Innovative Sensor Technology for Industrial and Agriculture Applications

presented by
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Applying electromagnetic, signal processing communication for innovative sensor systems
The research group of the Thailand Research Fund (TRF) Senior Research Scholar Project (2017-2020)

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Subprojects

- Metamaterial-based gas sensors for industrial and agricultural applications
- Microfluidic impedance sensors for medical applications
- Waveguide sensors for material characterization
- Motion sensors for industrial and medical applications
- Moisture content sensors for agricultural applications and historic place restoration
- Chipless RFID sensors for material quality monitoring
- Ground penetrating radar (GPR) for detecting and classifying buried objects and properties of soil layers for agricultures
- Wireless battery charging systems and wireless sensor networks
- Intelligent sensor systems for disaster monitoring and warning
The Most Impressive Pictures with Her Royal Highness Princess Sirindhorn on October 16, 2018 (2nd award)
Moisture content measurement systems

By Somporn Seewattanapon, key researcher from RUS
Rice paddy moisture content measurement system

Note: Growing rice area in Thailand = 56.5 million rai in year 2017 (data from Gistda)
Agricultural product exports

Milled rice

Source: FAO 2015

Natural dry rubber

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The rice paddy process in Thailand

The paddy is bought and sold based on weight.

- When a buyer purchases paddy, he measures the moisture content to estimate the value of paddy.
- The moisture content of paddy should not exceed 15%.
- If the moisture content of paddy is higher than 15%, the price of paddy will be decreased.
Two processes to develop a paddy to milled rice are a drying process and a rice milling process. For a rice milling process, a rice mill crack affected from a changing of a moisture content in a paddy.

For industry side, a drying process

Silo

Paddy cleaned

Paddy+etc. 15-30%(M)

a drying process

C/M 1

C/M 2

BLY-21

BLY-22

RF-2

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The drying system for rice paddy in a rice mill
Moisture content measurement types

- NIR method
- Capacitance method
- Resistive method
- Paddy sucker machine

Production line use
- Transmission line technique
- Resonant method

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The moisture measurement system

The paddy will be rotated in a silo and pass through a hot air in 20-28hr.

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The moisture measurement system design

The sensor system

The double dipole sensor

Size = W*L=110 mm*152 mm

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The moisture measurement system prototype
Installation of the moisture measurement system

1. Install diagram

2. Make a slot for placing a sensor box

3. The paddy is rotated in a silo and a moisture content will be decreased around 1% per hour. The cycle time about 20-28hr

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1. The moisture content data from an engineer is refer by a standard tool.
2. The moisture content data from the purpose system using an IOT.
3. The temperature, humidity, M21 energy are analised by graphic program.
Magnitude of digital moisture content of paddy rice data
Experiment results

The 36 measurement data are collected and analyzed by comparing with standard moisture content data.

The red line in a figure is a fit graph from these discrete data points to an equation below. The maximum error of extracted moisture content is 6.82%.

\[ %M = 3.64 \times 10^{-4} x^3 - 0.37x^2 + 125.98x - 14135.67 \]
In this work, the free space transmission technique with double dipole antenna is presented. The measurement system is located at the side of hopper silo to detect the moisture content of paddy. The proposed sensor can detect moisture content of paddy in hopper silo in range of 12-30%. The maximum error of extracted moisture content is 6.82%, causing from irregular filling of paddy during measurement.
Some ancients begin declining in several areas around Thailand. To maintain and repair these structures, the state of construction should be firstly analyzed and identified to give the sufficient information to the technician. The investigation of moisture content by using the method based on EM wave theory is the good candidate to be applied in the case of archaeological site because it does not need to take any building material out of structure for measurement, resulting in the noninvasive solution. Therefore, this approach becomes very attractive that can be seen from the cooperation of EM researcher group and department of Thailand Fine Arts under many restoration projects of old archaeological sites.
The main problem of the movement of soil moisture contents which result in changing of original structure sizes. If we know the positions under ground or under wall that have high moisture contents, we can release the moisture content in those areas.
A technique to determine the electromagnetic properties of soil using moisture content

