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Optical Container Code Recognition and its Impact on the Maritime Supply Chain

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Abstract

Container terminal operators worldwide have expressed the need for accurate real-time accounting of the incoming, outgoing and existing inventory. Container Optical Code Recognition (OCR) provides systems which can be integrated with RFID tags in order to give more accurate information to Maritime Supply Chain Management. The implementation of OCR systems for feasible identification and tracking of containers offers value added benefits. Container terminals utilizing OCR technology enjoy more efficient use of labor, yard space, and handling equipment while realizing improved productivity and profitability. This paper explains the development of the next generation of OCR systems using global image processing, hierarchical representations, probabilistic object tracking, color model transformation, statistical classifiers, neural networks, support vector machines, and Hidden Markov Models (HMM). Their fusion with RFID technology and the utilization of the recent wireless technologies integrated with iPADs allow for the deployment of very sophisticated but still cost effective systems.

Keywords
Container Optical Character Recognition, Supply Chain, Artificial Intelligence, Ports

1. Introduction

The maritime seaborne trade is directly influenced by the international economic performance, which is also affected by extraordinary events such as natural disasters, political conflicts and the volatility of energy and commodity prices among other factors. Proof of this is the financial crisis of 2009, where world seaborne trade experienced the same "V shape" behavior that the world merchandise trade, World Gross Domestic Product (GDP) and the Organization for Economic Cooperation and Development (OECD) Industrial Production Index experienced in the period from 2005 to 2011 (Figure 1) [1].

Container terminals face the challenge of adapting to the behavior of this globalized economy. Adaptation is very important in order to provide the capability to participate in the world seaborne trade in competitive ways. One approach in which container terminals have been able to achieve this flexibility has been through the insertion of container Optical Character Recognition (OCR) and automation systems that are capable of introducing greater profitability, improve quality and safety in operations, and bring in the ability for optimizing the workforce, supply chain, and financial resources in container handling operations [2]. In turn, these systems give port operators greater visibility into their processes and generate reliable information and added value services, counteracting the effects of delays in vessels turnaround time such as bottlenecks in the transfer pathways within the terminal and other issues related to integration of their activities with all the actors involved in the container supply chain.

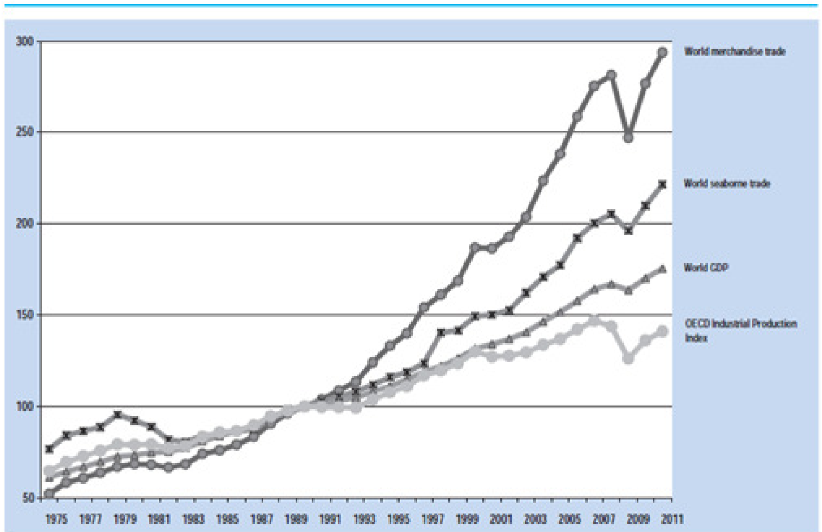

Figure 1: Review of Maritime Transport [3] – It is important to observe the correlations between World GDP and World seaborne trade

This paper explains the development of the next generation of OCR systems using global image processing, hierarchical representations, probabilistic object tracking, color model transformation, statistical classifiers, neural networks, support vector machines, and Hidden Markov Models (HMM). Their fusion with RFID technology and the utilization of the recent wireless technologies integrated with mobile devices present great advantages to port and container operations.

The remainder of this paper is organized as follows. The definition and description of a port and its processes are given in section 2. The description of technologies and their utilization is presented in section 3. The integration of OCR with RFID is described in section 4. The conclusions are given in section 5.

