MEI-Center Summer School 2018: Challenges of the IoT in Healthcare and Medicine in Osaka U.

The Internet of Things for Healthcare and Medicine

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Contents

- Applications
- Research & Prototyping
- Protocols & Standards
- IoT Healthcare
- Open Issues
- Security

A Conceptual Framework for an IoT-Based Health Assistant and Its Authorization Model
Internet of Things (IoT): Things to Human Value

Connected World

- A programmable world
- Everyday objects are interconnected
- Objects are smart enough to make decision
Wearable Computing Devices: Global Forecast

- Smart Watches
- Wearable 3D Motion Trackers
- Sports/Activity Trackers
- Healthcare
- Smart Glasses
- Smart Clothing
- Wearable Cameras

Graph showing the forecast of wearable computing devices from 2013 to 2019, with a significant increase in the healthcare segment predicted in 2019.
IoT Healthcare Devices

- Fitbit
- Smart Watch (Pebble, Samsung, Apple)
- Smart Slipper (24eight)
- Hapifork (Hapidlabs)
- Smart Glass/Lens (Google)
- Fiix (Conventis)
- Smart Pills (Proteus)
- GlowCaps (Vitality)
- Smart Seating/Bed/…
## IoT Healthcare Devices

### Clinical Efficiency
- AUGMEDIX
- TeleTracking
- fruit street
- AdhereTech
- Obaa
- simplifeye
- PRISTINE
- VOLUNTIS
- awarepoint
- evermind

### Clinical-Grade Biometric Sensors
- QUANTUS
- vitalconnect
- mc10
- Senseonics
- BL Healthcare
- connectedhealth
- Sotera Wireless
- iRhythm
- proteus Digital Health
- EarlySense
- Monica Healthcare
- SilentAlert
- EYENETRA

### Consumer / Home Monitoring
- Qardio
- Whoop
- aira
- CHRONOTHERAPEUTICS
- BIOSERENITY
- SUNSPRITE
- kinsa
- TURINGSENSE
- INFOBIONIC

### Infant Monitoring
- Sproutling
- BABYBJ
- mimo
- Owlet

### Sleep Monitoring
- beddit
- NovaSom
- hello

### Fitness Wearables
- senso®
- LUMO
- om signal
- lark
- motiv
- ATHOS
- ATLAS
- MOOV
- Withings
- Jawbone
- MISFIT

### Brain Sensors / Neurotechnology
- neuroVigil
- Thync
- muse
- NeuroSky
- halo

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[https://www.cbinsights.com/research/iot-healthcare-market-map-company-list/](https://www.cbinsights.com/research/iot-healthcare-market-map-company-list/)
Global Health and Aging

Young Children and Older People as a Percentage of Global Population: 1950-2050

The Speed of Population Aging
Time required or expected for percentage of population aged 65 and over to rise from 7 percent to 14 percent
Health Care Expenses for Elderly People

Bluetooth Tags in Healthcare

Source: Kontakt
IoT Healthcare Benefits

Improved Patient Engagement

Identify Patient Needs and Provide Tailored Services

Closing Patient-Provider Communication Gap

Improved Decision-Making

Reduction in Healthcare Cost
IoT-Based Healthcare

System

Clinical Care

Remote Monitoring

Healthcare Innovation
IoT Accelerates Healthcare Transformation

Traditional Model

New Model

Wellness and Preventive Care
IoT Healthcare Network

It supports access to the IoT backbone, facilitates the transmission and reception of medical data, and enables the use of healthcare-tailored communications.
The Internet of Things for Healthcare and Medicine: Advances and Challenges

**IoT Platform: Service Platform Framework**

A systematic hierarchical model of how caregivers or agents can access various databases from the application layer with the help of a support layer.