Determining the soil moisture content

Various sources and techniques are available to determine the required parameters – relative dielectric constant and ground conductivity – but they all tend to be cumbersome in some way or another. According to the IEEE the main techniques are:

1. direct current resistivity methods
2. surface impedance methods using very low frequency (up to 20 kHz) signals
3. propagation studies in which the receiver is sometimes located underground (also limited to very low frequency)
4. wave tilt method
5. self-impedance methods
6. mutual impedance methods
7. time domain reflectometry

The drawback of all these techniques, with the possible exception of time domain reflectometry, is that they cannot easily provide the required soil parameters at a specific frequency.
The dielectric constant of the soil varies as a function of its components. Soil composition is generally classified in terms of the percent of sand, clay, and silt. The quantity of water in the soil, which is usually measured as the volumetric water content (VWC).

**Signal Propagation Through Soil**

**Friis equation**

The received signal strength (RSS)

\[ P_r = P_t + G_r + G_t - L_0 - L_s \]

\[ L_s = L_\beta + L_\alpha \]

**Peplinski’s principle**

\[ L_\beta = 154 - 20 \log(f) + 20 \log(\beta), \quad L_\alpha = 8.69\alpha d. \]

\[
\alpha = \omega \frac{\mu \varepsilon'}{2 \sqrt{1 + \left(\frac{\varepsilon''}{\varepsilon'}\right)^2 - 1}}, \quad \beta = \omega \frac{\mu \varepsilon'}{2 \sqrt{1 + \left(\frac{\varepsilon''}{\varepsilon'}\right)^2 + 1}}
\]

\[
\varepsilon' = 1.15 \left[ 1 + \frac{\rho_b}{\rho_s} (\varepsilon_s^{\alpha'} - 1) + m_v \varepsilon_f^{\alpha'} - m_v \right]^{1/\alpha'} - 0.68, \quad \varepsilon'' = \left[ m_v \varepsilon_f^{\alpha'} \right]^{1/\alpha'}
\]

**Underground Channel Model**
The soil moisture detection system

A sensor design by using a two-dipole operated in UHF band (434 MHz)

Prototype calibration test by measuring S11 of MUT

Prototype 1

Final Prototype

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The sensors are placed in a network form.
Transceiver wireless module used for collecting real-time data

Spec: 2.4 ISM band, 126 channels, 2 Mbps max data rate
Some data obtained by the proposed system

<table>
<thead>
<tr>
<th>ID1 to ID15</th>
<th>Object Temperature</th>
<th>Humidity</th>
<th>RF energy1</th>
<th>RF energy2</th>
<th>Vibration &amp; x, y, z module sensor</th>
</tr>
</thead>
<tbody>
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<td></td>
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Remarks

• The moisture content measurement system has been developed for application in restoration of historic places.

• The real-time data of temperature, humidity and vibration have been obtained.

• The system and data will be very useful for archaeologists to investigate, analysis and repair the historic places.

• The proposed system can be used for other applications.
Ground Penetrating Radar (GPR) for Counter Improvised-Explosive Devices
By Akkarat Boonpoonga, key researcher from KMUTNB
GPR image-based Detection of Buried Objects

Background

Violence situation in 3 southern border provinces in Thailand
Excavating a hole to put a bomb
GPR image-based Detection of Buried Objects

Background

Ground Penetrating Radar: GPR

GPR Image

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GPR image-based Detection of Buried Objects

Background

(a) Measurement of B-scan  (b) Data presentation of B-scan
Why we need to develop own GPR

Limitation of commercial GPRs

- GPR power and frequency are not suitable for ground and road in Thailand, also the speed of car
- Need experts to use and determine the GPR signals
- Not be flexible (too difficult to tune) for applications in Thailand
- Very expensive
Development of the GPR system
Development of the GPR system
Pulse generator module

