High-Performance Computing Applications and Networking Technology

Becoming technological advanced — Case studies of IoT applications in smart areas

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**Background & Research Scope**

**Smart Agriculture**
- Remote Monitoring System of Pests
  - Field info. Monitoring
  - Automatic pest sensor
  - Pest population forecast
  - IPM applications
- Automatic Greenhouse
  - Adaptive environment control
  - Pest monitoring
  - Increase productivity of orchid
  - Productivity forecast
- Colony Collapse Disorder
  - Platform for CCD studies
  - In-out analysis of honey bees
  - Bee behavior analysis
- Remote Visual Monitoring System
  - Surveillance of critically endangered species of tern
  - Real-time imaging for tern
  - Energy-efficiency
  - Autonomous operation
  - Optimal scheduling
- Microwave Pest Killing Machine
  - Low-cost, high efficiency magnetic applicator
  - Non-destructive operation
  - Dosage analysis

**Smart City**
- Micro-Sensing Network
  - Sensors for intelligent space
  - Location awareness technology
  - Disease transmission forecast
- Air-quality Surveillance
  - High spatiotemporal resolution
  - Pollution spread analysis

**Smart Grid**
- Monitoring of EHV Power Transmission Lines System
  - Wide-range measurement of conductor temperature, line sag, etc.
  - Conductor temperature forecast
  - Dynamic thermal rating
  - Ampacity margin estimation of EHV lines

**Tech. Contents**
- Coverage Optimization
  - Improve quality of surveillance
  - Scheduling of sensors for saving energy
- Instrument Degradation Identification & Data Healing
  - Big data mining
  - Anomaly detection
  - Autonomous distributed operation
  - Critical data recovering
- Localization
  - Indoor/outdoor RF-based localization with high accuracy

**Lab leader: Joe-Air Jiang, Ph.D., Distinguished Professor**
Outline

• Introduction
  – What is IoT?

• Advanced IoT/WSN InfoCom Platform

• Cases studies of IoT applications in different scenarios
  – IoT/WSN-based pest monitoring system
  – Intelligent IoT/WSN-based monitoring system for greenhouse
  – IoT/WSN-based experimental platform for colony collapse disorder (CCD) of honey bees
  – IoT/WSN-based PV monitoring system
  – IoT/WSN-based grid-wide safety monitoring system for EHV grids
  – IoT/LoRa-based city-wide monitoring system for vehicles

• Q & A
WHAT Is IoT?
Internet of Things
 Physical objects can communicate with each other

 All the objects can assess to the Internet

 Object tags can be identified, located, and enabled/disabled

 IoT is interested in collecting data using a large network consisted of physical sensors and analyzing the collected data to build a service or flow model for target applications.

 Data modeling and scenario detection are the goals.
Advanced IoT/WSN InfoCom Platform

Sensing layer
- MSP-based
- Embedded-based

Data aggregation layer
- IPC-based

Network layer
- Data analysis & cloud service layer
  - Server & Database
  - Data mining

Data analysis & cloud service layer
- Functions
  - Data saving
  - Pest outbreak
  - Pest analysis of monitoring area

Intelligent pest monitoring and modeling
- Ambient temp./humidity illumination
- MSP-based
- Embedded-based

CCD research based on IoT/WSN
- Ambient temp./humidity
- Beehive temp./humidity
- Bee counts incoming/outgoing

Intelligent and automatic greenhouse monitoring system
- Orchid greenhouse temp./humidity
- Movable benches localization

Low power consumption ecological monitoring
- Ambient temp./humidity
- Ecological image

Intelligent pest monitoring and modeling
- Pest outbreak
- Pest analysis of monitoring area

CCD research based on IoT/WSN
- Bee behavior monitoring system
- Intelligent and automatic greenhouse monitoring system
  - Orchid quality image monitoring
  - Orchid greenhouse pest monitoring

Low power consumption ecological monitoring
- Matsu tern monitoring

Institute of Information Engineering, NTU
IoT/WSN-based Pest Monitoring System

Development of a remote agro-ecological monitoring system
Huge agricultural damage

About **570 million USD** annually in Taiwan

- Expensive, labor-intensive
- Time consuming (10 days) & inefficient counting
- No synchronized measurements on weather factors

Traditional pest monitoring techniques heavily depend on manual measurement
IoT/WSN-based Remote Pest Monitoring System

7-day forecast for pest population dynamics

Early warning of pest outbreaks

Objectives:
- Weather durability
- Scalability
- Reliability
- Remote control
- Real-time warning
- 7-day forecast