- **Accessing layer**
  - Community health center
  - Hospital
  - Personal device

- **Business implementation layer**
  - HL7/XML encode
  - Personal health record business
  - Diagnosis

- **Support layer**
  - Health record
    - Data organization
    - Data structure
  - Basic information system
    - User register
    - Information query
  - Privilege system
    - Function management
    - Role management

- **Data persistent layer**
  - Health record database
  - Health record database
  - User information database
  - Privilege database
Health Level Seven (HL7)

“Level Seven” refers to the highest level of ISO communication model

ISO Communication Architecture Model

HL7 Family of Standards

HL7 has “interoperability” as goal

The Internet of Things for Healthcare and Medicine: Advances and Challenges
IoT Healthcare Service Framework

The Internet of Things for Healthcare and Medicine: Advances and Challenges

- Context Awareness
- Wearable Healthcare Device Management
- Home Healthcare Device Management

Healthcare Device Domain

Healthcare Network Domain

Healthcare Application Domain

Open Device API

Open Service API

M2M Area Network

Healthcare M2M Gateway

M2M Core

Healthcare M2M SC

Healthcare Server Platform

Healthcare Provider Application

Diet & Wellness Monitoring

Family Care Application
IoT Platform: Automated Design Methodology

The diagram illustrates the process of designing an IoT platform for healthcare. It involves human machine interface, multidisciplinary optimization platform of ADM, behavior analysis, and design information and application management. The process includes human input, visualization interface, computer-aided design, strategy optimization, resource optimization, parameters optimization, subsystem optimization, database, information and application integration, design collaboration, and IoT technology. The goal is to move from a patient in a wheelchair to a healthy individual.
IoT Healthcare Platforms

- **Apple HealthKit (2014.6)**
  - Health data sharing platform for iOS8
  - Partnership with Mayo Clinic and Epic Systems
  - HealthKit data is limited to Apple specified types

- **Google Fit (2014.6)**
  - Cloud-based fitness data sharing platform
  - Provide cross-platform APIs for developer to keep track of customers’ fitness goals

- **Samsung SAMI (2014.5)**
  - Cloud-based healthcare platform to store and analyzing healthcare data
  - Simband: platform for collecting and analyzing biophysical data for preventative health
IoT-Healthcare Services and Applications

Smartphone in Healthcare

Smartphone auxiliary healthcare applications

- Johns Hopkins antibiotic guide, Prognosis, Diagnose, SMCC, 5-Minute infectious disease consult, MS diagnosis and management, Stanford guide to antimicrobial therapy, ePocrates ID, Infectious diseases, notes, UpToDate, Pocket medicine infectious diseases, Smart medical-labs, drug, clac, Palm LabDX, Normal lab values, Lab unit converter, Davis’s laboratory and diagnostic tests, Video laser level, EyeChart, DizzyFIX.

Diagnosis apps


Drug reference apps

- PubSearch, PubMed on tap, The/medical search, MD on tap, askMEDLINE, PICO, Disease associations, Retina medical search.

Literature search apps

- i-Surgery notebook, Medical diagnosis books, Eponyms, Netter’s atlas of human anatomy, Diseases dictionary, Netter’s anatomy flash card, Blausen ear atlas, Oxford handbook of clinical specialties, Dissection, Cranial nerves, iSilo, ICPR, iResus.

Medical education apps

- Epocrates MedMath, Calculate by QxMD, MedCalc, Medical calculator, Calculate, Caddy medical calculator, Archimedes, uBurn Lite, Softforce’s Antibiotic, Paeds ED, eGFR Calculators.

Calculator apps

- Voalte One, Clinical reach, Amcom mobile connect, Practice unite, Emergency medicine program, Tradassan, mVisum, Vocera.

Clinical communications apps

The Internet of Things for Healthcare and Medicine: Advances and Challenges
WBAN Towards IoT Healthcare

- A flexible solar energy harvester with MPPT
- A wearable sensor node with BLE transmission
- A smart phone application acting as the IoT gateway for sensor data visualization and emergency notification

“An autonomous wireless body area network implementation towards IoT connected healthcare applications”
Wearable IoT Data Architecture

- A traceability route formation using a network graph based on techniques such as tuple of inputs and the Büchi automaton.

