Non-invasive Means of Investigating Container Contents for Customs Agents at Port

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DISCLAIMER

Abstract

Project will pursue literature searches to access the latest information on the possibility of designing and building the required sub-system for a new technology that can be applied to container inspection. Project is intended to be preliminary, resulting in a technology assessment.

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Disclosure

"Project was funded in entirety under this contract to California Department of Transportation."

Introduction

The recent increase in Pacific Rim trade has caused the container volume at the ports of Long Beach and Los Angeles to expand at 10% per year. The major issue in this expansion has been the ability to move containers from the ports and on to their destinations within the continental U.S. The Alameda rail corridor has been constructed to facilitate rapid movement of goods from port to railhead, but other "bottlenecks" in the flow of goods are appearing that will limit the effectiveness of ports. With this increase in cargo comes increased awareness of tariff enforcement and security issues. Inspection is required to prevent contraband – explosives and drugs – from entering the U.S. The tragic events of September 11, 2001 have made port security the top priority of U.S. Customs and will profoundly affect future container movement. The burden placed on undermanned U.S. Customs to inspect more containers will likely produce that goods movement "bottleneck", affecting the national economy. For reasons of national security, there is no *official* estimate of the number of containers carrying contraband. One container carrying a nuclear device or biochemical agents is one container too many.

Containerized cargo, although a direct cause of this rapid improvement in intermodal shipping (container ship – rail – truck), is also the most difficult mode of transport to inspect without great expenditures of manpower (unloading and reloading the container) and resultant loss of valuable time in the anticipated movement-of-goods flow. This report proposes the use of emerging technologies to greatly assist the customs agents in their task of container inspection.

The effort begins with a heuristic argument outlining physical principles useful in container inspection. The report describes current security practices and what technologies are anticipated to assist inspection. The conclusion to the discussion specifies simultaneous use of two (2) very different regions of the electromagnetic spectrum. The first device, an x-ray/gamma ray imager (looks inside the container) is presently in various states of development, depending upon the specific inspection process. The second device, a radio wave spectrophotometer (determines materials inside container) has yet to be developed and is the subject of this limited but necessary study. The purpose of this study is to investigate an evolving algorithm for extracting a material's electrical characteristic from a radio wave transmitted through or reflected from that material. During this study, (1) a literature search was performed to determine uniqueness of this algorithm focusing primarily on the mathematical theory upon which the algorithm is based and (2) a "black-box" level hardware review was implemented to determine the feasibility of eventually fabricating a prototype of such a device.

Body of the Report

General Definition of Inspection Technology

As described in the preceding introduction, enhanced container inspection technologies to maintain port of entry throughput, as volume increases, are urgently needed for national security and revenue. A very general concept of "container" inspection is one that extends our senses. Prior to today's technology, inspection consisted of opening a container and visually inspecting its contents. These contents could be smelled or tasted in addition to the visual investigation. While the technology available for inspection has grown rapidly, the concept of inspection remains unchanged: determine what is within a container, be it a suitcase, shipping container, rail car, or intestinal tract. As technology advances, inspection technology naturally advances along the obvious lines of allowing humans to "see" into containers, and to "smell" or "taste" the contents to determine the chemical make-up of their contents. For reasons of privacy and the volume to be inspected, the proposed task is to determine quickly and completely the contents of a container *without* opening it. Presently only the ability to see the contents without opening the container exists. Small-scale x-ray machines are used to inspect personal containers at airports. Large scale, more powerful, machines for inspecting shipping containers are expensive and have a slow throughput, limiting their use at ports of entry and thus limiting the number of containers that can be inspected.

Present Use of Existing Technology

There are only two techniques of non-invasively "seeing" into a container, both involving projection and the resultant transmission or reflection of waves:

1) Electromagnetic (EM) waves (radio waves, light, x-rays, gamma rays, etc.)
2) Material vibration waves (ultrasound)

A variety of means exist for converting these waves into images suitable for human inspectors to interpret. U.S. Customs is now deploying recently developed x-ray (American Physical Laboratories, Inc.) and gamma ray (Scientific Applications International Corp.) imagers at a number of ports of entry. With the aid of a trained inspector, these devices have the ability to see into the containers, but not identify material content. Since this imaging inspection process still slows throughput and absorbs valuable manpower, the agency uses the conventional approach of trained dogs and profiling (as well as random selection) to choose which containers to image.
It is a somewhat unsatisfactory condition that the container's inspection is a two-step process and not a 100% screen. Presently only a small portion of containers (100,000 of 4 million) are imaged at the ports of LA/LB.