Challenges:
- Network reliability
- Remote accessibility
- Network scalability
Wild Field Monitoring System

2011

2 stand-alone stations
All for OFF

10 Gateways for TC
12 Gateways for OFF
245 sensors

94 sensors for TC
151 sensors for OFF

Today

Oriental Fruit Fly
Tobacco Cutworm

The deployment scenes in Taiwan

Pinglin (TC)
5 WSN-based monitoring stations
44 sensors

Yuanlin (OFF)
3 WSN-based monitoring stations
30 sensors

Lunbei (TC)
1 WSN-based monitoring station
10 sensors

Chiayi (OFF)
1 WSN-based monitoring station
20 sensors

Budai (TC)
1 WSN-based monitoring stations
10 sensors

Changjih (OFF)
2 WSN-based monitoring stations
48 sensors

Changjih (TC)
1 WSN-based monitoring station
10 sensors

NTU (OFF)
1 Standalone monitoring station

Yuanshan (OFF)
2 WSN-based monitoring stations
20 sensors

Shengang (OFF)
1 WSN-based monitoring station
3 sensors

Jhuchi (OFF)
3 WSN-based monitoring stations
30 sensors

Yijhu (TC)
1 WSN-based monitoring station
10 sensors

Jhunghu (OFF)
1 Standalone monitoring station

Kanding (TC)
1 WSN-based monitoring station
10 sensors
Wild Field Monitoring System

• Sensor node device

Sensing layer → Transmission layer → Application layer

Solar photovoltaic panel

Pest counting controller

Luminance sensor

Temperature and humidity sensors

Plastic box for battery

Automatic pest counting trap

Infrared interrupter controller

Wireless sensor node (ZigBee)
Wild Field Monitoring System

• Gateway platform
Wild Field Monitoring System

- Pest analysis of monitoring area
  - Farmers can bagging the fruit based on the analysis results
Wild Field Monitoring System

• Pest early alerting service
IoT/WSN-based pest monitoring system
Intelligent IoT/WSN-based Greenhouse

Development of an IoT/WSN-based Automated Greenhouse Monitoring System
Taiwan is the top 2 orchid exporting country world-wide (behind the Netherlands), and 1 out of 6 orchids in the world is produced in Taiwan. Orchid is one of the essential commercial crops in Taiwan. Taiwan has a critical advantage in the orchid market of the world – orchid diversity. The export value of the orchid reached 195 million US dollars in 2012 solely in Taiwan, which accounted for 93% of the total exports of flowers from the entire country.
The monitoring technology used in greenhouses was with low resolution in the past, which hindered the chance of achieving optimal growth conditions.

Temperature diversity at different locations > 3°C
Automatic Greenhouse Monitoring System

• System architecture

A generic IoT/WSN framework

- Sensor node localization
- Dynamic network topology management
- Cloud computing capability

Large-scale greenhouse

- Fixed node
- Mobile node
- Mobile plant-bed

Cloud service
- Storage service
- Analysis service

Decision support for greenhouse owners
- Ethernet hub for high-speed data exchanging
- Embedded systems for enhancing local analyzing capability (connected with private cloud)

Automatic Greenhouse Monitoring System
Greenhouse Deployments

- Mayshan (flowering)
  - From July 15 to Nov. 3, 2014
  - 22 Wi-Fi cameras (Morphological trait inspection)
  - 20 sensor nodes (Environment Monitoring)

- Gukang (large seedling)
  - From March 13 to July 15, 2014
  - 48 Wi-Fi cameras (Morphological trait inspection)
  - 30 sensors nodes (Environment Monitoring)

- Dalin (middle seedling)
  - Since March, 2012
  - 58 Fixed Nodes
    - Anchor for localization
  - 62 Mobile nodes
    - Dynamic network topology
    - Target for localization
  - 5 PANS
    - Centralized/distributed network managements
Intelligent IoT/WSN-based Greenhouse

Real deployment status

- Gukeng greenhouse (mature in 3.5 inch)
  - From 3/31~till now
  - 48 Wi-Fi cam (Growth status monitoring)
  - 24 Wireless sensor nodes (Environment monitoring)

Total: 288 plant
Intelligent IoT/WSN-based Greenhouse

- Automated pest (e.g. Bradysia) monitoring system of orchid greenhouse

![Diagram of the greenhouse system](image)