- Provides proper trace routes for the personal data from the originating source to the Health Information System (HIS)

“Wearable IoT Data Architecture”
Cloud-IoT in Health Monitoring

1. Scalable capabilities and resources of the cloud compensate IoT technological constraints

2. While the IoT capability to interact with real world things enables diversification of cloud based services

“A Cloud-IoT Based Sensing Service for Health Monitoring”
IoT-Healthcare: Health Assessment Framework

“A comprehensive health assessment framework to facilitate IoT-assisted smart workouts: A predictive healthcare perspective”
Ontology in IoT Healthcare

Type-2 fuzzy ontology-aided recommendation systems for IoT-based healthcare
We-Care System for IoT Healthcare

Architecture:
(1) We-Watch wristband, the (2) We-Care services board and the (3) cloud services

It follows a standardized protocol stack
Non-invasive method to detect PD is to check for a voice disorder, because almost 90% of PD patients suffer from the impairment or disorder of the vocal folds.
“Wearable IoT sensor based healthcare system for identifying and controlling chikungunya virus”
IoT in Precision Medicine

Risk minimization in ADR
Safe and Secure Medication
Medical Error Minimization
Automation in Gene Expression Measurement

A conceptual model of an IoT-aided personalized DBS therapy.
The Internet of Things for Healthcare and Medicine: Advances and Challenges

- Protocols & Standards
- Research & Prototyping
- Applications
- Open Issues
- Security

IoT Healthcare
IoT Device Interoperability
IoT Healthcare Device Life Cycle

1. Manufactured
   - Installed
   - Commissioned

2. Application running

3. SW update
   - Application reconfigured

4. Application running

5. Decommissioned
   - Removed & replaced
   - Reownership & recommissioned

- Bootstraping
- Operational
- Maintenance & re-bootstrapping
- Operational
- Maintenance & re-bootstrapping

Time
Internet of Things (IoT) Stack

- **Application**
  - Application (JSON)
  - HTTP/CoAP

- **Middleware**
  - TLS/DTLS

- **Transport**
  - TCP/UDP

- **Network**
  - RPL
  - IPv6
  - 6LoWPAN
  - 3G/4G
    - IEEE 802.11
    - IEEE 802.15.4

- **Adaptation**

- **PHY & MAC**

- **ISO/IEEE 11073**
  - Health
  - Zigbee
  - BLE
IEEE 802.15.4

- Defines the operation of LR-WPANs (PHY & MAC)
- 10-meter range and a transfer rate of 250 kbps
- RT suitability by reservation of guaranteed time slots
- Collision avoidance through CSMA/CA
- Three possible frequency bands: 868/915/2450 MHz.
Zigbee and BLE

<table>
<thead>
<tr>
<th>Protocols &amp; Standards</th>
<th>Sejong University (CSE)</th>
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<tbody>
<tr>
<td><strong>Zigbee Network</strong></td>
<td></td>
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</table>

**Applications:** Medical device data collection, healthcare, fitness, beacons, security, and home entertainment industries.

<table>
<thead>
<tr>
<th>Network type</th>
<th>Bluetooth (BLE)</th>
<th>ZigBee</th>
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</thead>
<tbody>
<tr>
<td>Personal area network (PAN), which supports few nodes</td>
<td>Local area network (LAN), which supports many nodes</td>
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</table>

<table>
<thead>
<tr>
<th>Range*</th>
<th>77 meters</th>
<th>291 meters</th>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Operating system</th>
<th>Android, iOS, Windows 8, OS X</th>
<th>Not currently compatible</th>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Topology</th>
<th>Mesh and star</th>
<th>Mesh only</th>
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<table>
<thead>
<tr>
<th>Throughput</th>
<th>270 kbps</th>
<th>250 kbps</th>
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</table>

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Frequency-hopping spread spectrum (FHSS)</th>
<th>Direct-sequence spread spectrum (DSSS)</th>
</tr>
</thead>
</table>

| Transmit power | 10 mW | 100 mW |
6LoWPAN Standard

- **6LoWPAN**—“IPv6 over Low-Power Wireless Personal Area Networks”
- A networking technology or adaptation layer that allows IPv6 packets to be carried efficiently within small link layer frames, such as those defined by IEEE 802.15.4.