Benefits of Proposed Technology

There are two obvious solutions. First, one could add another technology capable of detecting trace amounts of internal materials that penetrate and escape the container. Second, one could use additional characteristics of a projected, penetrating visualization wave to determine internal material characteristics. These can be summarized as follows:

1) External trace detectors (dogs, gas chromatographs, etc.)
2) Penetrating wave characteristics (sonic densitometers, IR spectrophotometers, x-ray backscatter, magnetometers, radio wave dielectrometers, nuclear magnetic resonance, acoustic signatures, etc.)

These latter devices may use powerful computer algorithms to determine the chemicals present from the absorption energy of the substances, or the excitation energy due to the incident radiation. One must note that these algorithms only format the data for analysis by trained personnel, but could be extended to become capable of that analysis as well.

All known inspection technology has been considered in the previous discussion. For example,

1) Computer profiling via documentation triage:
    a) running manifests and ports of call
    b) shipping records

2) Simple visual imaging:
    a) low energy x-rays for airport luggage
    b) ground penetrating radar for pipeline location
    c) ultrasonic weld inspection

3) External trace detectors in conjunction with visual inspection:
    a) gas chromatograph "breathalyzers" with trained observation
    b) dogs to locate hidden explosives or drugs, and resultant visual search
    c) visual search and seizure leading to laboratory analysis

4) Simultaneous imaging and material characterization:
    a) infrared imaging to look for humans among foliage
    b) nuclear magnetic imaging of human tissue structures to look for cancers
    c) ultrasonic fetus imaging to monitor skeletal formation

What fundamental inspection technology principles are applied are determined by the particular application.

Technology Application to Containerized Cargo

For the present study, consider containerized cargo inspections. Further assume for reasons of economy and manpower that the containers cannot be delayed or opened unless a high degree of certainty exists that the container and its contents must be removed from the flow of goods. Small quantities of well-sealed materials of interest might preclude external trace detectors leaving only ”simultaneous imaging and material characterization”. Since the container is formed of steel about an eighth inch thick, either short (x-ray or gamma ray) or long wavelength (radio wave) EM radiation may penetrate it. Ultrasonic imaging requires intimate contact with the container, which is most awkward while the container is in transport. Further, the long wavelength EM radiation lacks the resolution for imaging person-sized objects, leaving the shorter x-ray and gamma ray radiation to perform imaging. Note also that these imaging energies, high enough to penetrate the steel container, preclude refined, material characterization. One might consider the penetrating, longer wavelength for that task.

It is the purpose of this study to determine the feasibility of using long wavelength EM radiation to infer material makeup. The approach consists of (1) a literature search of an evolving algorithm for extracting permittivity, permeability, and conductivity information from a transmitted long-wavelength radio wave, and (2) a technology review of hardware and computer systems capable of producing and detecting such waves.

Proposed Algorithm and Literature Investigation

The proposed algorithm is unique and has not been considered before. It has similarities to recently developed optical coherence tomography. This technique has been shown to be a powerful tool in skin cancer detection. Light of a predetermined coherence (ultra short EM "wavelets" with random phases in the skin cancer applications) is split into two identical beams. One beam penetrates the skin and is partially reflected; the other traverses a reference path of precisely known distance. The reflected beam and the reference beam are then recombined and caused to interfere with each other. The interference is only “constructive” when the phases of the "wavelets" are identical, i.e., when they are in fact parts of the same "wavelet" that split into the two beams. Adjusting and measuring the reference path to produce constructive interference indicates the exact distance the reflected beam traversed before reflection occurred in the skin. Knowing the location and degree of reflection allows doctors to detect minute, precancerous cell clusters in skin tissue.