- Raspberry Pi B+, Camera and Relay
- LED
- 12V Power Supply
- 5V Power Supply
- CPU ARM1176JZF-S
- GPIO
- Camera
- Wireless LAN Card
- USB hub
- Motor
- LED
- Turn on/off
- Command
- Data
- Photograph
- Soc BCM2835
- Relay
Accuracy test of the automated pest monitoring system in orchid greenhouse

- Sample: 95 monitoring images
- RMSE: 2.06
- Relative Error: 4.91%
- Margin of error: 0.86%

Intelligent IoTWSN-based Greenhouse
Intelligent IoT/WSN-based Greenhouse

Real time monitoring – Time-lapse photography

Gukang large seedling area
- 48 WiFi cameras
- 30 sensors nodes (tmp/hum/light)
- 15 advanced soil sensors
- 4 advanced light sensors

Mayshan flowering area
- 22 WiFi cameras
- 20 sensor nodes (tmp/hum/light)
- 6 advanced soil sensors
- 2 advanced light sensors
Intelligent IoT/WSN-based Greenhouse

- Leaf overlapping estimation and reconstruction
  - Leading overlapping issue between each orchid plants
  - Using the symmetry of orchid leaf to estimate the overlapping area
Leaf overlapping estimation and reconstruction

- Morphological traits + HSV + Canny edge detection
- An increase in analyzed samples
- The estimation error of the non-overlapping image: 0.67% ~ 3.06%
- The estimation error done by Huang and Lin is between 1.8% ~ 4.02% in 2002, and done by Weng is between 5% ~ 8% in 2012

<table>
<thead>
<tr>
<th>Overlapping image</th>
<th>Processed image of overlapping leaves</th>
<th>Non-overlapping image</th>
<th>Processed image of non-overlapping leaves</th>
<th>Pixel</th>
<th>repainting method</th>
<th>Pixel</th>
<th>Error</th>
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Technological Accomplishments

Impacts of environmental factors

✓ Experimental period: April 19 ~ July 4, 2015

<table>
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<tr>
<th>Region</th>
<th>Avg. growth of leaf area (mm²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>79.41</td>
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<tr>
<td>2</td>
<td>75.46</td>
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<tr>
<td>3</td>
<td>74.15</td>
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<tr>
<td>4</td>
<td>57.68</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>T ± STD. (°C)</th>
<th>H ± STD. (%RH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.83 ± 2.58</td>
<td>71.81 ± 8.88</td>
</tr>
<tr>
<td>2</td>
<td>30.57 ± 3.45</td>
<td>71.43 ± 11.04</td>
</tr>
<tr>
<td>3</td>
<td>30.01 ± 3.18</td>
<td>72.17 ± 10.06</td>
</tr>
<tr>
<td>4</td>
<td>28.59 ± 2.76</td>
<td>79.95 ± 9.13</td>
</tr>
</tbody>
</table>
Technological Accomplishments

Relationship between blossom quality and exterior characteristics

✓ Hierarchical clustering

➢ The highest class of orchids
  • The length of the stalk > 20 cm
  • The number of blossoms > 8
  • The area of the leaf > 35000 mm$^2$

➢ The lowest class of orchids
  • The length of the stalk < 15 cm
  • The number of blossoms < 7
  • The area of the leaf < 28000 mm$^2$

✓ The most significant boundaries of exterior characters
Key lessons

Leaf Area (mm²)

Days

0 10 20 30 40 50 60 70

22000 24000 26000 28000 30000 32000 34000 36000

Growth Data of R1
Growth Data of R2
Growth Data of R3
Growth Data of R4
Fitted Curve of R1
Fitted Curve of R2
Fitted Curve of R3
Fitted Curve of R4

<table>
<thead>
<tr>
<th>Region</th>
<th>Blossom on phase I (A/B/G/N.A.*)</th>
<th>Blossom on phase II (A/B/F/N.A.*)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>23/9/24/16</td>
<td>33/19/4/16</td>
</tr>
<tr>
<td>2</td>
<td>26/8/25/13</td>
<td>41/16/2/13</td>
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<td>3</td>
<td>11/9/33/19</td>
<td>25/20/8/19</td>
</tr>
<tr>
<td>4</td>
<td>4/0/36/32</td>
<td>16/11/13/32</td>
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</table>
Intelligent IoT/WSN-based Greenhouse

(Courtesy of Intel-NTU CCC Center)
Colony Collapse Disorder

Development of an IoT/WSN-based experimental platform for electrophysiological and behavioral study of honey bees
Sudden disappearance of honeybees

