ALBERTA INFORMATICS CIRCLE OF RESEARCH EXCELLENCE

2005 Research Report

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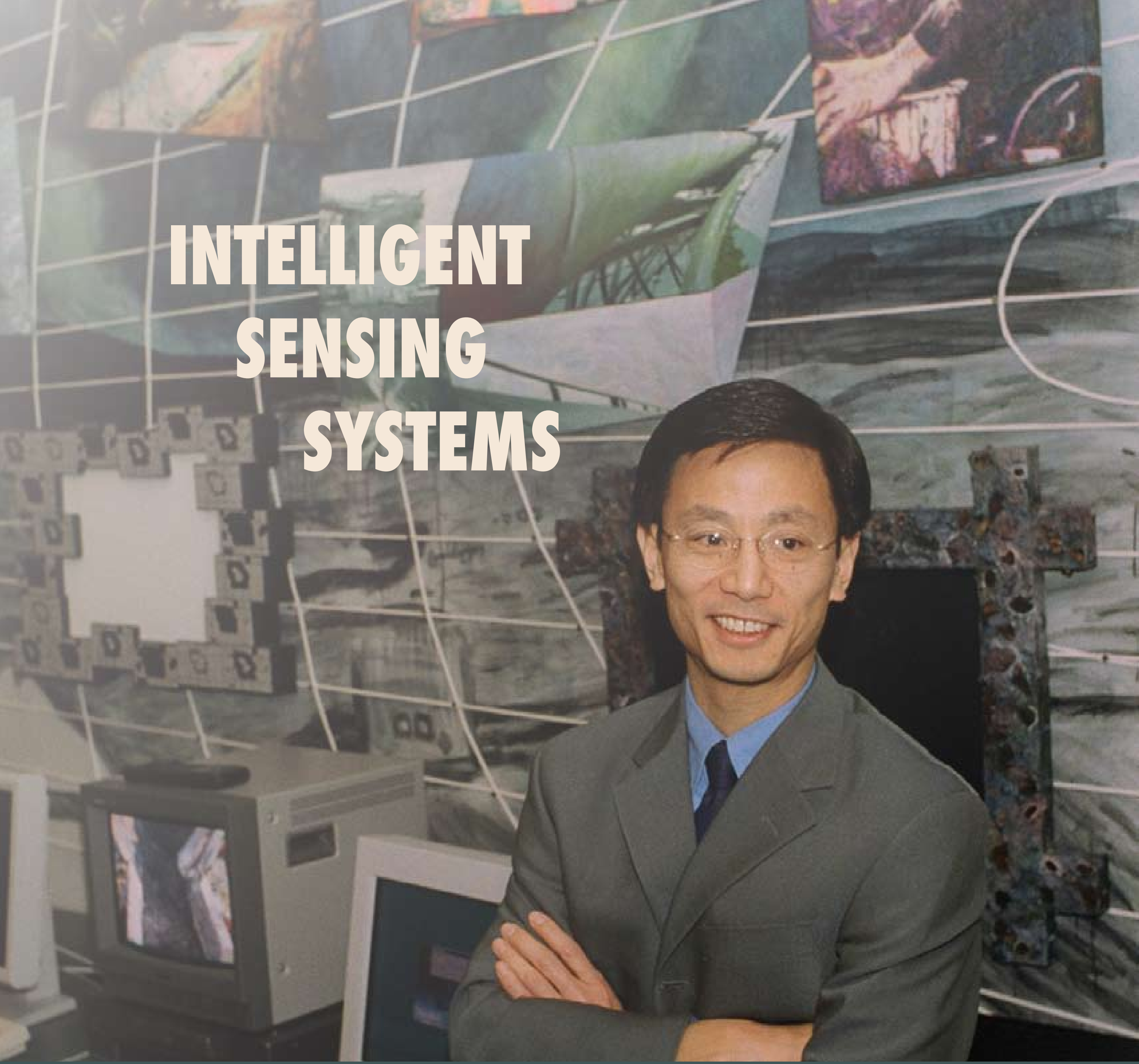
INTELLIGENT SENSING SYSTEMS



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This second annual report of the NSERC/iCORE Syncrude/Matrikon Industrial Research Chair research program will highlight the projects in fundamental research in intelligent sensing systems and the application of this research to the monitoring of oil sand mining operations, conducted in the Centre for Intelligent Mining Systems (CIMS) at the University of Alberta. The second year of the Chair's research has seen the assembly of the core research personnel and solid progress in several areas of importance.

