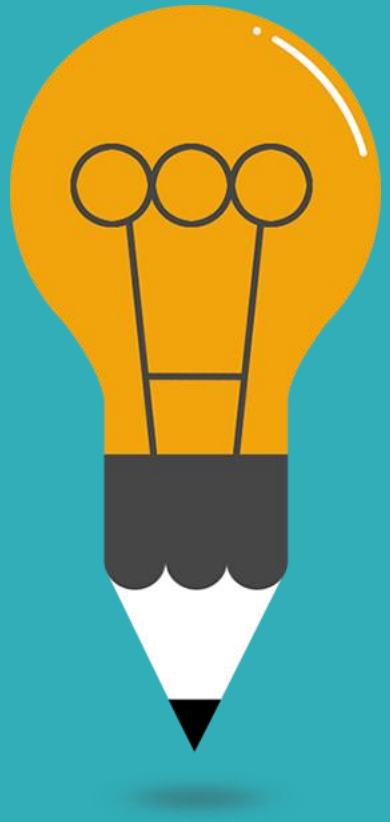
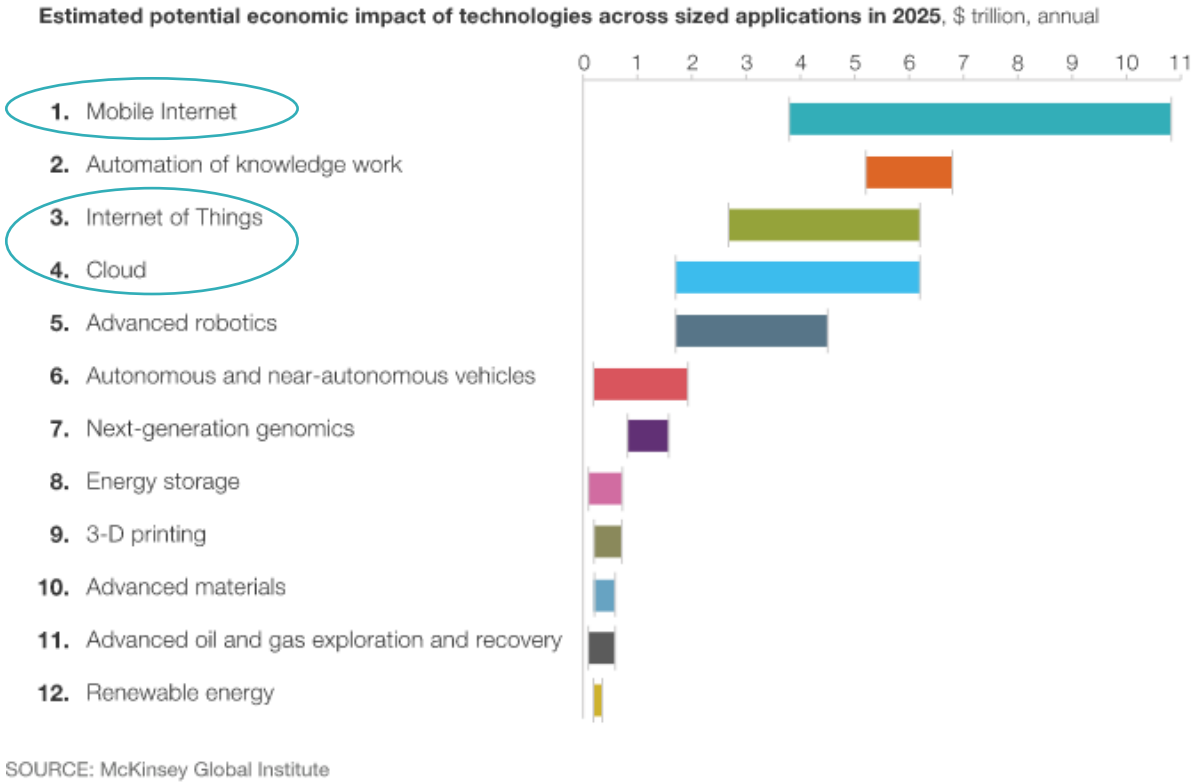


IoT and Mobile Sensing

What is IoT?

Twelve Potentially Economically Disruptive Technologies (2025)



What is the Internet of Things?

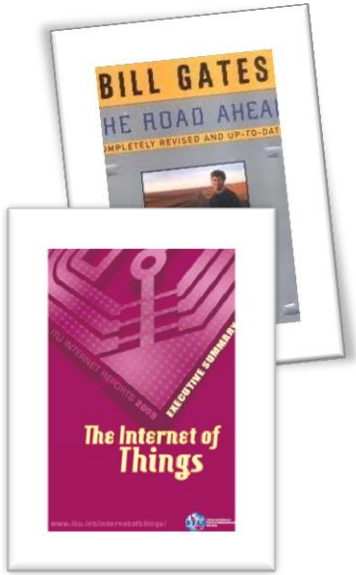
- Internet connects all people, so it is called “the Internet of People”
- IoT connects all things, so it is called “the Internet of Things”

Origin

The basic idea of the Internet of Things appeared in the 1990s

1995

Bill Gates ‘The Road to the Future’ Object Internetworking



2005

International Telecommunication Union (ITU), ‘ITU Internet Report 2005’
The ubiquitous "Internet of Things" communication era is coming soon