2. What is a Port?

A port is a geographic area that serves as a land and sea interface and where it is convenient to anchor ships. Ports are classified according to their type of ownership, administration, and operation responsibilities as landlord ports, tool ports and service ports, emphasizing that greater level of productivity in port operations can be reached with more participation of the private sector as operator. A port is a set of complex entities supporting the procurement of raw materials, manufacturing and distribution of finished goods and potential members of different supply chains. A port builds its efficiency and effectiveness levels on the availability of appropriate infrastructure, inland connections and the ability of logistics and transport operators to accomplish qualitative attributes of demand (i.e., reliability, punctuality, frequency, information availability, and security).

Several studies using process modeling have demonstrated and concluded that transparency of data flow along the maritime value chain is a relevant factor for terminal operation. Not only within the container terminal to optimize processes but to create an optimized value chain between port authorities, customs, shipping agency, and the terminal.

A port may encompass one or more terminals dedicated to handle different types of cargo that may include containers, break bulk, liquid bulk or general cargo, among others. A container terminal is characterized for having three main physical areas which are the quayside where containerships moor to discharge and/or load containers, the container storage yard that serves as a buffer area to store containers waiting to be picked up by Tractor Trailer Units (TTU) or other horizontal means of transport, and the landside area where containers get in and out of the terminal and complete their administrative and customs duties.

Coordinated tasks in a container terminal are developed to maximize the integration and facilitate the use of physical facilities mentioned in the above paragraph. These tasks utilize specialized equipment, technology, and human resources. This integration allows for a smooth container flow from the time the container arrives to the terminal until it is withdrawn by the consignee. An additional element to ensure efficient container traffic within the terminal is to through a synchronized information flow, hence, to make sure the right information is delivered at the right time to those involved in the planning and operation of the container logistics. OCR and RFID technologies are very important to support the required information flow that coordinates the different tasks and processes.

Figure 2 shows how the flow of information must be embedded with the container terminal operation to reach a smooth traffic flow:

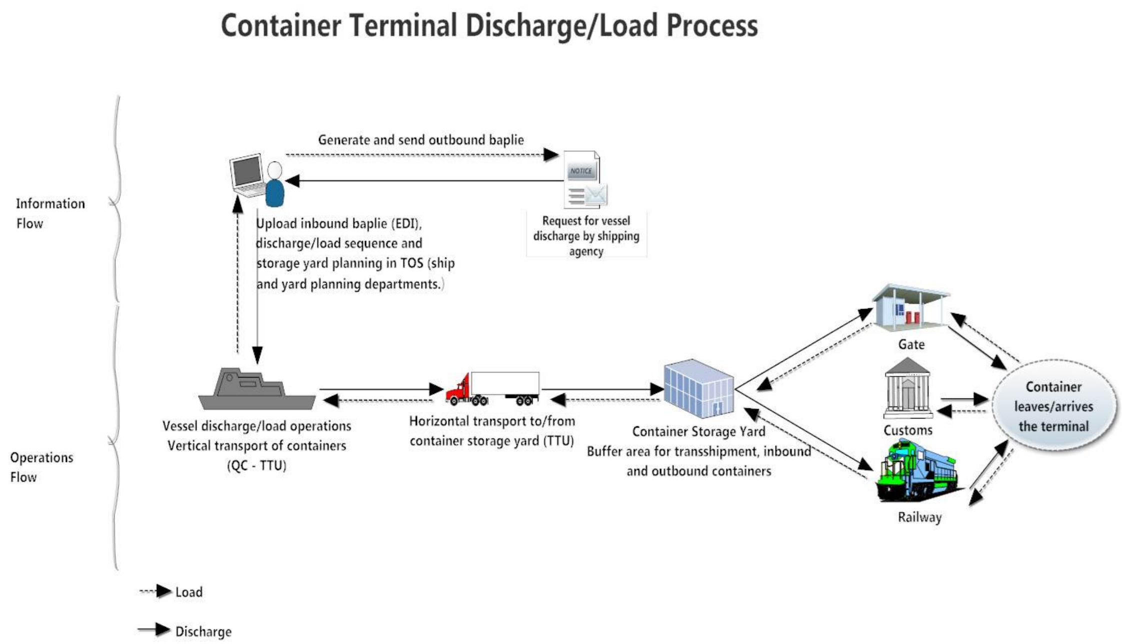

Figure 2: Schematic representation of the flow of operations and information in the discharge and load process of containers

Container terminal characteristics are very similar. However, the planning and operational processes that take place in the container logistics for each terminal are very different. Container logistics are determined by the geographic and economic characteristics where the container terminals are placed [4,5]. Different terminals around the world have variations in size and demand. These variations in size and demand cause differences in their activities. Hence, not all the terminals use the same operational systems for the processes of loading and the discharge of containers [6,7].