The proposed algorithm for shipping container contents inspection differs from the optical coherence tomography in two (2) distinct ways. First, long wavelength, EM radio waves are used instead of very short optical waves; and second, the reflected wave is not used to determine location of reflection but rather the electrical characteristics of the material which has caused the reflection; location is a secondary benefit of this new algorithm. The technique appears to be similar to radar but, in fact, utilizes an entirely different method of signal processing. Thus, the literature investigation involved the overview of the general mathematics applicable to (and of interference type) signal detection. Of the many articles searched, those found to be of primary interest, as well as short critiques, are listed here:

M. Liou and C. Kurth, Computation of Group Delay from Attenuation Characteristics via Hilbert Transformation and Spline Function and Its Application to Filter Design, *IEEE Transactions on Circuits and Systems*, Vol. CAS 22, No 9, Sept. 1975.

It outlines an interesting approach to an aspect of filter design. It is as an example of a novel approach to an established problem and thus it models a problem solving methodology. The researchers are developing a new algorithm; consequently, examples of independent reasoning are useful.

A. von Hippel. Editor, Dielectric Materials and Applications, Artech House, 1995

This text gives empirical data on the dielectric parameters of materials. This information is necessary in order to run computer simulations. The researchers will do this to test their model of the physical system and accuracy of their algorithm.

L. Debnath and P. Mikusinski, Introduction to Hilbert Spaces with Applications, Academic Press, 1990, 458 – 459

The text is an exposition of Hilbert space theory and functional analysis. The Hilbert space methods are applied to problems in approximation theory. The specific pages referenced give a theoretical outline of how to use an iterative scheme to calculate orthonormal polynomials. The researchers can exploit this to achieve computational speed and scale in their calculations.

E. Isaacson and H. Keller, Analysis of Numerical Methods, Dover, 1994, 203 – 205

This text discusses the theory on numerical methods. The text covers numerical solutions of linear and nonlinear systems of equations, polynomial approximation, numerical differentiation and integration. The specific pages referenced state theorems and proofs of polynomial relations. These relations are employed to justify arguments employed in the augmentation of other numerical theorems. The researchers can use this material to solidify the theoretical foundation of their work.

K. Atkinson, Numerical Analysis, John Wiley & Sons, 1989, 249 – 329

This text covers both theory and application of numerical analysis. The pages referenced are the chapter on numerical integration. The discussion of that topic in this text is sufficiently broad to allow the reader to contrast different approaches to a problem of numerical integration. The researchers have used this to facilitate in making decisions about what numerical integration approach will be optimal under conditions manifest in the development of the algorithm.

S. Bedrosian, Normalized Design of 90^{o} Phase-Difference Networks, IRE Transactions on Circuit Theory, June 1960, 128 –136

This article discusses the network required to achieve a Hilbert phase transformation of a signal. The author's paper is an exposition on the mathematical arguments necessary to model such a network. The researchers will expand on this in the modeling of the system.

The conclusions of this literature search are that the proposed algorithm is unique and should be further pursued by considering a means of implementing such a signal processing technique in hardware.

Hardware Review

While the analysis algorithm is different from those used in low frequency radar, the hardware and detection approaches are not. Implementation of short pulse, ultra-wide-band (UWB) radar systems was first realized in the early 1990's by the military in the United States and Russia. Recently, "rediscovered" techniques of ground penetrating radar, as they apply to landmine location, have proven a fertile field for a hardware design review.

The task of generating incoherent electro-magnetic waves is straightforward in the optical domain, since the waves are generated by naturally random atomic events. However, radar sources are inherently coherent since they are generated by man-made systems. Three approaches used to derive the requisite wide range of frequencies are the sweep method, the short-pulse, wide-band or Fourier Transform (FT) method, and the spread-spectrum method. The first two methods are typical spectrographic approaches utilized for infrared and visible frequencies, while the latter approach is unique to low frequency radio waves and has been refined with the development of cell-phone technology.

Improvements in the spread-spectrum, multi-spectral techniques and the evolution of computer systems capable of processing such information cause these techniques to be the most promising for eventual implementation of the proposed system. Thus, the literature investigation involved the overview of UWB radar systems. Of the many articles searched, those found to be of primary interest are listed and briefly critiqued here:

S. Azevedo, *IEEE Potentials,* October / November 1998, 19-20

This brief article, from a trade journal, is a discussion of the application of impulse radar to land mine detection. It is practical implementation of a simpler electromagnetic technique. For the researchers it is confirmation that wideband electromagnetic signal processing is a viable technique.