2009

IBM ‘smart planet’

2009

Prime Minister (Mr. Wen)
‘Sensing China’

Development: Diverse Sources

- RFID
  - In 1999, the MIT Auto-ID Center proposed the EPC (Electronic Product Code) system and the concept of the Internet of Things
- Pervasive Computing
  - Sensing and Inter-connection
- Embedded System
  - In the late 1990s, the sensor network started
  - In 2006, NSF workshop on CPS (Cyber-Physical Systems)

The Concept of IoT

- Definition (------Wikipedia)

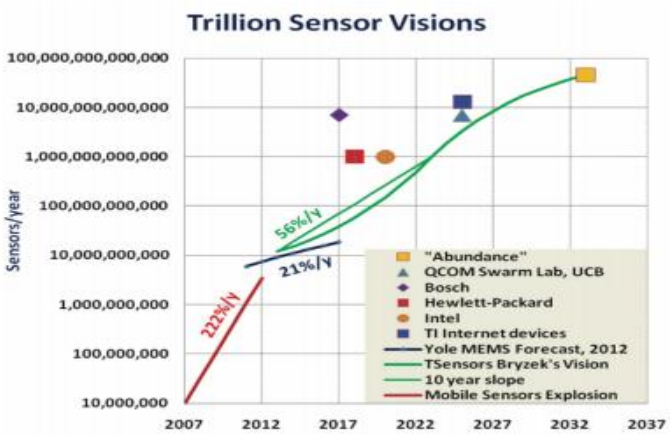
  The Internet of Things, also called The Internet of Objects, refers to a wireless network between objects, usually the network will be wireless and self-configuring, such as household appliances.

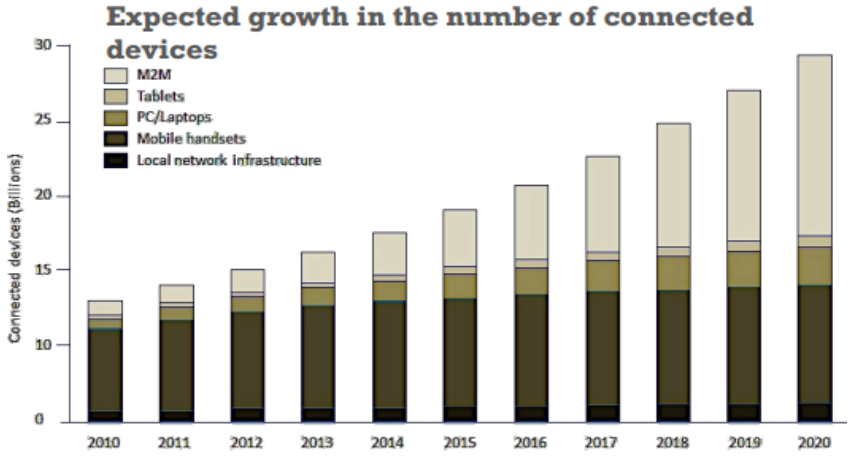
- The concept of the Internet of Things is actually proposed by Chinese, integrating the concepts of CPS (Cyber-Physical Systems), the European Union IoT (Internet of Things) and Japan's U-Japan.
- It is an information carrier based on the Internet and traditional telecommunication networks, so that physical objects that can be independently addressed can be interconnected. Object equipment, autonomous terminal interconnection and universal service intelligence are three important features.