The following are examples of how economic and geographic characteristics may influence container terminal activities and operations systems:

- **Storage Yard Layout:** Configuration of the container storage yard is directly affected by the container supply chain. For container terminals that receive a high percentage of transshipment containers, operations at the quayside, container storage yard and the transfer zone between them (transfer pathways) will be of primary interest of analysis. Optimization will have an objective function emphasizing congestion avoidance. This emphasis must produce reduced vessel turnaround times, improved productivity, and provide higher levels of effectiveness in their operations. Figure 3 presents a transshipment container terminal typical layout. OCR and RFID can be integrated in different processes in order to contribute to this optimization. We have been mapping ports such as Balboa in the Republic of Panama (Pacific entrance to the Panama Canal). This container terminal is recognized as a world-class hub. Balboa ranks in the top fifty busiest container terminals in the world with over 3.0 million twenty-foot equivalent units (TEU) containers. Balboa is the busiest container terminal in Latin America followed by Santos, Brazil. Balboa handles around 85% of the transshipment containers for the region in an efficient way. Transshipments are very common in this container terminal which can benefit from the integration of OCR and RFID.

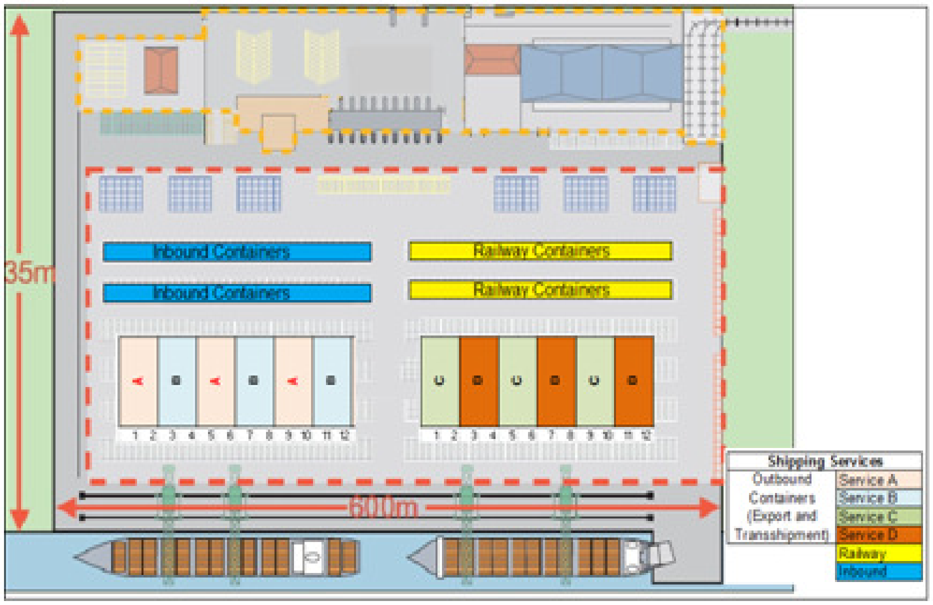

Figure 3: Storage Yard Layout for a transshipment container terminal. Higher detail in stacking criteria and configuration of storage blocks [8]

- **Operations Systems:** The choice of operation systems and the approach for the respective integration of container handling equipment for horizontal and vertical transportation of the container to be used within the terminal will depend on geographic, economic, environmental, and demand aspects, among others. For example, Balboa uses rubber tired gantry cranes (RTGCs) with TTUs as their operation system for the transport of containers from the storage yard to the quayside and landside area. This operation system allows greater storage capacity and represents lower operating costs in countries where labor is cheaper. On the other hand this system requires more skilled equipment operators (for RTGCs or TTUs) (Figure 4). RTGCs and TTUs can be equipped with OCR systems.

