threats?

No 1 2 3 4 5 6 7 8 9 10 Yes

7. Did X-ARRAY cause you to carry out more, or fewer manual bag inspections (compared to existing systems)?

Fewer 1 2 3 4 5 6 7 8 9 10 More

8. Which features of the system did you find useful and to what degree?

	Not Useful									Very Useful
Zoom	1	2	3	4	5	6	7	8	9	10
Reset	1	2	3	4	5	6	7	8	9	10
Recall	1	2	3	4	5	6	7	8	9	10
Color	1	2	3	4	5	6	7	8	9	10
Invert	1	2	3	4	5	6	7	8	9	10
Contrast	1	2	3	4	5	6	7	8	9	10

9. How much time did you spend with X-ARRAY?

a) 10 - 20 hr.
b) 20 - 30 hr.
c) 30 - 40 hr.
d) More than 40 hr.

Appendix D

Purchased Hardware
and Deliverables

Purchased Hardware

The following items were purchased under this and previous X-Array contracts with Transport Canada. Pursuant to the completion of this phase of X-Array, these items are to be returned to Transport Canada.

Quantity	Description
2	IBM-Compatible PCs (with 486 processors)
2	IBM-Compatible PCs (Pentium 120 processors) including mouse, keyboard
1	14 inch monitor
1	17 inch touch-screen monitor
2	Transtech Parastation Pizza-Box style Parallel Processing Units with 3 i860 processors and upgraded RAM as per hardware specifications

Software Deliverables

Three key software packages make up the X-Array deliverables. These packages are the source and object code for the Windows 3.1 version, the source and object code for the Windows NT version, and the scanned bag image data collected during the field trial.

The two software components are installed and functional on one of the Pentium 120 computers listed in the previous section. The Windows 3.1 version is found in the CAXSS directory, and the Windows NT version is found in the CAXSSNT\CAXSS directory. No separation has been made between the source and object code. Both software packages are in a functional state, and represent the final versions of the software developed under this project.

Due to the large volume of information represented by the collection of scanned bag images, this data is not present on the system.. Instead, the images are provided in an archived format, on two Ditto 2GB tapes. The files have been grouped by day on the tapes, allowing for quick retrieval of specific scanned images.

As a backup, the source code of both the Windows NT and Windows 3.1 versions have also been placed on the Ditto tapes.

To restore data from the tapes, simply run the tape backup and retrieval program provided with the standard Ditto tape drive.