EXECUTIVE SUMMARY

In the past year, we successfully recruited two research associates, one post-doctoral fellow, and three new graduate students, and graduated one MSc student. Our main basic research activities have focused on:

- A general framework based on wavelet analysis for oil sand image segmentation
- Adaptive image processing algorithms based on machine learning
- Adaptive color classification
- Steam detection
- Adaptive contrast enhancement

The main applied research activities in the past year have included:

- A fines model for oil sand particles
- Automated region of interest detection
- Rejects chute evaluation
- Modeling of comminution circuits
- The integration of CIMS ore size analysis system (Ore Size Analyst or OSA) with Matrikon's industrial software (ProcessMonitor), in preparation for its field trial

RESEARCH PROGRAM OVERVIEW

The long-term direction of the Chair's research program is to push the scientific envelope of information and communications technologies and apply these technologies to optimizing the performance of oil sands mining operations. We study sensor processing algorithms for monitoring the various stages of oil sands mining, where the research will lead to objective performance models of the mining components and the entire mining process. These performance models will enable the industry to improve the performance of its mining process by maximizing the throughput, while minimizing the rejects and the environmental impact.

A key performance indicator of the mining process is the size of the oil sand ore as it progresses through the ore sizing and delivery pipeline. On that basis, our research addresses two areas that are fundamental for objectively evaluating a mining process, focusing on ore size:

- Reliable sensor processing algorithms for ore size measurement under variable environmental conditions
- Statistical modeling of a system and its components with respect to their performance metrics.

In order to establish a comprehensive framework for the oil sand size analysis throughout the oil sand sizing process, we investigate the use of both gray-scale intensity images and range images, captured with stereo vision or laser range finder, as a more direct means of measuring oil sand size. We tune a multitude of image analysis techniques and algorithms that have proved their success in other domains, for our application. Our research is first developed in CIMS on scaled models of field equipment and streamed field sensory data (video or range), and then tested and fine-tuned at Syncrude's North Mine or Aurora Mine.

With respect to specific applications of the research developed within CIMS, in the early stage of research, after careful consultation with our industrial partner Syncrude, we have decided to focus our efforts on the particle size measurement of conveyed oil sand ore. An immediate benefit of the ability to measure the ore size on a conveyor belt is to allow Syncrude to effectively evaluate the efficiency of the screens that are deployed at several junctions in the oil sand sizing process to separate the large ore fragments from the small ones. Another benefit is to ensure that Syncrude will be able to objectively determine if their crushers do indeed reduce ore size according to their design specifications, and do not place unintended strains on the subsequent ore sizing and delivery operations.

RESEARCH PROJECTS

Adaptive Multi-scale Direct Contrast Enhancement

Analyzing oil-sand images is very challenging. Oil-sand ore comes in a variety of sizes, shapes, colors and textures and is most often mixed with dirt and fine particles. Varying lighting and weather conditions also play a significant role. The goal of this research is to improve the segmentation of oil-sand images through proper contrast enhancement as a necessary first step.

Our proposed contrast enhancement method is based on several assumptions. First of all, only a certain degree of enhancement is required, and both over enhancement and under enhancement are undesirable. To achieve this, we employ a contrast enhancement method that is direct, in which the amount of enhancement is controlled based on a contrast measure. Secondly, objects of different sizes in an image are best enhanced on their corresponding scales. To develop an algorithm capable of this, our proposed method is multi-scale in which the scale of enhancement is selected based on expected object size. Finally, since objects in different local areas are of different sizes, each local area requires a different degree of enhancement. Our method is spatially adaptive in which different local regions are enhanced differently.

Hong Zhang

Image Segmentation by Adaptive Thresholding and Gradient Watershed

Many images consist of distinctive regions with different characteristics. The segmentation of such images, therefore, calls for separate algorithms applied to different regions. Typical oil sand images contain coarse pieces and fine particles. The coarse pieces within the Region of Interest (ROI) are characterized by being relatively bright, while the fine particles between the coarse pieces collectively look like a texture. Each must be treated using different segmentation techniques.