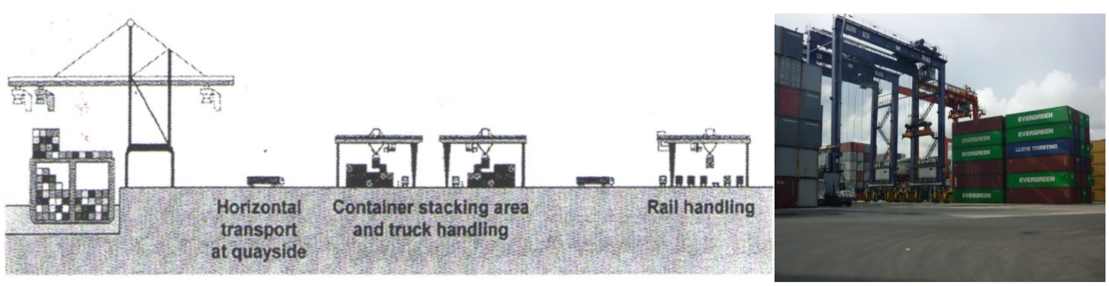

Figure 4: Operation system of Container Terminal: RTGs and TTUs

On the other hand, the Burchardkai Terminal located in the port of Hamburg uses automated guided vehicles (AGVs) to transport containers within the terminal. In this terminal, TTUs are replaced by automated shuttle carriers to stack and horizontal transport of containers. The return on investment in automated vehicles for these operational tasks is very high due to higher labor costs in Germany. RFID is a very dominant technology in these automated shuttle carrier systems.

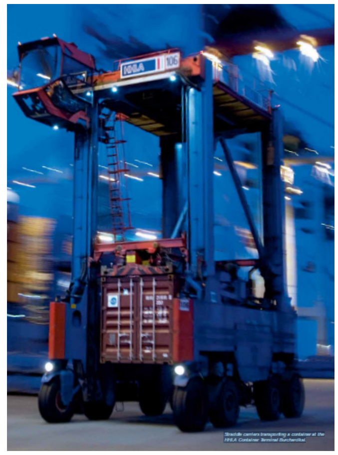

Figure 5: Automated Shuttle Carrier transporting a container [7]

Therefore, process modeling of the operations is very important. It is also essential to model the information flows. Modeling of traffic as well as the characterizations of the infrastructure and superstructure must be performed in order to establish the opportunities and design for OCR and RFID systems in a container terminal. The implementation of container OCR systems for feasible identification and tracking of containers offers value added benefits and makes possible to achieve integration between the information and operations flow in an optimized way.

3. Description of Technologies for Advanced Container OCR

The development of advanced container OCR systems is a field where Artificial Intelligence (AI), new technologies such as wireless communications, and traditional image processing can be merged. AI in particular can help achieving higher levels of reliability.

Digital image and video processing remains a challenging domain for several reasons. First the issue of digital image processing appeared relatively late in computer history. It had to wait for the arrival of the first graphical operating systems to become a true matter. Secondly, digital image processing is a computationally intensive problem and hence it requires the most careful optimizations and especially for real time applications [9].

Video tracking or analytics systems usually employ a motion model which describes how the image of the target might change for different possible motions of the object to track. There are two major components of a visual tracking system, target representation and localization (mostly a bottom up process and computationally low complex) and filtering and data association (mostly top- down and computationally intensive). The later one involves incorporating prior information about the scene or object, dealing with object dynamics, and evaluation of different hypotheses. The main difficulty in video tracking is to associate target locations in consecutive video frames, especially when the objects are moving fast relative to the frame rate [10,11].

For a given input image, if we perform image processing, image analysis and image understanding then respectively we will get an image out, measurement out and high level description out. Container Optical Code Recognition (OCR), automatic License Plate Recognition (LPR) and similar video analytics problems belong to the image or video understanding domain. There are three important steps that the software requires for identifying the characters in the Region of Interest (ROI) on a container or characters in the ROI on a License Plate (LP) [12,13]:

- **Step 1: Localization of ROI**

  This is responsible for finding and isolating the region or plate on the picture. These could be achieved through one or few of the following methods.

  (i) Binary image processing
  (ii) Gray level processing: This could be achieved by one or few of the following techniques
    - Global image processing

- Partial image analysis
- Statistical measurement
- Hierarchical representation
- Region segmentation
- Probabilistic object tracking in video
- Image transformations

(iii) Color processing

- Color model transformation
- Fuzzy set theory
- Histogram processing
- Classifiers

(iv) Classifiers

- Statistical classifiers
- Computational intelligence

- **Step 2: Character segmentation**

  The following methods are used to find the individual characters on the container or LP.