- **RPL**: Routing for Mesh topology network to achieve long range communications
- RPL is located at the IPv6 and is not interfaced directly to the lower level protocols, so that it's easy to integrate to any connectivity solutions.
Constrained Application Protocol (CoAP)

- CoAP has lower communication overhead compared to HTTP
- CoAP headers are represented using binary coding to minimize payload overheads
- HTTP transaction bytes are 10 times higher than CoAP transaction bytes
User Datagram Protocol (UDP)

- Packets are transmitted over UDP instead of TCP
- UDP is suitable for lossy networks with limited bandwidth
- Sizes of UDP headers are smaller than TCP headers
- UDP does not require 3-way handshake

### TCP Segment Header Format

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<tr>
<th>Bit #</th>
<th>0</th>
<th>7</th>
<th>8</th>
<th>15</th>
<th>16</th>
<th>23</th>
<th>24</th>
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<td>96</td>
<td>Data Offset</td>
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<th>8</th>
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</tbody>
</table>

### UDP Datagram Header Format

<table>
<thead>
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<th>7</th>
<th>8</th>
<th>15</th>
<th>16</th>
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</table>
ISO/IEEE 11073 Health Informatics Standard

- Enables communication between medical, health care and wellness devices and with external computer systems.

- Personal health and fitness devices: Glucose monitors, pulse oximeters, weighing scales, medication dispensers and activity monitors.

- Continuing and acute care devices: Pulse oximeters, ventilators and infusion pumps.

MIDI- Medical Data Information Base; CMDISE- Common Medical Device Information Service Element; ACSE- Association Service Control Element

✓ RT plug-and-play interoperability.
✓ Efficient exchange of care device data.
A Conceptual Framework for an IoT-Based Health Assistant and Its Authorization Model
IoT Healthcare Security

**IoT Security: Motivation**

- **Case study**
  - Remotely hacked an IoT enabled car
  - Consumer gadgets sending phishing and spam emails

- **Security study by HP, 2014**

<table>
<thead>
<tr>
<th>Security Issue</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vulnerable user interface</td>
<td>60%</td>
</tr>
<tr>
<td>Unencrypted communication</td>
<td>70%</td>
</tr>
<tr>
<td>Weak password</td>
<td>80%</td>
</tr>
<tr>
<td>Violate user privacy</td>
<td>80%</td>
</tr>
</tbody>
</table>

Internet connectivity in Healthcare Raises potential security risks and threats.

- Healthcare devices deal with private information
- This information needs to be protected from been revealed, modified or forged
- Critical to identify and analyze distinct features of IoT security and privacy
Security Issues in IoT Healthcare

Threat mode
- Attack surface
- Attacks
- Adversary
- Risk
- Consequences

Security services

Research issue
IoT Healthcare Security Requirements

- **Information Security**
  - Integrity
  - Confidentiality
  - Anonymity
  - Non Repudiation
  - Freshness

- **Functional Security**
  - Interoperability
  - Scalability
  - Availability

- **Access Level Security**
  - Authentication
  - Authorization
IoT Healthcare Security Constraints/Challenges

**HW Limitations**
- Low CPU speed
- Low Communication BW
- Low storage

**SW Limitations**
- Lightweight OS
- Lack of dynamic SW update

**Network Limitations**
- Multi-protocol Communications
- Heterogeneous Devices and Media
# IoT Healthcare Attack Surface