- 66% crops in the world are pollinated by honeybees
- The total U.S. crop value that was wholly dependent on honeybee pollination was estimated to exceed $15 billions
Possible reasons of CCD

- Malnutrition – GM corns or a single crop in farm
- Virus
- Electromagnetic radiation

- Pesticide
- Environmental/climate change

Our concerns

CCD
Colony Collapse Disorder
Architecture of the automatic foraging behavior monitoring system

Environmental factors | Honey bees’ activities
---|---
Automatic foraging behavior detection system | Wireless Protocol (Zigbee)
Beehives | Gateway (Industrial personal computer)
Power Supply

Traditional mains supply | Renewable Solar, Wind
---|---

Research Issues
- Pesticide effects on honey bees
- Novel device for bee research
- Optimal environment analysis for honey bee activity
- Foraging behavior of honey bee and environmental factors of beehives
- Environmental factors of beehives
- Smart beehive environmental control

Smart beehive Cloud
- Data storage
- Server
- Data mining
- Early warning

SMS messages
- DISAPPEAR
- Colony Collapse Disorder
- Honey bee activity prediction model
Architecture of the counting system

Practical setup and deployment

MAIN ACHIEVEMENTS
Bees will drag the dead bodies out from the bee hive to avoid the entire hive collapse via the virus.
Accuracy test of the automatic foraging behavior monitoring system

- Location: Tomatake Hall, NTU
- Time: 2015/12/22
- Weather:
  - Temp. 21.8 ~ 29.6 °C
  - Temp. relative higher

Result

- Automatic foraging behavior monitoring system
  - Outgoing: 4348
  - Incoming: 4713

- Human counting
  - Outgoing: 4657
  - Incoming: 5061

- Counting error
  - Outgoing: 11.08%
  - Incoming: 11.24%
Accuracy test of the automatic foraging behavior monitoring system

- Regression analysis of automatic foraging behavior monitoring system: accuracy test/counting error
  - System avg. accuracy
    - Income: 84.92%
    - Outgoing: 85.95%
  - R²
    - Incoming: 0.924
    - Outgoing: 0.937

Statistical analysis results for proposed system – incoming activity detection

Statistical analysis results for proposed system – outgoing activity detection
The frequency of honey bees’ incoming activities is similar to outgoing activities.

The daily difference between the outgoing and incoming counting of honey bees was lesser than 300 counts/day.

The temperatures near at the nectar region inside the beehive were ranged from 18 to 34 °C.

The average values and standard deviations of the relative humidity:
- Inside the beehives: 74.3 ± 11.6 %RH
- Outside the beehives: 85.1 ± 4.88 %RH
Honey bees are more active between 5:00 a.m. and 6:00 p.m.

The total frequency of honey bees’ incoming behavior was 81,912, and the total frequency of honey bees’ outgoing behavior was 83,347.

The trend of the ambient temperature was also similar to the beehive temperature.

The trend of the ambient relative humidity was not similar to that of the beehive relative humidity.

- Inside the beehives: 74.0 % RH to 83.0 % RH
- Outside the beehives: 38.0 % RH to 90.0 % RH
Prediction of in-and-out activities of honey bees

Time Delay Neural Networks
The Results of TDNNs

2014/9/1

- Actual: 29327
- Predict: 29661
- APE: 38
- RMSE: 0.0032
The Results of TDNNs
Providing a micro-climate monitoring system for investigating honeybee’s behavior

• A stable system is necessary
• Using the system to investigate the impact of pesticides and the electromagnetic radiation on honeybees

Find the reasons why CCD happened

The system integrates an IoT/WSN-based ecological monitoring system and a counting system

By the sensing data, modeling the dynamic behavior of bees is possible

• Predicting colony of honey bees if a beehive is going to be better or worse
• Finding out the causes for the CCD of honey bees
Automatic foraging behavior monitoring system
An IoT/WSN-based Monitoring System for PV Generation Plant
In Taiwan, most of PV generation plants are small and medium-size (generation capacities are about 200 to 300 kW, plant covering are about 2000 to 9000 m²). Using cable monitoring system to detect multiple signals, such as voltage, current, temperature, humidity, illumination and other sensing signals is difficult. Because each signal is independent of individual signal lines, the cost of wire and construction are very expensive.

WSN has the great convenience and low cost of deployment. By using different number of sensing nodes, the sensing range can be flexible.

