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Investigation of electro-acoustic technology for topographic applications

Frederick W. Rohde

SEPTEMBER 1978

U.S. ARMY CORPS OF ENGINEERS
ENGINEER TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VIRGINIA 22060

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 ETL-0160	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 INVESTIGATION OF ELECTRO-ACOUSTIC TECHNOLOGY FOR TOPOGRAPHIC APPLICATIONS.		5. TYPE OF REPORT & PERIOD COVERED Research Note,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Frederick W. Rohde		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Engineer Topographic Laboratories Ft. Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 16 4A161101A91D 17 Task 01 Work Unit 0059
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Engineer Topographic Laboratories Ft. Belvoir, Virginia 22060		12. REPORT DATE 11 September 1978
		13. NUMBER OF PAGES 9
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 12 12p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release: distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Studies were made of surface acoustic wave (SAW) and acousto-optical (A/O) devices for image processing and feature extraction from images. In the report, each device is defined, signal processing with the devices is discussed, and topographic applications for the devices are reviewed. The report concludes that the devices may be used in signal processing and decision circuitry for topographic systems, for example, distance measurement equipment (DME), radar return receivers, and image analyzers.

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Preface

■ The work in this report was performed under Project 4A161101A91D Task 01, Work Unit 0059 entitled "Investigation of Electro-Acoustic Technology for Topographic Applications." The work was performed in the Center for Theoretical and Applied Sciences, Research Institute, U.S. Army Engineer Topographic Laboratories (USAETL).

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Introduction

■ The interest in surface acoustic wave (SAW) and acousto-optical (A/O) devices has increased during recent years because they provide signal processing capabilities unavailable by other means. For example, 1-inch long acousto-electric convolvers have been made that instantaneously convolve one arbitrary analog waveform with another. Because a photographic image may be considered as a two-dimensional signal, it is of interest to know whether or not SAW and A/O devices can be useful for image processing. In some A/O devices, the light distribution of the image can interact directly with the sound signal generated in the A/O device.

Investigated in this study is the application of SAW and A/O devices to image processing and feature extraction from images; specifically, the potential of these devices for performing such functions as Fourier transforms, convolutions, and matched filtering.

In this report, the physics of SAW and A/O devices is briefly discussed. Also, various signal processing functions and their technical realizations are researched with respect to image analysis and feature extraction. In addition, future development trends for the devices are briefly outlined. However, signal processing functions that require coherent laser light are not included. The work covered in this report will be continued under the work units entitled "Electronic Image Analysis for Feature Extraction" and "Integrated Optics and Acousto-Optics Research for Topography."

Investigation

■ **SAW devices.** Figure 1 shows the basic configuration of a SAW device. The device consists of a piezoelectric substrate and two metallic interdigital transducers that

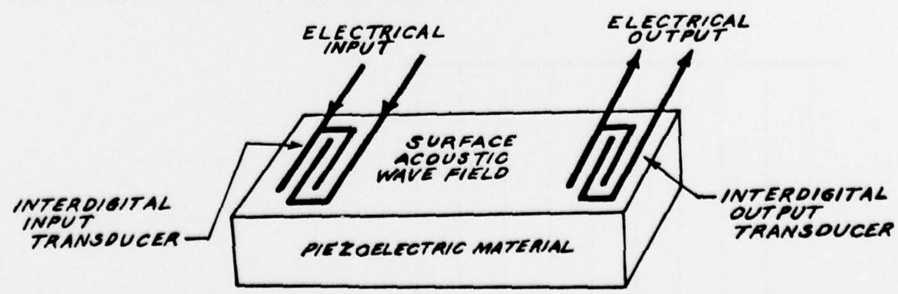

Figure 1. Basic Configuration of a SAW Device

are attached to the surface of the piezoelectric substrate. The input transducer converts the electrical signal into surface vibrations that propagate as surface acoustic waves, or Rayleigh waves, to the output transducer. The output transducer converts the surface acoustic waveform into an electrical signal. The significance of SAW devices is illustrated by comparing the propagation velocity, c, of electromagnetic waves with the propagation velocity, v, of the surface acoustic waves. Electrical signals propagate with a velocity of about 3 times 10^8 meters per second; whereas, surface acoustic signals propagate with a velocity of about 3 times 10^3 meters per second. Thus, the ratio of v/c is about 10^{-5} when converted into a surface acoustic wave. An electrical signal of 10 microseconds, for example, will produce a spatial signal train of about 3,000 meters. The same signal train would occupy only a length of 3 centimeters when propagated as a surface acoustic wave. The compression of a wave field to a manageable size makes it possible to perform signal processing formations not readily available by other means. A signal delay of 10 microseconds, for example, can be accomplished by spacing the transducers about 3 centimeters apart on the surface of the piezoelectric substrate. If the signal would be delayed by the same time through a cable, a cable length of about 2,000 meters would be required.