<table>
<thead>
<tr>
<th>Network</th>
<th>Attack Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constrained Network</td>
<td><strong>Device ↔ Device</strong>   &lt;br&gt;e.g. Communication Between Body Temp Sensor and Env. Temp Sensor</td>
</tr>
<tr>
<td></td>
<td><strong>Device ↔ Coordinator</strong> &lt;br&gt;e.g. Communication Between ECG Sensor and Sensor Hub</td>
</tr>
<tr>
<td></td>
<td><strong>Coordinator ↔ Gateway</strong> &lt;br&gt;e.g. Communication Between Sensor Hub and Medicine Box</td>
</tr>
<tr>
<td></td>
<td><strong>Device ↔ Controller</strong> &lt;br&gt;e.g. Communication Between EMG Sensor and Smartphone</td>
</tr>
<tr>
<td>Public Network</td>
<td><strong>Controller ↔ IoT Service Provider</strong> &lt;br&gt;e.g. Communication Between Smartphone and Home Device</td>
</tr>
<tr>
<td></td>
<td><strong>Service ↔ Service</strong> &lt;br&gt;e.g. Medical IoT service consumes Payment service</td>
</tr>
</tbody>
</table>
IoT Healthcare Attach Tack Taxonomy

- Information Disruption-Centric
- Host Properties-Centric
- Network Properties-Centric
Attack Taxonomy: Information Disruptions

- Interruption
  - Denial – Of – Service attack.
  - Communication links lost or made unavailable

- Interception
  - Eavesdrop on the information to threaten data privacy and confidentiality

- Modification
  - Tamper medical information

- Fabrication
  - Forge or inject false information

- Replay
  - Replay existing information
Attack Taxonomy: Host Properties

- **User Compromise**
  - Compromise a user’s health device or network
  - Mostly involves revealing passwords, cryptographic keys or user data
- **Hardware Compromise**
  - Physically tamper the device
  - Extract on – device program code, keys and data
  - Reprogram with false program
- **Software Compromise**
  - Forces malfunction by taking advantages of the vulnerabilities in either the operating system or other applications of the device
Attack Taxonomy: Network Properties

- Standard Protocol Compromise
  - An attacker deviates from standard protocols
  - Acts maliciously to threaten service availability, message privacy, integrity, and authenticity

- Network Protocol Stack Attack
Attack Taxonomy: Network Properties Communication Protection

- **End to End Network Security**
  - Host Identity Protocol (HIP) based approaches

- **End to End Transport Security**
  - Datagram Transport Layer Security (DTLS) based approaches

- **Provides**
  - Authentication
  - Confidentiality
  - Integrity
  - Non repudiation

- **Goal**
  - Reduced computation
  - Reduced communication
IoT Healthcare: Security Model

[Diagram showing the security model with steps for protection, detection, and reaction services, including feedback loops and security concerns for attack, threat, and vulnerability.]
IoT Healthcare Forensics

1. Identification
   - Incident
   - Evidence

2. Preservation
   - Secure Logging

3. Organization
   - Examination
   - Analysis
   - Correlation

4. Collection
   - Logged Evidence - Retrieval

5. Presentation
   - Proof
   - Examination Result
   - Analysis output
A Conceptual Framework for an IoT-Based Health Assistant and Its Authorization Model
Continua Design Guidelines

- Secure end-to-end ICT framework for personal connected health and care using open standards (by the Personal Connected Health Alliance (PCHAlliance))

- Provides a set of defined interfaces that enable the secure flow of medical data among sensors, gateways, and end services

- Interoperable ecosystem of personal connected health devices.
Continua E2E Reference Architecture
Continua Architecture for IoT Healthcare

**Personal Health Device**
- Thermometer
- Pulse Oximeter
- Pulse/Blood Pressure

**IoT Wearable Healthcare Device**
- Smart Band (Fitbit)
- Smart Watch (Apple Watch, Galaxy Gear)
- Smart Patch (CGM-Dexcom)

**Aggregation Manager**

**IoT Healthcare Platform**

**Health Records**
- EHR
- PHR

**Web Client**

**Center for U-Healthcare Convergence Network**

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The Internet of Things for Healthcare and Medicine: Advances and Challenges
IoT Healthcare Convergence Architecture

XML

Constrained Environment

Secure

Efficient

Reliable

Extensible

Simple

Platform Independent

11073 DIM*

CoAP/SOAP**

DTLS/TLS

UDP/TCP

6LoWPAN

Internet

IoT Healthcare Network

* DIM: Domain Information Model
**CoAP: Constrained Application Protocol
SOAP: Simple Object Access Protocol
IoT Health Convergence Architecture: Standard