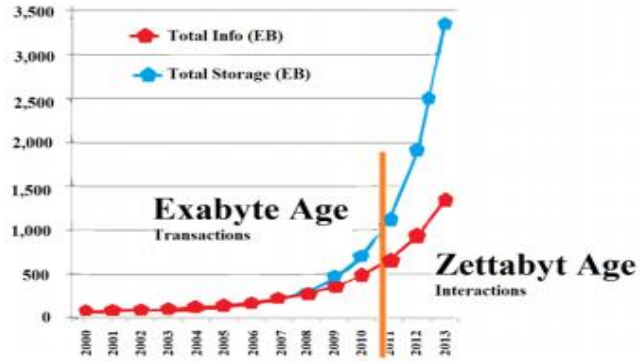
Object Interconnection

Object Interconnection: Bridge the physical world and the information world

The Development of IoT



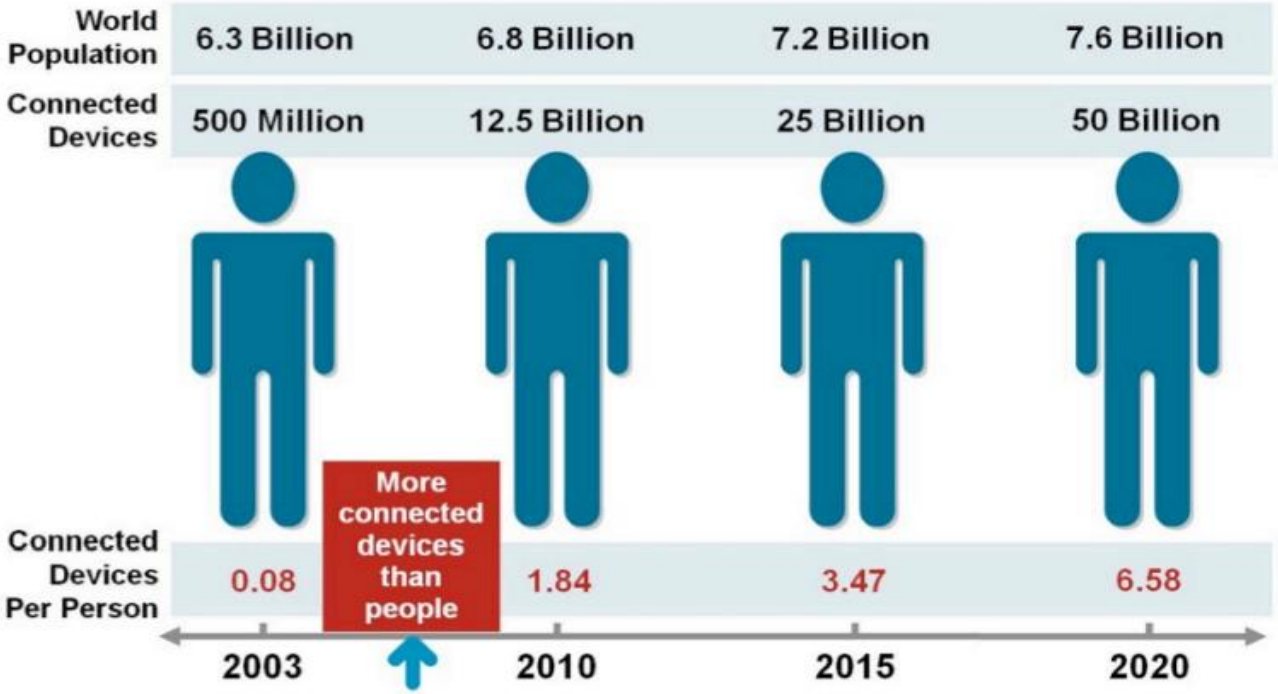




IoT:

Communication between device, people, processes, exchange of useful information and knowledge, generation of value

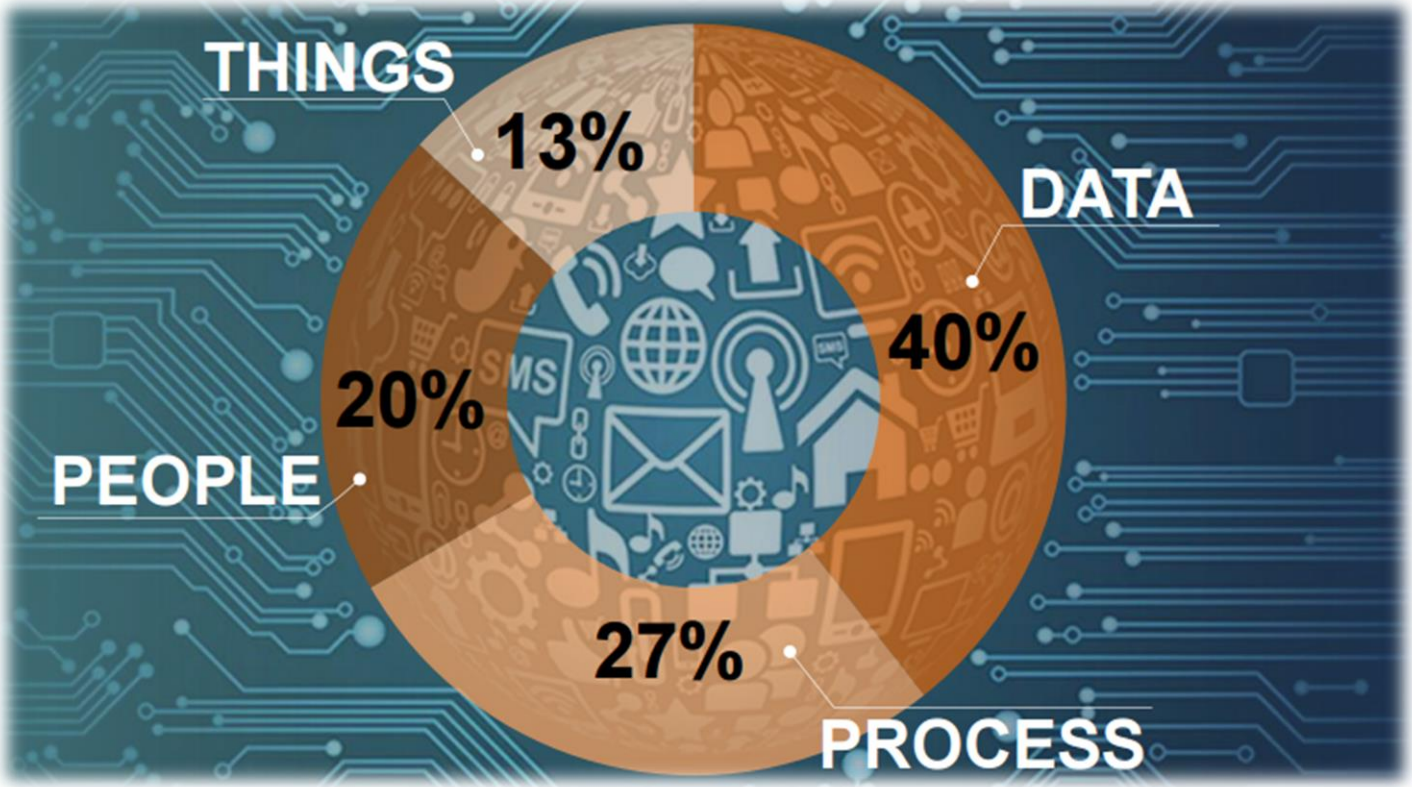
The Number of Connected Devices has Increased Rapidly