The specific processing function of a SAW device is determined by the shape and size of the transducers, the material and structure of the substrate, the length and size of the surface acoustic wave field between transducers, and structures that are placed into the wave field or near it. The filtering properties of these devices are completely determined by the processes of converting the electrical signal into acoustic energy, and vice versa, at the input and output transducers. A direct relationship exists between transducer geometry and the impulse response of the transducer. Figure 2 shows an unweighted periodic transducer that produces a sinusoidal impulse

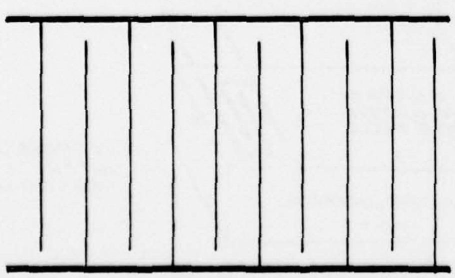

Figure 2. Unweighted Periodic Transducer

response. Figures 3 and 4 show two weighted transducers that produce a Gaussian and a Sinc X impulse response, respectively. A similarity exists between the transducer structure and the shape of the impulse response. The Fourier transform of the impulse response is the transfer function of the transducer. If the wave form of a specific signal signature is known, the transfer function of a filter can be determined that matches the wave form of the signal signature. The inverse Fourier transform of the transfer function is the impulse response. Therefore, the transfer function of the transducer provides some guidance for the designing of appropriate transducers for specific processing functions. Even if SAW devices are being developed and fabricated with specific performance goals, trial and error methods are used because the design parameters are not yet sufficiently predictable.

Acousto-optical devices. Acoustic waves produce compressions and rarefactions in the medium through which they travel. The compressions and rarefactions in the medium may cause local changes of its physical properties, such as refractive index, photoelectrical conductivity, or polarization. If a light beam interacts with a medium that is modulated by an acoustic signal, certain acousto-optical effects may occur that can be

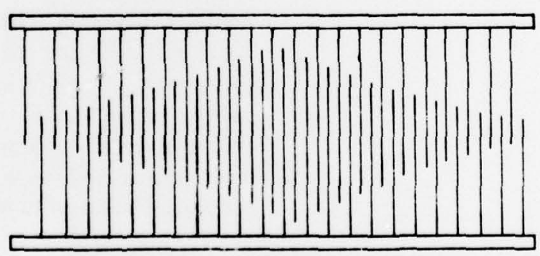

Figure 3. Gaussian Weighted Transducer

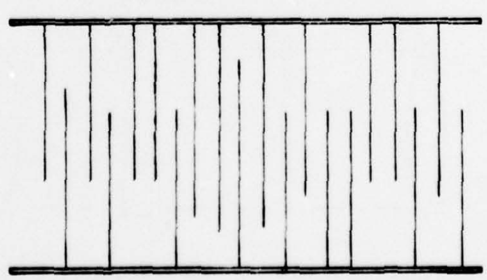

Figure 4. Sinc X Weighted Transducer

exploited for signal processing. Figure 5 shows a configuration of an optical analyzer. Light radiated by the point light source is collimated by lens 1. The collimated light beam is then spatially modulated by the gray shade distribution of the image. The modulated light beam goes through the transparent acousto-optical filter. This filter consists of a transducer T, the absorber A, and the acousto-optical field between T and A. This field consists of a transparent solid or a liquid medium with suitable index of refraction. The transducer generates an acoustic waveform that interacts with the modulated light beam in such a way that the desired signal processing may be accomplished. The processed light beam is focused on a photo cell by the lens 2. Several variants of the configuration shown in figure 5 are possible depending on their specific use, for example integral, sectional, or sample processing.

The possibility of modulating the resistivity of an electro-optical film by acoustic waves is employed in another class of acousto-optical devices. The Direct Electronic Fourier Transform (DEFT) device, which performs a direct electronic Fourier transform of an image, belongs into this class and is now being researched in depth by the U.S. Army Engineer Topographic Laboratories (ETL).

Signal processing with SAW and A/O devices. To date SAW and A/O devices have been used almost exclusively for processing electrical signals, especially in communication. In A/O devices for example, the electrical signal is first converted into an optical signal by modulating the light source or into an acousto-optical signal by using a second acousto-optical filter as modulator.