IoT Standard (oneM2M)
- Application
- CoAP/HTTP
- DTLS/TLS
- UDP/TCP
- IPv4/IPv6 (IETF 6LoWPAN)
  - 3G/4G, IEEE 802.11, IEEE 802.15.4

Healthcare Standard (ISO/IEEE 11073 PHD)
- ISO/IEEE 11073 DIM
- ISO/IEEE 11073 – 20601 (ROSE/ACSE)
- Bluetooth/Zigbee (No IP)
  - IEEE 802.15.1, IEEE 802.15.4

IoT Healthcare Platform based International Standard
- ISO/IEEE 11073 DIM
- ISO/IEEE 11073 Service Model
- CoAP/HTTP/SOAP
- DTLS/TLS
- UDP/TCP
- IPv4/IPv6 (IETF 6LoWPAN)
  - 3G/4G, IEEE 802.11, IEEE 802.15.4

Center for U-Healthcare Convergence Network
IoT Healthcare Open Issues

1. Standardization
2. App Development Process
3. Cost Analysis
4. Technology Transition
5. Business Model
6. QoS and Plan B
7. Security
8. Ecological Impact
IoT Healthcare Security Research Directions

- Energy-Efficient Security
- Identity Management
- Trust Management
- Secure Group Management
- IoT Forensics
- Data Transparency
- Privacy
Contents

- Applications
- Protocols & Standards
- Open Issues
- Security
- Research & Prototyping
- IoT Healthcare

A Conceptual Framework for an IoT-Based Health Assistant and Its Authorization Model
Research & Prototyping: Smart Devices

**T-mote Sky**
- Advanticsys
- IEEE 802.15.4 compliant wireless sensor module

**Re Mote**
- Zolertia
- Hardware Development Platform
- IEEE 802.15.4 & Zigbee compliant

**Waspmote**
- Libelium
- 4G / 3G / GPRS /GPS
- ZigBee/ 802.15.4 /WiFi
- RFID/NFC /BL

http://www.snm.ethz.ch/Projects/TmoteSky
https://github.com/Zolertia/Resources/wiki/RE-Mote
http://www.libelium.com/products/waspmote/
# Research & Prototyping: IoT Operating System

<table>
<thead>
<tr>
<th>Contiki</th>
<th>TinyOS</th>
<th>RIOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Open Source</td>
<td>• Embedded, component-based OS and platform for low-power wireless devices.</td>
<td>• Linux of IoT</td>
</tr>
<tr>
<td>• For networked, memory-constrained systems with a focus on IoT devices.</td>
<td></td>
<td>• Allows application programming with C/C++,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Provides multithreading and RT abilities</td>
</tr>
</tbody>
</table>
Research & Prototyping: Cloud Platform

Watson IoT  AWS IoT  Azure IoT

https://thingspeak.com/
Development Platform for Medical Devices

- **BODY POSITION SENSOR**
- **SNORE SENSOR**
- **ALERT PATIENT BUTTON**
- **SPIROMETER**
- **TEMPERATURE SENSOR**
- **SOUND GENERATOR**
- **EMG SENSOR**
- **ECG SENSOR**
- **AIRFLOW SENSOR**
- **GSR SENSOR**
- **GLUCOMETER SENSOR**
- **SPO2 PULSIOXIMETER**
- **BLOOD PRESSURE SENSOR**

**HW**

**SW**
Healthcare Ecosystem
Electronic Health Record with CDSS

ADT- Admission, Discharge, Transfer; CPOE- Computer Provider Order Entry.
Tools and Technologies

Concluding Remarks

IoT Healthcare is a Interdisciplinary Subject.

Helping transform to a data-driven, patient-centric model (collaborative, distributed, and personalized).

IoT healthcare will change elderly care.

Multi-dimensional R&D efforts in IoT-driven healthcare are visible.

IoT Healthcare Convergence and Security are two major issues.
Discussion