Source: Cisco IBSG, 2011

Core Element of IoT

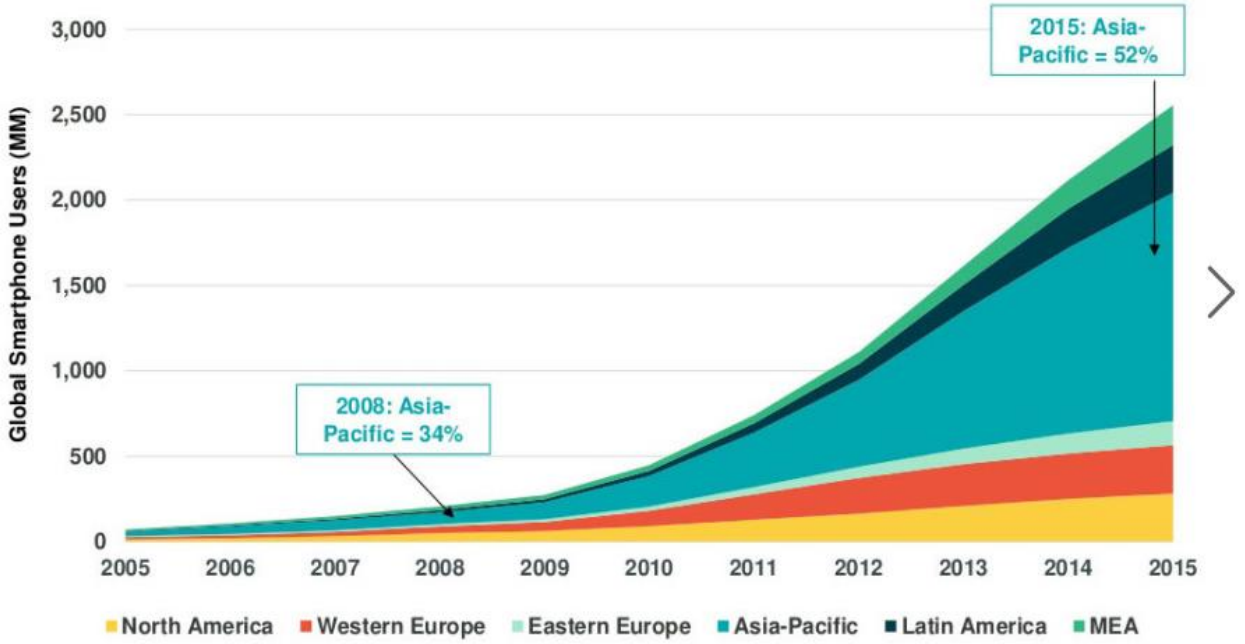
IoT is not only about Things



Source: Cisco IoT Global Study, 2014

Smartphone Users Increased Dramatically

World-wide Smartphone User Number, 2005-2015



Source: Internet Queen 2016 Internet Trend Report