- Pulse trigger (PRF: Pulse repetition frequency)
- Center frequency of pulse = 850 MHz
Antenna design

Scutcheon antenna

Start freq = 400 MHz

Antenna patterns at (a) 710 MHz (b) 960 MHz
GPR Transceiver with FPGA
Development of the GPR system

The second prototype

Computer

Transceive

Antennas

The third prototype

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Proposed Approach

Short-time matrix pencil method (STMPM)

Ground Bound
Early-Time
Late-Time

Finite size object in free space illuminated by plane wave

Transient response: \[ y(t) = \sum_{i=1}^{M} R_i e^{\lambda_i t} + n(t) \]

Proposed Approach

The procedure of the signal processing was divided into four main steps as follows:

1) Preprocessing step to reduce clutter due to the effect of ground bounce and soil-layer interface
2) Estimating late-time response with cross-correlation technique
3) Pole extraction from the estimated late-time response with STMPM
4) Object classification from the extracted poles and a pole library using SVM
Proposed Approach

1. Preprocessing

Clutter can be removed using the background subtraction method comprising subtracting an estimation of the background from the received signal

\[ r_n'(t) = r_n(t) - c_{n-1}(t) \]  \hspace{1cm} (1)

2. Estimation of Late-time Response

The late-time response irradiated by an EM pulse can be modeled as a sum of damped exponentials given by

\[ r_{n,LT}'(kT_s) \approx \sum_{m=0}^{M-1} R_{m,n} e^{s_{m,a} kT_s} \]  \hspace{1cm} (2)

the cross-correlation between the transmitted pulse referred \( r_n'(kT_s) \) as reference signal \( u(kT_s) \) and received signal is defined as

\[ C_n[\tau] = \sum_{k=-\infty}^{\infty} x[k] r_n'[k - \tau] \]  \hspace{1cm} (3)
3. Pole Extraction using STMPM

Regarding to (2), a sliding window of length $T_w$ started from $t_{LT}$ along time variable $kT_s$. Thus, the windowed signal in the late-time can be expressed as

$$ r'_{n,LT}(kT_s) \approx \sum_{m=0}^{M-1} R_{m,n}^{LT} e^{s_{m,n}(kT_s-t_{LT})} \tag{4} $$

where

$$ R_{m,n}^{LT} = R_{m,n} e^{s_{m,n}t_{LT}} = R_{m,n} e^{(-\alpha_{m,n} + j\omega_{m,n})t_{LT}} \tag{5} $$

In natural logarithmic scale, (4) can be rewritten as

$$ Ln\left(\left|R_{m,n}^{LT}\right|\right) = Ln\left(\left|R_{m,n}\right|\right) - \alpha_{m,n} t_{LT}. \tag{6} $$
Proposed Approach

4. Object Classification using SVM

the decision boundary of classification is obtained from the training data by finding a separating hyperplane that maximizes the margins between the two data sets. Consider $P$ training samples \( \{(s_0, q_0), (s_1, q_1), \ldots, (s_{P-1}, q_{P-1})\} \) where \( s_i = a_i + j\omega_i \in s_{m,n} \) is a library of poles. \( q_i \in \{1, -1\} \) is a decision target. the decision function can be written as

\[
q_i \left( \langle w, s_i \rangle + b \right) \geq 1 \quad i = 0, 1, \ldots, P-1 \quad (4)
\]

where \( b, w, \langle w, s \rangle \) are a bias term, the vector normal to the hyperplane, and the dot product of the vectors \( w \) and pole \( s \), respectively.
Simulations & Results

**Details**

- Simulation tool: HOBBIES EM software
- Antenna: Bowtie antenna
- Antenna mode: bistatic
- Distance between the antenna: 30 cm
- Height of antenna from ground: 20 cm
- Frequency Range: 0.2 – 1.0 GHz
- Sample: 101 point
- Frequency step: 8 MHz
- Dimensions of soil: 100x300x100 cm
- Diameter of cylindrical hole: 34 cm
- Length of cylindrical hole: 100 cm
- Diameter of cylindrical PEC: 32 cm
- Length of cylindrical PEC: 67 cm
Simulations & Results

Generating a Library of Poles

A library of poles must be generated first and employed in order to detect and classify the buried objects.