Based on the different characteristics between the coarse fragments and fine particles, we have proposed a two-stage image segmentation method combining gradient watershed transform and adaptive thresholding. Since watershed segmentation is time-consuming and does not meet the real-time needs, we employ an image-retrieval-like approach to accelerate the size measurement of the fine particles.

To define a signature for the implementation of the image-retrieval-like solution, we employ wavelet analysis, which provides a multi-resolution and orientation representation of an image via subbands, consistent with the human visual system. Due to this characteristic of wavelet analysis, it has been used as an efficient tool for texture analysis. Various methods of wavelet-based texture characterization have been proposed, based on the statistical properties of intra-band. There are three typical wavelet texture signatures: Extended Energy (EE) signature, Generalized Gaussian Density (GGD) signature and Co-occurrence signature. Based on the ore fragmentation process, we propose in this paper a new wavelet signature: the Weibull signature. The experimental results show that the Weibull wavelet signature provides better performance than the existing wavelet signatures.

Optimization of Image Processing Parameters

In this project, we are interested in being able to determine the optimal parameter setting of an image processing algorithm, for a given image. In general, the performance of image processing algorithms is sensitive to parameter values such as thresholds and window size. A desired solution is to select image processing parameter values automatically on a per image basis.

To that end, we explore a solution based on an existing image interpretation system (MR ADORE). Our solution demonstrates a great potential of applying machine learning techniques to the ore size measurement domain. Experimental results show that the adaptive system outperforms its counterpart in which a constant set of parameter values are used independently of the images being processed.

We focus on the problem of oil sand image segmentation as a first step toward an adaptive parameter selection algorithm that can be applied to any image processing systems, which experience the problem of parameter selection. As our solution approach, we adopt MR ADORE as a machine-learning framework, supporting it with a new scoring metric, a set of feature extraction techniques, and a given sequence of image processing operators. We make use of a domain-independent approach in which a control policy over the space of vision operators is machine learned, and this represents an innovative application of Artificial Intelligence technology, which is supported with the empirical evaluation. Most importantly, the system is adaptable to other image processing applications.

Ore Size Analysis of Moving Oil Sand Particles

In this project, we develop a novel approach to estimate the 2D shapes of moving rejects, which combines adaptive Gaussian mixture model and optical flow methods in order to achieve robust and accurate extraction of moving objects in a static background. This image processing algorithm is useful for evaluating the efficiency of the screen at the rejects chute where particles unable to pass the screen holes are rejected. The algorithm works well for image sequences with many moving objects of different sizes. Extensive experimental results have been obtained on real image sequences to demonstrate the feasibility and the efficiency of the proposed technique.

Many approaches of segmentation of moving objects in image sequence have been proposed in the literature. They can be classified into temporal differencing, background subtraction and optical flow.

Our analysis of the three common segmentation methods reveals that temporal differencing is good at providing initial coarse motion areas. Background subtraction can provide the most complete feature data. Optical flow technique has an advantage at detecting movement or the velocities of objects from an image sequences. Our approach of using a combination of the data from these three different methods produces better results than any one of the three alone.

Some of Hong Zhang's research group on a visit to the Fort McMurray oil sand mine

Image Processing Algorithms for Steam Detection and Removal

Due to the use of hot water in the oil extraction process and because of the lower temperatures registered during most of the year in the mining sites in northern Alberta, presence of steam is an unavoidable factor which may affect considerably the performance of video image processing algorithms applied to computing the ore size distribution. In this context, detection and quantification of areas covered by steam is a very important task which can be used to determine if a video frame should be considered for analysis.

In this project, we attempt to develop a real-time image processing technique for detection of steam in oil sand video images. The problem of detecting steam in an oil sand video stream is treated as a supervised pattern recognition problem. We use a wavelet-based steam signature, especially designed for the purpose of characterization of the steam texture, as an input to a Support Vector Machine technique. By detecting and providing the total area covered by steam in a video frame, a computerized image processing system can automatically decide if the frame can be used for further analysis. The proposed method has been quantitatively evaluated by using a labeled image dataset sampled from real video frames.