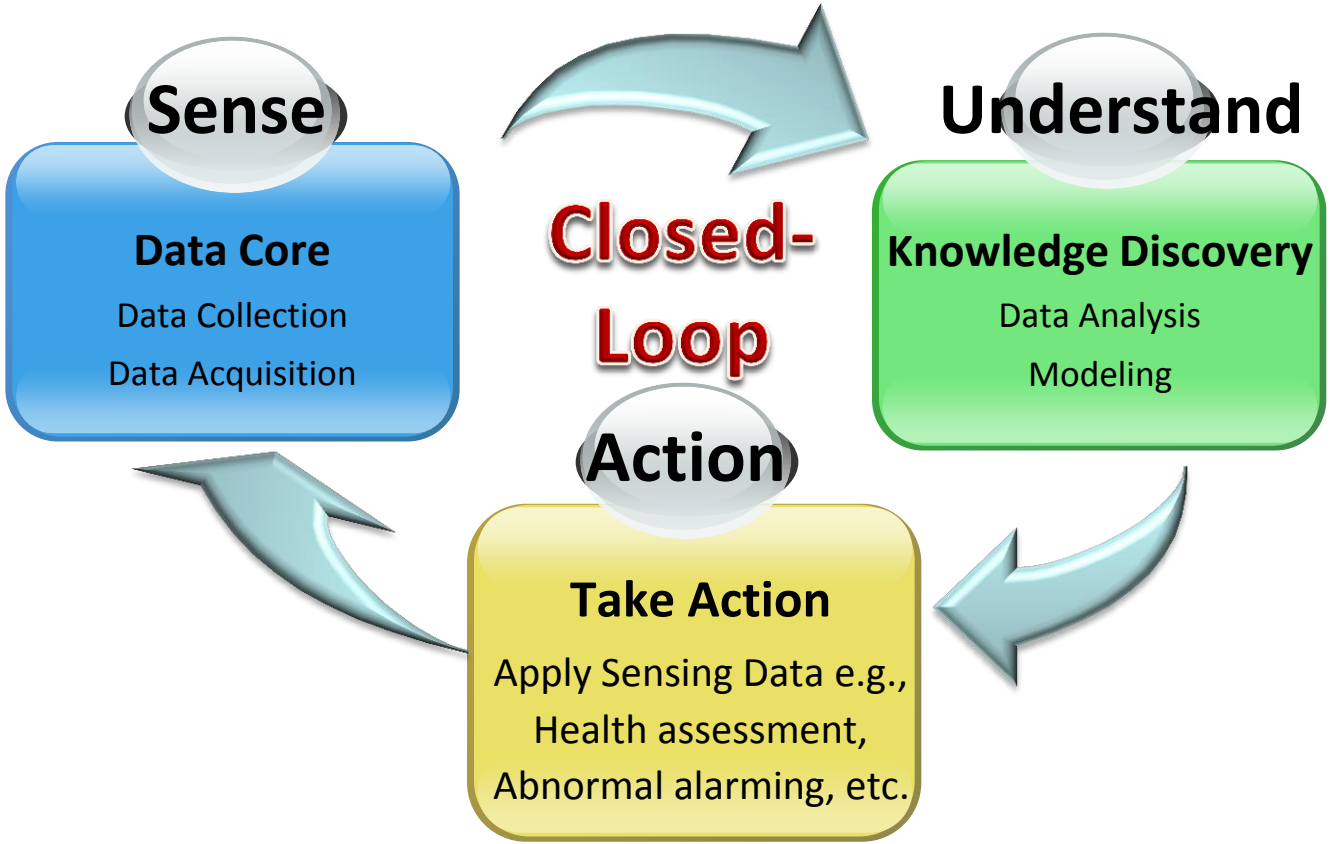
The Sensing Capability of Smartphone becomes Stronger

Sensors

Camera: Eye	Audio: Ear	Accelerator: Speed	GPS: Location	Gyro: Movement	Compass: Direction	Distance	Light: Ear	Others

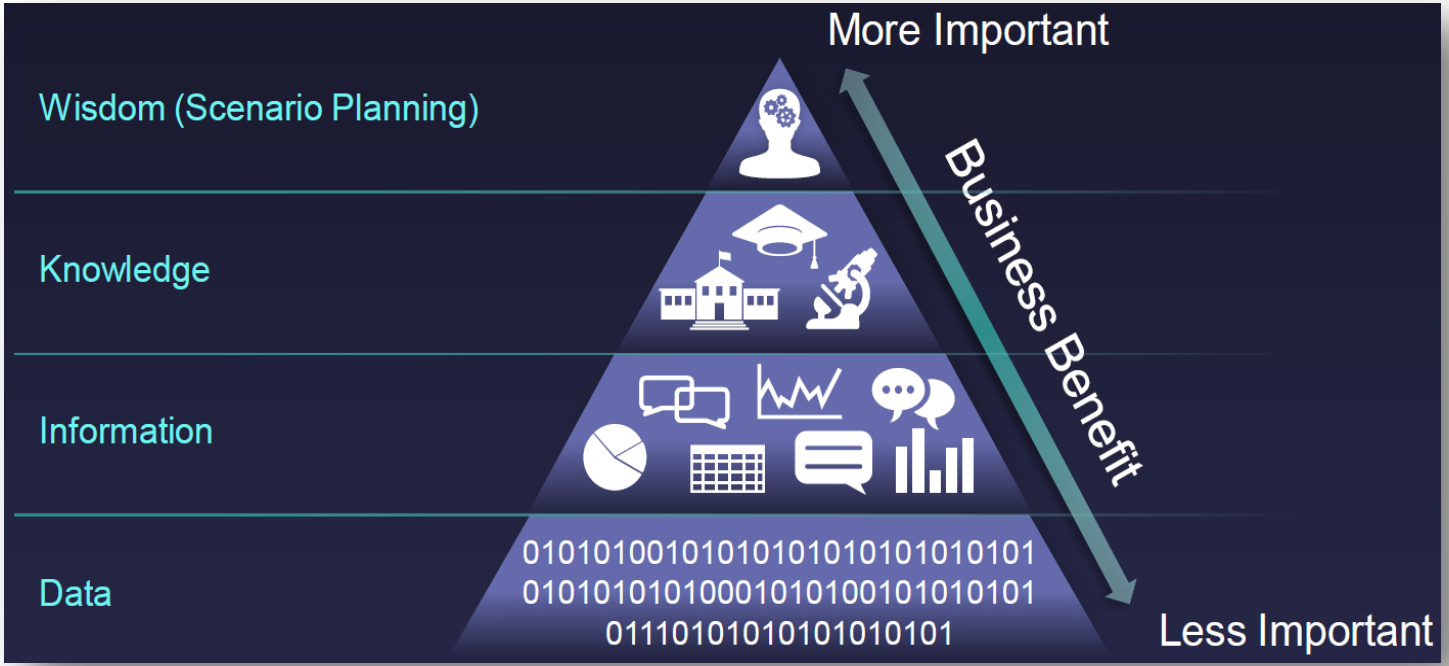
Smartphone becomes the remote control center of the IoT era