The selection of sensors are very customized. Industries can choose many kinds of sensors according to their considering issue, like using thermometers to study the relationship between module temperature and power generation.
IoT/WSN-based monitoring system for PV generation

- **System architecture**

  - MCMS: microcontroller with multiple sensors
  - WCM: wireless communication module
  - RMG: remote monitoring gateway

  ![Diagram](image-url)
Wireless Sensor Node

- Actual Photo

Installed thermometer and illuminometer with transparent shell

IoT/WSN-based monitoring system for PV generation

- Time Module
- Wireless Transmission Module
- ATmega32P-PU
- Voltmeter
- Thermometer
- Illuminometer
- Galvanometer
Real deployment status

A power supply for all the hardware

Schematic diagram of the MCMS and WCM

Box behind the PCS

Industrial grade box

Schematic diagram of the RMG
IoT/WSN-based monitoring system for PV generation

Voltage Synchronizing Technique for Solar System

Wireless Sensor Network

Sensor Node

Gateway

- MPPT
- Wireless Communication Module

Weather Module

Node

Gateways

- Temperature & Humidity
- Irradiation
- MPPs

PC

Simulation & Analysis

Database
Surface Temperature Estimation and Cooling Technology for Photovoltaic Modules

IoT/WSN-based monitoring system for PV generation
IoT/WSN-based monitoring system for PV generation
Development of an IoT/WSN-based Grid-Wide Safety Monitoring System for EHV Power Grids
Among the power grids with different voltage levels, extra-high voltage (EHV) transmission grid serves as an important role of the entire power system, just like main artery.

These facts further caused the power grids to face severe challenges of reliability, security, efficiency, etc.

Large power flow of power grid usually causes high line conductor temperature and severe line sag and then might induce line ground fault.
To certify the availability and safety for power grids, many utilities adopted manual-inspection approach to check power grids, which is an inefficient, high-cost, and labor-intensive inspection method.
IoT/WSN-based Grid-Wide Safety Monitoring System

Real deployment

[Images of a tower, a yellow car, and people working on the ground.]
IoT/WSN-based Grid-Wide Safety Monitoring System

Real deployment status
IoT/WSN-based Grid-Wide Safety Monitoring System

- Demo video
IoT/LoRa-based Smart City

Development of an IoT/LoRa-based city-wide monitoring system for vehicles
In 2008 year, IBM proposed the concept of *smart planet*, which then lead to smart city.

Smart city is an ideal urban vision by *integrating information and communication technology (ICT)* and *Internet of Things (IoT)*.

Vehicles can provide real-time information about the surrounding environment.

This research developed a vehicle monitoring system based on the IoT/LoRa technology.

**106,078,000**
Taipei IoT Experimental Platform

In 2016, Taipei City Government established the Taipei LoRa platform.

- The first citywide LoRa platform in Asia
- The communication range up to 15-20 kilometers
- Only 11 LoRa base stations needed to cover Taipei City
Vehicle-box (V-box)
The device integrated with LoRa and sensors

Technical specs
- 12 VDC
- Timekeeping Chip
- SD card support (data redundancy)

Interface
- LoRa
- OBD II
- RS-232
- USB port
- Uart port *2

Sensor
- SO₂
- CO
- O₃
- NO₂
- GPS
- Accelerometer
- Temperature
- Humidity
- TSP
- PM 2.5
- PM 10
Results – Packet reception ratio (PRR) test for LoRa

Limit: 1 packet per minute

20 packets per 200 meters

1 cycle

90 sec 60 sec 30 sec 0 sec

800m 600m 400m 200m 0m
Results - Packet reception ratio (PRR)
User Interface for IoT/LoRa-based city-wide monitoring system

Taipei Vehicle Monitoring Platform

Weather
Temperature: 25 °C
Humidity: 36.4%

Vehicle Information
Vehicle Speed: 0 km/h
Engine Loading: 38%
Coolant Temperature: 85 °C
Intake Temperature: 42 °C

Air Quality
PM 2.5: 2.3 ppm
PM 10: 1 ppm
Sulfur Dioxide: 1 ppb
Carbon Monoxide: 16.9 ppm
Ozone: 6.5 ppb
Nitrogen Dioxide: 26.8 ppb

Established by IBM Bluemix
Demo video for testing IoT/LoRa-based city-wide monitoring system
Future Smart Services & Applications by IoVs

- Disease Spreading model
- Alarm for Hospital
- Medical planning

- Congestion Predict
- Road Pothole Detection
- Traffic Planning

- Air Quality Standard
- Alarm for Air Pollution
- Environmental planning

Traffic

Medicine

Environment
Internet of Things (IoT) makes every thing possible

Q&A

Thanks for your attention!