  (i) Binary image Processing

  - Projections and binary algorithms
  - Mathematical morphology
  - Contours

  (ii) Grey Level processing

  - Histogram processing
  - Local/adaptive thresholding and transformations
  - Classifiers e.g. Hidden Markov Model (HMM)

- **Step 3: Optical character recognition**

  This process identifies each character in the ROI on container. We must give much importance for the syntactical or geometrical analysis and positions against country specific rules. Therefore, we have to integrate Rule-based systems with classifiers such as:

  (i) Classifiers

  - Statistical /hybrid classifiers
  - Artificial Neural Networks (ANN)
  - Support Vector Machines (SVM)
  - Classification Trees

  (ii) Pattern/Template matching

3.1 License plate recognition (LPR)

The most advanced video analytics algorithms and tools recognize numbers on the vehicle/container license plate as text. This could be compared with a local or centralized database for accurate real-time accounting of the incoming, outgoing and existing vehicles, traffic violations, toll gate collections, and efficient management of parking. Figure 6 and section 3.3 describe the implementation.

3.2 Container optical code recognition:

Container terminal operators worldwide have expressed the need for accurate real-time accounting of the incoming, outgoing and existing inventory. The implementation of OCR systems for feasible identification and tracking of containers offers value added benefits viz., efficient use of labor, yard space, and handling equipment. Container terminals utilizing OCR technology will enjoy more efficient use of labor, yard space, and handling equipment while realizing improved productivity and profitability.

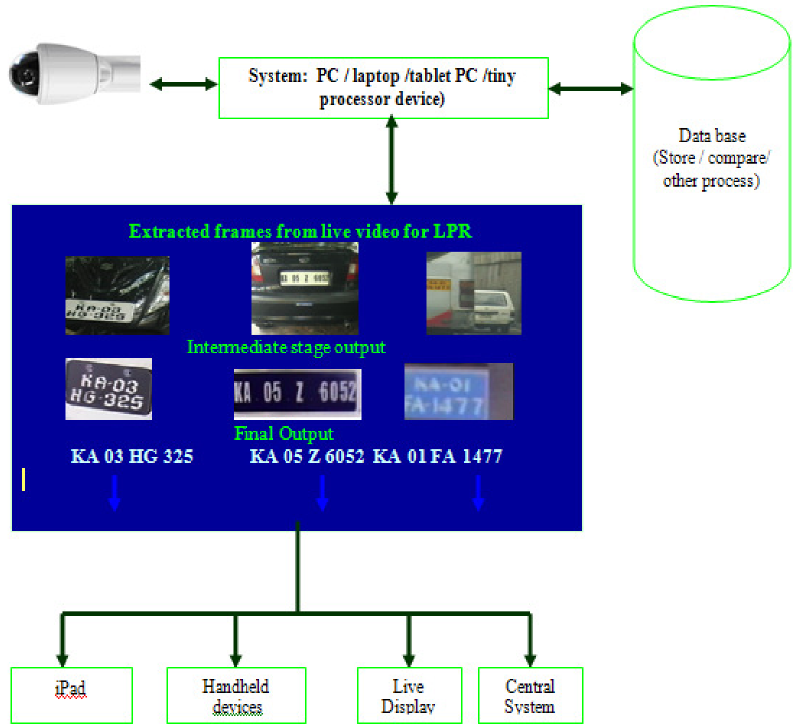

Figure 6: Real time implementation of LPR system

This work explains the development of next generation of OCR systems using novel methods, feasible technologies and efficient implementations. Real time video analytics fusion with RFID technology and the utilization of the recent wireless technologies integrated with iPADs allow for the deployment of very sophisticated but still cost effective systems. Implementation of Container OCR system is described in Figure 7. In actual scenario there will be multiple container bays after first level OCR scanning and RFID tags it will be classified as normal or high risk bay. High risk bay container further undergoes second level screening with X Ray or Gamma screening or Neutron. In each process all the information is analyzed in real time and decisions are made automatically through the centralized risk management system. Final output will be relayed to the iPAD or any handheld device or live monitoring and decision team or networked to centralized system. This system offers value added benefits to Maritime Supply Chain Management (SCM). We have studied the different processes in ports and one potential implementation for solutions is described in Section 3.3.