The Core of IoT: Sense-Understand-Action

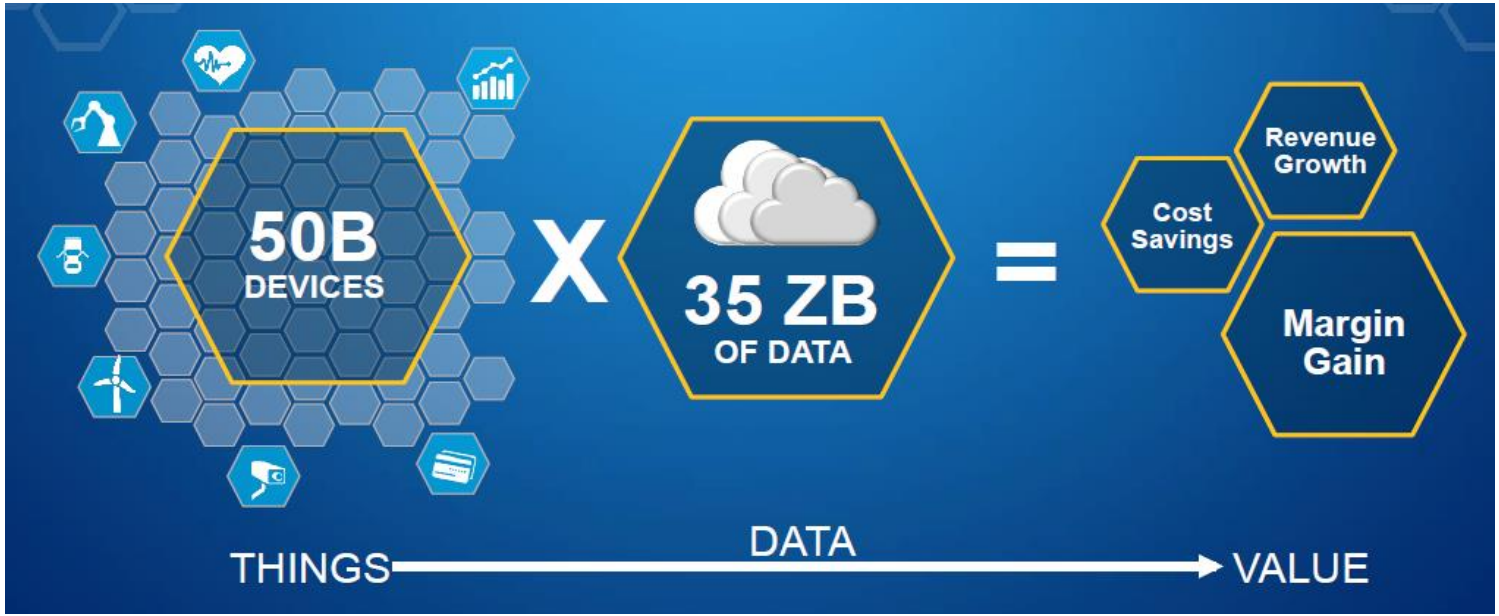


IoT Convert Data into Wisdom

Big Data becomes Open Data for Customers, Consumers to Use

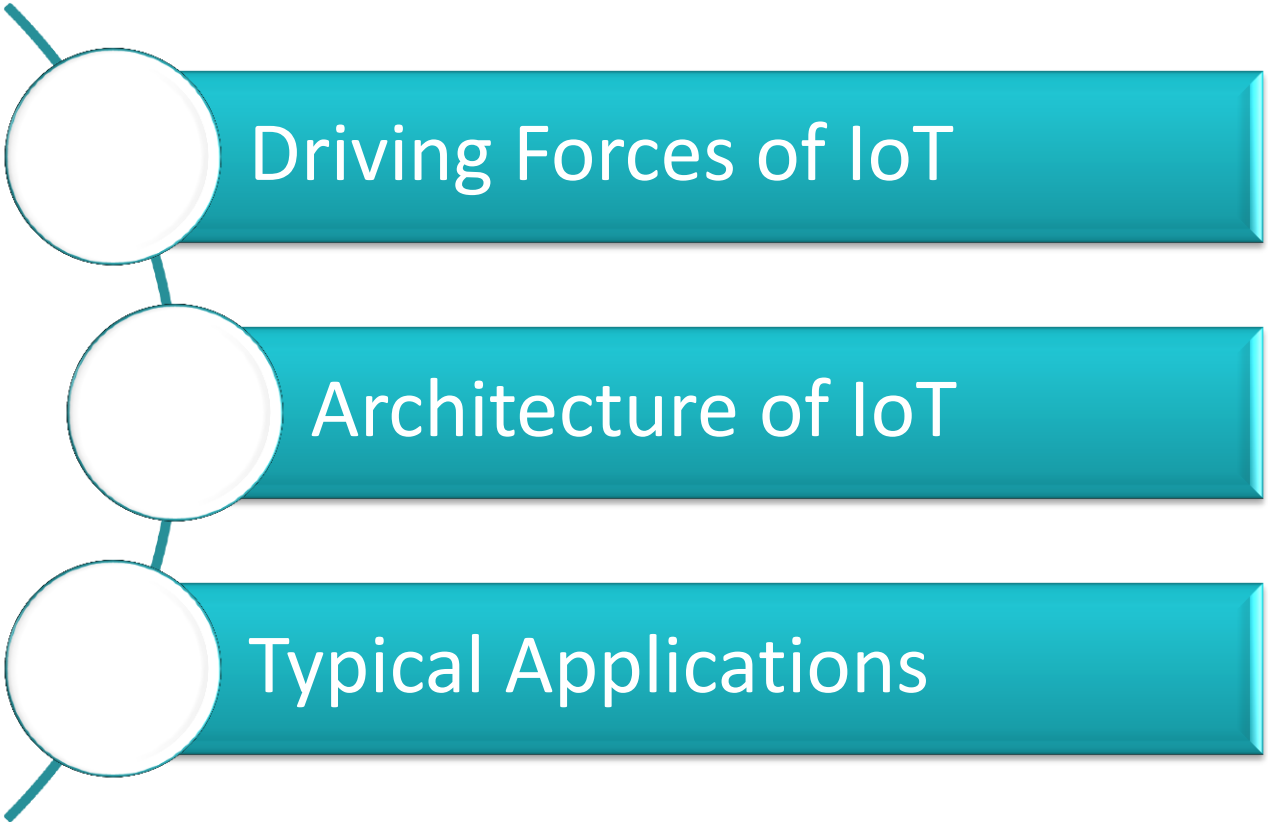


IoTs x AI = Unprecedented Value



IoT won't work without **Artificial Intelligence**

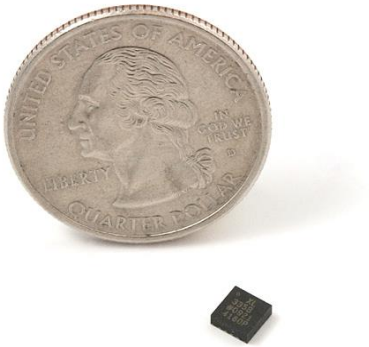
Doug Davis, Vice President
Internet of Things Group, Intel Corp.


Driving Forces of IoT
Architecture of IoT
Typical Applications

Driving Forces of IoT

1. Sensor Technology – Tiny, Cheap, Variety
2. Cheap Miniature Computers