Adaptive Color Classification

Color has been used in many computer vision applications, such as image segmentation, object tracking and recognition. The appearance of an image is affected by illumination so color-based vision applications have often faced the problem of colors being sensitive to illumination variation. A static color model can not handle illumination variation and so an adaptive color model was introduced to deal with dynamic illumination.

This project is motivated by the need for color classification in many practical applications. We developed an adaptive color classification algorithm that uses a two component Gaussian Mixture Model (GMM) to model a color distribution in YUV color space. The components of this model represent the diffuse and the specular parts of the dichromatic reflectance model. The GMM is derived from classified color pixels using the standard Expectation-Maximization (EM) algorithm, and the color model is repeatedly updated with the derived GMM. We propose the novel idea that a GMM with two Gaussian components is an accurate and complete representation of the color distribution of a dichromatic surface. This work is of practical significance because our adaptive system provides accurate color classification under variant lighting conditions and it outperforms the previous color vision system without adversely affecting efficiency.

OSA Integration with ProcessMonitor and ProcessNet

OSA calculates the size distribution of the ore fragments in each image it receives. The size data by itself is of limited value; however, useful information can be derived when size is combined with other process data. In this project, OSA has been integrated with Matrikon's software platforms to turn ore size data into practical information. A prototype has been built which combines the size distribution of ore fragments calculated by OSA with feed-rate data recorded in Syncrude's historian to automatically monitor the performance of sieving screens. At present, Syncrude does not have a way to continuously monitor the screen efficiency, and therefore no way to optimize the use of these screens.

Our OSA-based screen efficiency prototype is at present running in the CIMS lab. A camera at the Fort McMurray mine site streams live video through a fiber network to the CIMS lab in Edmonton. An image acquisition card in a standard PC computer grabs images from the video feed. These sampled images are presented to the OSA in which fast image processing algorithms are employed to segment the image and calculate size distribution statistics. The OSA process is extremely fast and can sample and segment the images at a rate of over three images per second on a standard PC (1.8 GHz Intel processor). Matrikon's ProcessMonitor software reads size data from OSA, as well as the feed rate data through the Internet from Syncrude's PI historian. The data is checked for validity, and screen efficiency is calculated. The results generated in ProcessMonitor are passed on to a ProcessNet server. ProcessNet organizes the information derived by ProcessMonitor into tables, graphs, and trend charts, along with images to produce and serve various web pages that contain information relevant to Syncrude.

Modeling of Comminution Circuits (Crushers and Screens)

Comminution circuits are used in mining to reduce dimensionally large raw ore to a size that can be used as a product. This is done mainly through the use of crushers, screens, conveyor belts, and ore bins. To ensure that the circuit is operating at its highest efficiency, simulation and optimization are essential. Through surveying and modeling of the circuit components, simulations can be validated and optimization procedures can be run so as to increase efficiency. With the increase in comminution circuit efficiency, energy and cost savings can be obtained or increased plant product output can be achieved to increase revenue. This research looks at the process of plant surveying and system modeling with a review of simulation and optimization methods which might be applicable to modeling the crushers and screens that are widely used in sizing oil sand ore.

OBJECTIVES FOR NEXT YEAR

We will maintain the momentum that has been obtained in the first year and a half of the Chair's research program and continue to strike a balance between basic research in information and communications technology and the applications of such research to oil sand mining. With respect to basic research, we will invest time and effort in formulating image segmentation algorithms that make use of multiple cues and spatial constraints in theoretically rigorous frameworks. In addition, we will expand our research in applying existing machine learning techniques to the optimization of image processing algorithms. With respect to the applications of our research, in addition to our development of ore size algorithms for conveyor belt and rejects chute, we will revisit the problem of large lump detection, which is known to cause production stoppage due to the jamming of crushers in winter seasons. To realize the practical value of our research, we will work with our industrial partners in an attempt to provide operation support to the mine operators by delivering objective performance measures.