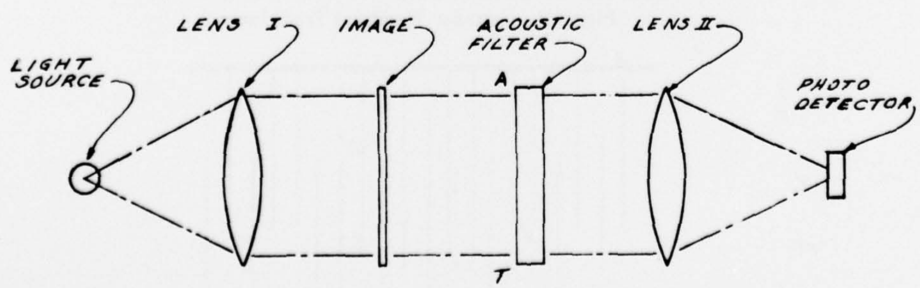

Figure 5. Acousto-Optical Analyzer with Transparent Acoustic Filter

The following processing functions have been accomplished by SAW devices:

Signal Delay	Correlation	Storage or Memory
Convolution	Fourier Transform	Matched Filtering

Figure 6 shows the schematic of a convolver, which also may be used as a correlator. In both cases a multiplication of the two input signals has to be accomplished, and the product integrated over the wave field or portions thereof. To accomplish the multiplication, the area where both input waveforms interact must have nonlinear properties. Convolutions and correlations may be accomplished in the time and spatial domains. Of particular interest are matched filters for signals up to 100 microseconds.

Even though SAW devices have already been incorporated in communication and radar systems, the technology of SAW devices is still in the early development state.

The following functions for A/O devices have been developed:

Optical switches
Spectral (Fourier) analysis
Correlation

However, A/O devices are in the early stages of development. With the tremendous improvement of optical fibers and the increased demand for optical communication, the development of A/O devices will probably be accelerated.

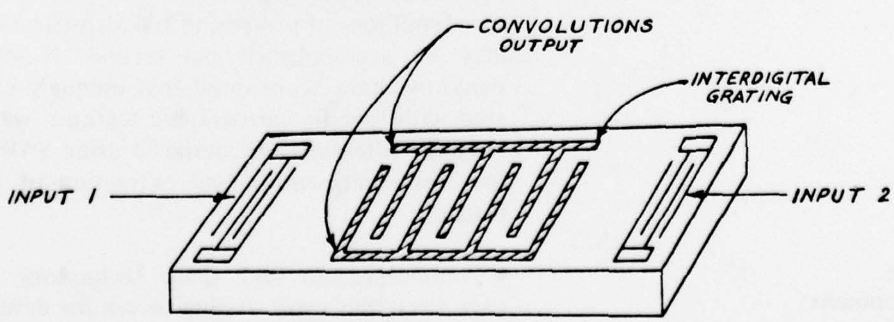

Figure 6. Convolver

Topographic Applications

■ **Distance Measurements.** In electronic distance measuring equipment, SAW devices may be used to improve signal-to-noise ratios and measurement accuracy. In optical distance measuring equipment, A/O devices may be used for optical switches or modulators.

Radar backscattering from terrain. SAW matched filters, combined with suitable SAW delay lines, may be used in terrain radar equipment to produce higher resolution and to bring out more details of the return signal.

Image analysis. Because images represent two-dimensional signals, SAW and A/O devices may be used for image processing. Global or local correlations and transforms of the image may be performed with A/O devices. Correlations, particularly local correlations, with representative feature waveforms may be used for feature identification and transformation of the image or portions thereof into other functional domains such as Fourier or Bessel. The transforms of cartographic features, such as road intersections, rivers, lakes, may have more simple signal signatures than the image itself.

To perform various signal processing functions such as transforms, convolutions, and correlations, SAW devices may be used. The signals have to be derived from the image by means of scanners or sensing arrays. Signal processing may transform the cartographic feature information from the image intensity signature into a signal signature that can be identified by means of correlation, convolution, or matched filtering. Because the signal processing can be accomplished with high speed, millions of processing and identification functions may be accomplished per second. If sets of signal signatures have been found that uniquely can be associated with specific cartographic features, waveforms and matched filters may be designed using SAW technology for fast identification and extraction of cartographic features.

Future Development Trends

■ Communication and space technology applications have been the main driving forces for developing SAW and A/O devices. Additional applications for SAW and A/O devices will come from automation requirements.

Examples of functions that may be automated and where SAW and A/O devices could be used as components of automation equipment are (1) reading of addresses on all letters, (2) controlling and inspecting assembly lines, and (3) recognizing and identifying sizes, shapes, and patterns of objects. Along with improved manufacturing methods, the quality and application potential of these devices will increase; whereas, the price per unit will decrease. Also, indications are that SAW and A/O devices will be used in integrated electronics and optics.

Conclusions

■ On the basis of this study, the following conclusions are reached:

1. Surface Acoustic Wave (SAW) and Acousto-Optical (A/O) devices may be used in signal processing and decision circuitry for topographic systems; examples are distance measurement equipment (DME), radar return receivers, and image analyzers.

2. At this time, no complete theories and procedures are available for the design of SAW and A/O devices. Trial and error methods are frequently used in the development procedure.

3. Devices for recognition and identification of signal signatures, such as matched filters, convolvers, and correlators, have been designed and tested for relatively simple waveforms.

4. At this time, a serious gap exists in the availability of characteristic signatures of cartographic features that can be processed for recognition, identification, and extraction.