3. Low Power Connectivity
4. Capable Mobile Devices
5. Power of the Cloud

1. Sensor Technology



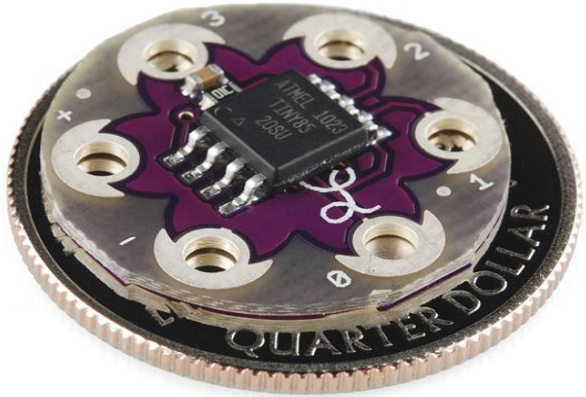
Accelerometer
(4mm diameter)

Force Sensor
(0.1N – 10N)

Pulse Sensor
$25

https://www.sparkfun.com/
https://www.adafruit.com/

2. Cheap Mini Computers



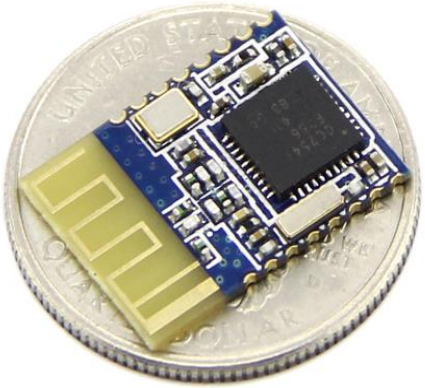
Lily Tiny

Key Parameters

Flash: 8 Kbytes
Pin Count: 8
Max. Operating Freq: 20 MHz
CPU: 8-bit AVR
Max I/O Pins: 6
Ext Interrupts: 6
SPI: 1
I2C: 1

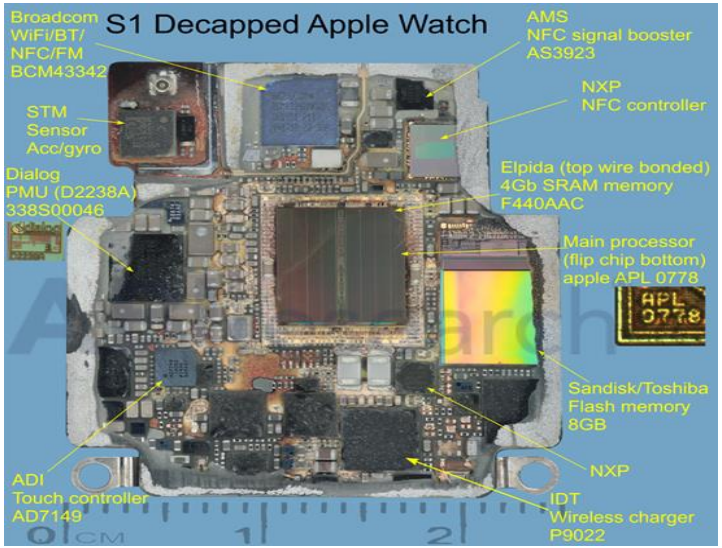
http://www.atmel.com/devices/ATTINY85.aspx?tab=parameters