Our approach to ore size analysis has been to interpret it as one of image segmentation. Existing segmentation algorithms mostly depend on a single cue, edge, intensity, or texture, for example. However, these systems are fragile because rarely is a single cue sufficiently characteristic to extract the exact shapes of complete ore fragments, and this leads to inaccuracies and at times failures of the algorithms. In the coming year, we will explore a different approach in which multiple cues are combined to label the pixels of an image for the segmentation of ore fragments. Our approach will be built on a Bayesian framework, with each cue contributing to the segmentation decision in terms of a probability of a pixel belonging to an ore fragment. In addition, we will apply the Markov Random Field (MRF) theory to impose spatial and temporal constraints in the interpretation of an image so that neighboring pixels are segmented jointly, possibly over a video sequence when applicable.

Another area of considerable interest to our research is the use of machine learning techniques for sensory data processing algorithms. Advances have been made in the field of machine learning in the past few years. In addition, there exists considerable strength at the University of Alberta in the area. We will take advantage of this strength in three different ways. First, we will continue our research in adaptively selecting image processing parameters with respect to a given image. Secondly, we will develop image processing algorithms that benefit from human image interpretation skills. Finally, we will develop techniques by which past experiences — both successes and failures — in image interpretation can direct how new similar images should be processed.

Crushers are used to reduce ore size and, due to the cold winter in Northern Alberta, crushers are jammed often as the result of large frozen lumps, interrupting the production pileline. Therefore, there is a pressing need to develop a technique to detect the presence of large lumps in the feed going into a crusher so that the crusher operator can be warned and take action to reduce the possibility of jamming. We have developed such a software based on analyzing a static image while ignoring the rich information present in a video sequence as a large lump travels through the conveying system. This new dimension of information will be utilized to improve the reliability of the large lump detection software.

RESEARCH TEAM MEMBERS AND CONTRIBUTIONS

NAME	ROLE/TOPIC
Dr Hong Zhang	CIMS director/Chair holder
Dr Ron Kube	CIMS co-director/industrial partner from Syncrude
Dr Mark Polak	Lab Manager/industrial partner from Matrikon
Dr Martin Jagersand	Faculty member
Dr Dongxiang Zhou	Post-doctoral fellow
Dr Minghong Pi	Research associate
Dr Ricardo Ferrari	Research associate
Ilya Levner	PhD candidate
Xiang Wang	PhD candidate
John Sheldon	MSc candidate
Xiaoli Wang	MSc candidate
Andrzej Zadorozny	MSc candidate
Xiaohu Lu	MSc candidate
David Laing	Undergraduate student
Yury Potapovich	Undergraduate student/IIP student with Syncrude
Lizhen Wang	Visiting professor
Melanie Calvert	Administrative Assistant

FUNDING

Hong Zhang received ~$200K this year from NSERC to combine with his iCORE Industrial Chair ($150K) funding. He also recieves yearly funding from his industrial partners Syncrude ($100K) and Matrikon ($50K).

PUBLICATIONS

REFEREED JOURNAL PUBLICATIONS

"A Multistage Adaptive Thresholding Method", Feixiang Yan, Hong Zhang and C. Ronald Kube, *Pattern Recognition Letters,* Volume 26, Issue 8, June, 2005, pp. 1183-1191.

"Collective Robotic Site Preparation", Chris Parker and Hong Zhang, to appear in Adaptive Behavior.

REFEREED CONFERENCE PROCEEDINGS

"Toward Versatility of Multi-Robot Systems", Colin Cherry and Hong Zhang *3rd International NRL Workshop on Multi-Robot Systems*, March 14-16, 2005 Washington, D.C.

Collective Decision Making: A Biologically Inspired Approach to Making Up All of Your Minds", Chris Parker and Hong Zhang, in *Proc. of 2004 IEEE International Conference on Robotics and Biomimetics*, China, August 22-26, 2004.

"Biologically Inspired Decision Making for Collective Robotic Systems", Chris Parker and Hong Zhang, *Proc. 2004 IEEE International Conference on Intelligent Robots and Systems*, Sendai, Japan, September 28-October 2, 2004.

"Collective Sorting with Local Communication", Sean Verret, Hong Zhang, and Max Q.-H. Meng, *Proc. 2004 IEEE International Conference on Intelligent Robots and Systems*, Sendai, Japan, September 28-October 2, 2004.

"Characterization of Acuity Laser Rangefinder", Xiujuan Luo and Hong Zhang, *Eighth International Conference on Control, Automation, Robotics and Vision* (ICARCV 2004), December 6-9, 2004, Kunming, China.