Frequency response of GPR at $y = 100$ cm

Time-domain response of GPR at $y = 100$ cm

(a) before (b) after performing clutter reduction
Simulations & Results

Generating a Library of Poles

Five successive poles obtained from the late-time response were chosen as training samples in order to make a library of poles.

Extracted poles of the buried object
(a) Imaginary part (b) Real part
(c) Magnitude of the residues
Generating a Library of Poles

- Five successive poles obtained from the late-time response were chosen as training samples in order to make a library of poles.

- The margin perpendicular to the hyperplane is \( \frac{2}{\|w\|} = 5.73 \times 10^8 \).

A library of poles classified by using SVM
Simulations & Results

Single-layer Soil Effect

• The overall classification rate defined by an average of classification which takes A-scan signals collected from $y = 50$ cm to $y = 150$ cm, in case of $\varepsilon_r = 4, 4.5$ and $5$ into account.

• It is seen that when the number of poles is equal to 3, the GPR system can slightly improve its classification.

Overall classification rate of buried objects in the single-layer soil.
**Simulations & Results**

**Multilayer Soil Effect**

• The overall classification rate is smaller than that of objects in a single-layer soil, it still higher than 50%. The new training data obtained from the GPR system in the context of multi-layer should be employed to make a new library of poles. This will increase the classification rate.

Overall classification rate of buried objects in the multi-layer soil.
The Detection Technique: Neural Network and Curve Fitting

Simulation Case:
- Used raw data image received from GPR.
- This technique is long time to process one GPR image as 42 minutes.
- This the detection accuracy approximately is 75%.

Experimental results Curve Fitting of impulse GPR Data

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Proposed Approach: image processing

Region Analysis

2D Image (Raw data) → Ground surface elimination → Normalization → Pre-Processing → Elimination of Background → Image report

Object Detection (Region Analysis)
Proposed Approach: image processing

Region Analysis

1. Regionalization

A region is composed of one or more 1-pixel connected in 8 directions as shown in Figure. Two adjacent regions can be combined into a single region.

8 Directions of Regionalization

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Proposed Approach: image processing

Region Analysis

2. Hyperbolic Estimation

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Proposed Approach: image processing

Simulation Setup

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Material</th>
<th>( \varepsilon_r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 m</td>
<td>Asphalt Dry</td>
<td>3</td>
</tr>
<tr>
<td>0.25 m</td>
<td>Ground Layer 1</td>
<td></td>
</tr>
<tr>
<td>0.15 m</td>
<td>Ground Layer 2</td>
<td></td>
</tr>
<tr>
<td>2.5 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I. The Series Ground

<table>
<thead>
<tr>
<th>Ground Series</th>
<th>Ground Layer 1</th>
<th>Ground Layer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacho</td>
<td>Sand Dry</td>
<td>*Sand Dry</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_r = 3 )</td>
<td>( \varepsilon_r = 5 )</td>
</tr>
<tr>
<td>Nathawi</td>
<td>Clay Loam</td>
<td>*Clay Loam</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_r = 34 )</td>
<td>( \varepsilon_r = 39 )</td>
</tr>
<tr>
<td>Rangae</td>
<td>Loam</td>
<td>Clay</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_r = 9 )</td>
<td>( \varepsilon_r = 39 )</td>
</tr>
<tr>
<td>SaiBuri</td>
<td>Loam Wet</td>
<td>*Loam Wet</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_r = 24 )</td>
<td>( \varepsilon_r = 29 )</td>
</tr>
<tr>
<td>Trang</td>
<td>Clay loam</td>
<td>Clay</td>
</tr>
<tr>
<td></td>
<td>( \varepsilon_r = 25 )</td>
<td>( \varepsilon_r = 30 )</td>
</tr>
</tbody>
</table>