J. Stratton, Electromagnetic Theory, McGraw-Hill, 1941, 490 – 524

This is an authoritative text on general electromagnetic theory. It has extensive coverage of both electrostatics and electrodynamics. The specific pages referenced cover, with more detail, the interaction of an electromagnetic wave front with various media. This supported the researchers need for a comprehensive electromagnetic model.

J. Jackson, Classical Electrodynamics, John Wiley & Sons, 1975, 335 – 339
This is an authoritative text on general electromagnetic theory. It is a standard reference in both electromagnetic physics and electronics engineering. The pages referenced discuss the interaction of an electromagnetic wave with a conducting medium. In particular, it addresses the modeling of this interaction when the conducting material is not ideal. This is a starting point for a more realistic model of such an interaction. The material supported the researchers' argument for a more detailed model of this interaction.

J. Schwinger, L. DeRaad, K. Milton and W. Tsai, Classical Electrodynamics, Perseus Books, 1998, 445 – 448
This is an advanced text on electrodynamics. It addresses traditional questions in electrodynamics using other than classical approaches. Further, it develops arguments using the principle of variation. The pages referenced discuss the reflection of an electromagnetic wave by an imperfect conductor. The researchers are working on expanding the argument.

T. Boyer, Penetration of the electric and magnetic velocity fields of nonrelativistic point charge into a conducting plane, Physical Review A, Volume 9, Number 1, January 1974, 68 – 82
"The electric and magnetic fields of a point charge moving with constant velocity outside and parallel to a conducting wall of finite conductivity are studied within classical electrodynamics for a nonrelativistic particle and a good conductor." "The results obtained here are quite different from those of the familiar calculations involving radiation fields where the penetration depth and the size of the fields inside the conductor are governed by the resistively. The new results run contrary to the expectations of some physicists and contradict some earlier work in the literature." The author of this article has adopted an independent approach to the problem of this interaction and consequently obtained results that contrast with the established wisdom on the topic. The researchers are working on expanding the argument.

D. Herskovitz, Wide, Wider Widest, *Microwave Journal* 1995, pp26-40
This article, from a trade journal, gives an overview of ultrawideband (UWB) radar. It is relevant because the technology the researchers will make use of is this wideband technology. The researchers have used this to further substantiate their argument that this is a realistic approach to the engineering problem.

The hardware review inplies that implementation of the algorithm into a UWB radar system -formed with cell-phone chip sets – is feasible, with few modifications to existing radio frequency source and antenna systems.

Conclusion and Recommendations

The increase in Pacific Rim trade has caused the ports of Long Beach and Los Angeles to become congested. The Alameda rail corridor will facilitate rapid movement of goods from port to railhead, but other "bottlenecks" in the flow of goods will likely appear, limiting the effectiveness of the soon-to-be-operative corridor. With this increase in cargo comes increased awareness of tariff enforcement and security issues. The burden placed on undermanned U.S. Customs will likely produce that "bottleneck". In particular, containerized cargo, although a direct cause of this rapid improvement in intermodal shipping (container ship – rail – truck), is also the most difficult mode of transport to inspect without great expenditures of manpower (unloading and reloading the container) and resultant loss of valuable time in the anticipated movement-of-goods flow.

Application of existing, high energy, electromagnetic imaging devices has begun to alleviate the inspector's workload. Coupling the proposed algorithm discussed in this project with the rapidly evolving UWB technology will usher in an entirely new form of inspection technology; similar to the development of NMR and ultrasound in the medical arena. The resultant technology will allow for the determination of the material makeup of the cargo within a container.

By placing the existing EM imaging and proposed EM material sensing sources directly on the cranes that are removing the containers from the ships, a 100%, non-invasive screen could be accomplished. This screen will eliminate the need for profiling, trained dogs, etc. The actual inspection will then take place while the crane is transporting the container. Since the data is recorded electronically, the computer processing equipment and trained inspector(s) may be located remotely. This recommended shift to more advanced computer algorithms allow for the eventual reduction in the need of trained inspectors freeing them for other, more urgent enforcement duties.