The implementation of Neural Networks for these applications is not straightforward. It is important to say that selection of features is performed by using modifications to other methodologies. The data sets and the numbers of features are important issues to solve in our systems using neural networks. We have conducted studies where the utilization of Principal Component Analysis (PCA) has been able to boost the learning capability and generalization of neural networks. The key has been to eliminate correlations of the different measurements (in particular with raw data) and facilitate quick learning sessions.

3.3 Computer implementation steps

There will be many design variations while implementing OCR or LPR on a computing device with.respect.to techniques and algorithms published in any research journal or books. The objective of all OCR or LPR is to extract ASCII characters from a real time video which in-turn is a n dimensional variable with sub-variables having distinct characteristics.

$$\text{ASCII character texts } (C_i) \leftarrow [f(\mathbf{V_j})]_{KxL} \qquad (1)$$

Where

C_i : ASCI characters i,j : 1,2, 3,…, K € $\mathbf{N^+}$

$\mathbf{V_j}$: a n dimension distinct parameter variables. Few variables are vectors and it

proceeds from the past toward the future
K x L : Region of Interest / (image/video resolution)

In our implementation, we assume that our digitized video signal is a function of spatial coordinates (x, y) which are divided into N rows and M columns, depth (z), color (λ), and time (t).

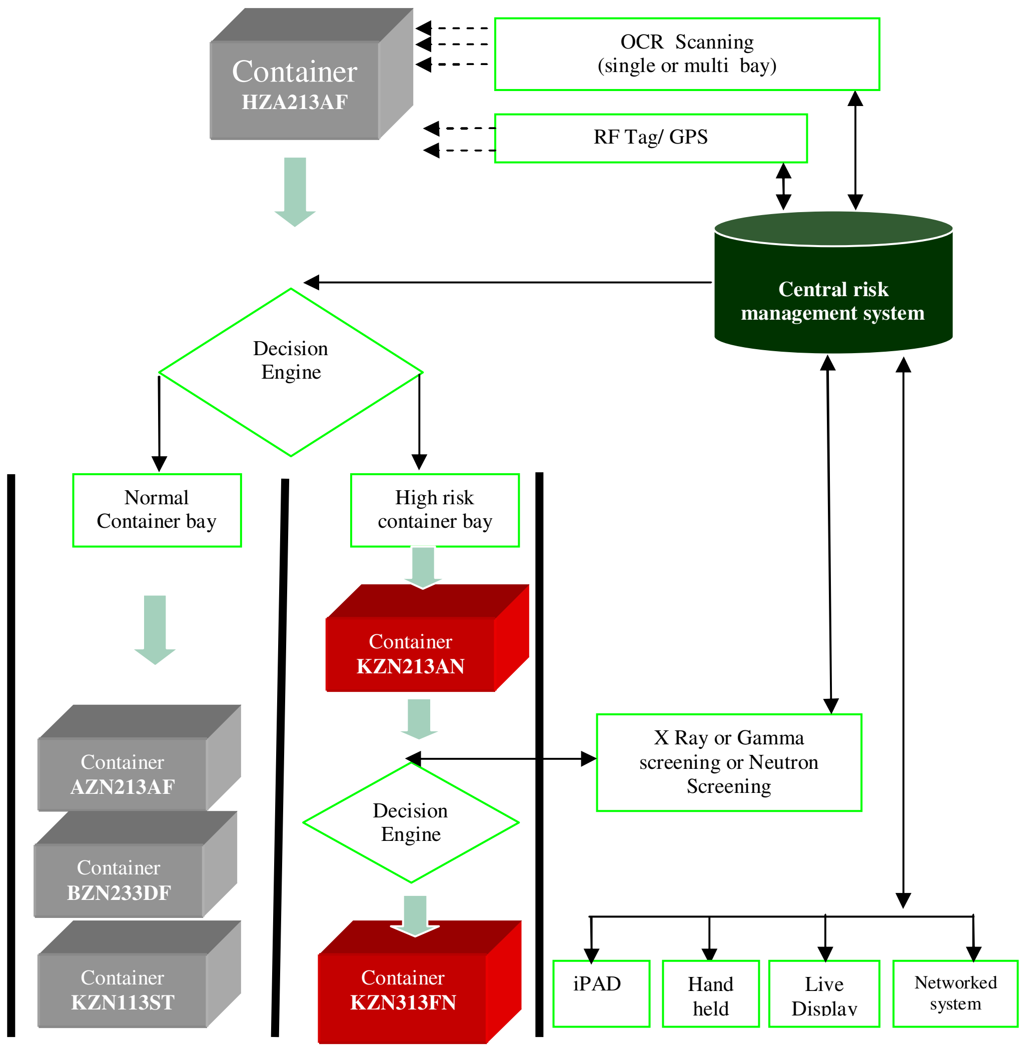

Figure 7. Container Optical Code Recognition

Reference video, $V_{Reference} = f(x, y, z, \lambda, t)$ (2)
where

x: 0,1,2,3,…, M-1 and y : 0,1,2,3,…, N-1,
Z: n- bit depth,
λ: n –tuple,
t: time in second or frame rate.

Video sampling involves taking samples along a new and different (time) dimensions. Since images contain thousands of pixels, each with multiple channels: channels are usually encoded in as few bits as possible (e.g., high quality videos are with 15/16/24/30/36/48 bits). Real-time time OCR or LPR processing is data intensive. These real time problems require vast computational, bandwidth and storage resources. Data compression is important here and the understanding and modeling of the time delays embedded in the different processing stages are important.

3.4 Major issues to be addressed in Container Optical character recognition

There are some of th e important issues:

- Poor image resolution: This could be either due to ROI being too far away or the quality of the camera is low.
- Blurry images: Primary cause could be motion blurs
- Poor lighting and low contrast: It's due to over exposure, reflection or shadows.
- Dirt on the ROI: due to environment
- Difference fonts and size: Non availability of international or national standard

Another important issue is the recent utilization of the Semantic Web in order to allow the seamless integration of the flow of information from the different media and formats. These advanced decision-making systems (using iPads) will provide users interactive and dynamically accurate visualizations of processes and help risk management systems.

4. Fusion with RFID

4.1 Active RFID Tags