*Characteristics and Properties of Established Soil Series in the Peninsular and Southeast Coast Regions of Thailand, Department of Lands, Bangkok, Thailand, September 2005

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Proposed Approach: image processing

Simulation Setup

In this experiment has 3 object placement settings (named A, B, and C) of two type of objects. On five different ground series to test the region

Condition all 3 case
- Triangle: W = 346, H=47.7 mm
- Circle (Landmine): Radius = 78 mm
- Circle (Landmine): in the Ground layer 2

Object Placement A

Object Placement B

Object Placement C

Simulated by GPRmax (FDTD technique)
Proposed Approach: image processing

Simulation results

Object Placement A

Results of Object Placement A

Detection

Processing

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Proposed Approach: image processing

Simulation results

Object Placement B

Detection

Processing

Results of Object Placement B

RGJ-PhD Congress XVI

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Proposed Approach: image processing

Simulation results

Object Placement C

Results of Object Placement C

Detection

Processing
Proposed Approach: image processing

Simulation results

<table>
<thead>
<tr>
<th>Ground Series</th>
<th>F-Measure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Object Placement A</td>
<td>Object Placement B</td>
</tr>
<tr>
<td>Bacho</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Nathawi</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Rangae</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>SaiBuri</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Trang</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

F-Measure formula is:

\[
F = \frac{2PR}{P + R}
\]

- Show that the detection results of the object placement A and B in all ground are 1.0. This means our technique can successfully detect all landmines buried underground and ignore all landmines buried.
- The results are all 0.8 because there are two undetected landmines. The two landmines are placed together with 0 cm. space.
- Results in Table II also show that different ground series do not affect the detection accuracy.
Proposed Approach: image processing

Simulation results

Table III The Processing Times

<table>
<thead>
<tr>
<th>Ground Series</th>
<th>The Time Processing (Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Object Placement A</td>
</tr>
<tr>
<td>Bacho</td>
<td>258</td>
</tr>
<tr>
<td>Nathawi</td>
<td>255</td>
</tr>
<tr>
<td>Rangae</td>
<td>255</td>
</tr>
<tr>
<td>SaiBuri</td>
<td>257</td>
</tr>
<tr>
<td>Trang</td>
<td>253</td>
</tr>
<tr>
<td>Average</td>
<td>255.6</td>
</tr>
</tbody>
</table>

- Results in Table III also shows that the time processing in Placement A, B is difference, but the landmine and triangle is 4 equal object. The received signal in Placement A consist shifting angle of the triangle differ in Placement B is triangular in form usually get the received signal.
- The time processing is proportional to white pixels in the images.
Experimentation of GPR

Experimental setup in anechoic chamber.

Operating Frequency
Step-frequency Mode
Antenna: Bow-tie

Experimental setup on road.

Excavating a trial hole beside the road is a way of putting the gas tank under the road.
Experimentation of GPR

Experimentation setup on road

Experimental setup on road

B-scan image tested on road

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Experimental results on road

B-scan image tested on road

B-scan image after estimating axis ratio.

B-scan image after performing Regionalization.

Preprocessing

Regionalization

estimating axis ratio

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Experimentation of GPR

Experimental results on road

B-scan image after estimating axis ratio.

Fuzzy logic

B-scan image after performing fuzzy logic.
Remarks

- The in-house GPR has been developed for detecting buried objects.
- We propose an approach to detect buried objects based on GPR images that employs a simple technique.
- The results show that we can achieve high detection accuracy while greatly reducing processing time.
- Regarding the processing time, our technique is much faster (in comparison with all cases) calculation that is faster than 90% and the accuracy of 80%.
Thank you very much for your attention
Contact: prayoot.a@eng.kmutnb.ac.th