Active RFID tags can be also attached to the cranes and other equipment. RFID tags are used to track the equipment as it moves containers in and out of ships, rail cars or trucks. The status of containers can be determined by monitoring the different equipment. Increased productivity, reduced losses, and increased asset utilization are benefits of this technology [14].

RFID can be integrated with Container OCR. There are problems with RFID tags and metallic containers. In addition, it is important to compare the reliability of both technologies. Information fusion is needed because, when properly implemented, it can reduce the dependence that the information needed may have on a particular information source. One of the benefits of using information fusion is that we can expect the fused detection resulting from the two sources (RFID and OCR) to be more robust to the different environmental, operations, cultural, and political situations.

4.2 Fusion

We have been studying different fusion techniques in order to create more robust systems. The studies have included Bayesian fusion and the Entropy fusion model (EFM).

Bayesian fusion is a statistical approach in which all forms of uncertainty in the information provided by the different sources are expressed in terms of probability measures [15]. This allows the information provided by the sources to be of different physical meanings. Bayesian fusion allows that uncertain information to be fused and the dependencies between those sources to be expressed through the Bayes rule for decision-making.

EFM is a probabilistic fusion model based on Bayesian theory. The main difference between the two fusion approaches is that EFM provides a means to quantify the imprecision about the uncertainty of a hypothesis, while in Bayesian theory, imprecision is assumed to be null. To quantify imprecision, Fassinut-Mombot et al.[16] use Shannon's entropy measure (i.e., entropy is defined in the context of a probabilistic model), a measure of the average information content one is missing when one does not know the value of the random variable (P). For a discrete random variable P (in this case the probability that a given hypothesis is true), Shannon's entropy describes the randomness (imprecision) of P as follows [17]:

$$H(P) = -\sum P \log P \tag{3}$$

5. Conclusions and Further Research

The operation of a container terminal has been examined following a line of investigation that combines literature review, and process and information modeling. The focus has been on emerging technological solutions such as Container OCR and RFID and their respective fusion. The utilization of Artificial Intelligence techniques is a required module in these systems.

Their contributions to the visibility of the supply chain will allow for higher levels of performance. These higher levels of performance are important because of global demand and the growth being experienced by container terminals. These container terminals handle millions and millions of containers using sophisticated multi-modal operations within the constraints of space, globalization issues, yard management, deadlines, human interactions, and the environment.

Acknowledgements

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