3. Low Power Connectivity



Bluetooth Smart (4.0)
(Up to 2 years with a single Coin-cell battery)

4. Capable Mobile Devices



Quad Core 1.5 GHz
128 GB Internal Memory
3 GB RAM
16 MP Camera
2160p@30fps video
WiFI, GPS, BLE

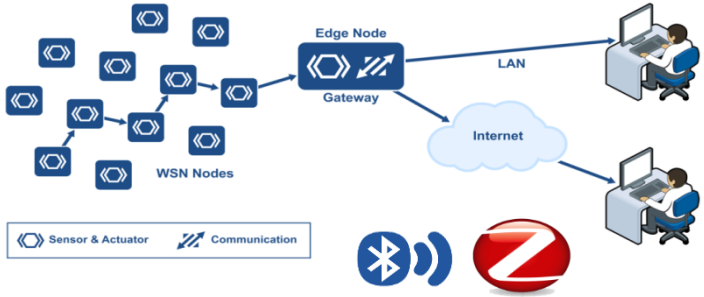
5. Power of the Cloud

ABCD's of IoT

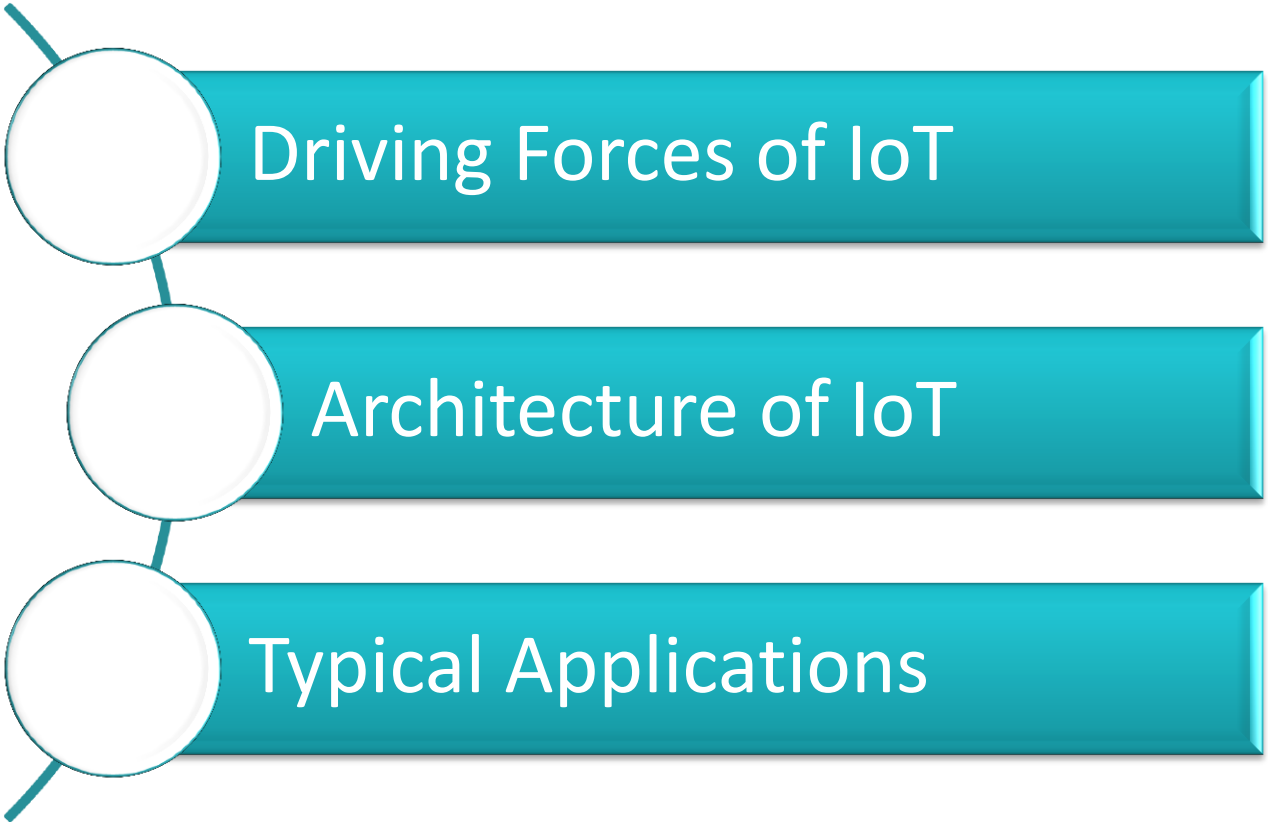
Applications

Big Data Analytics

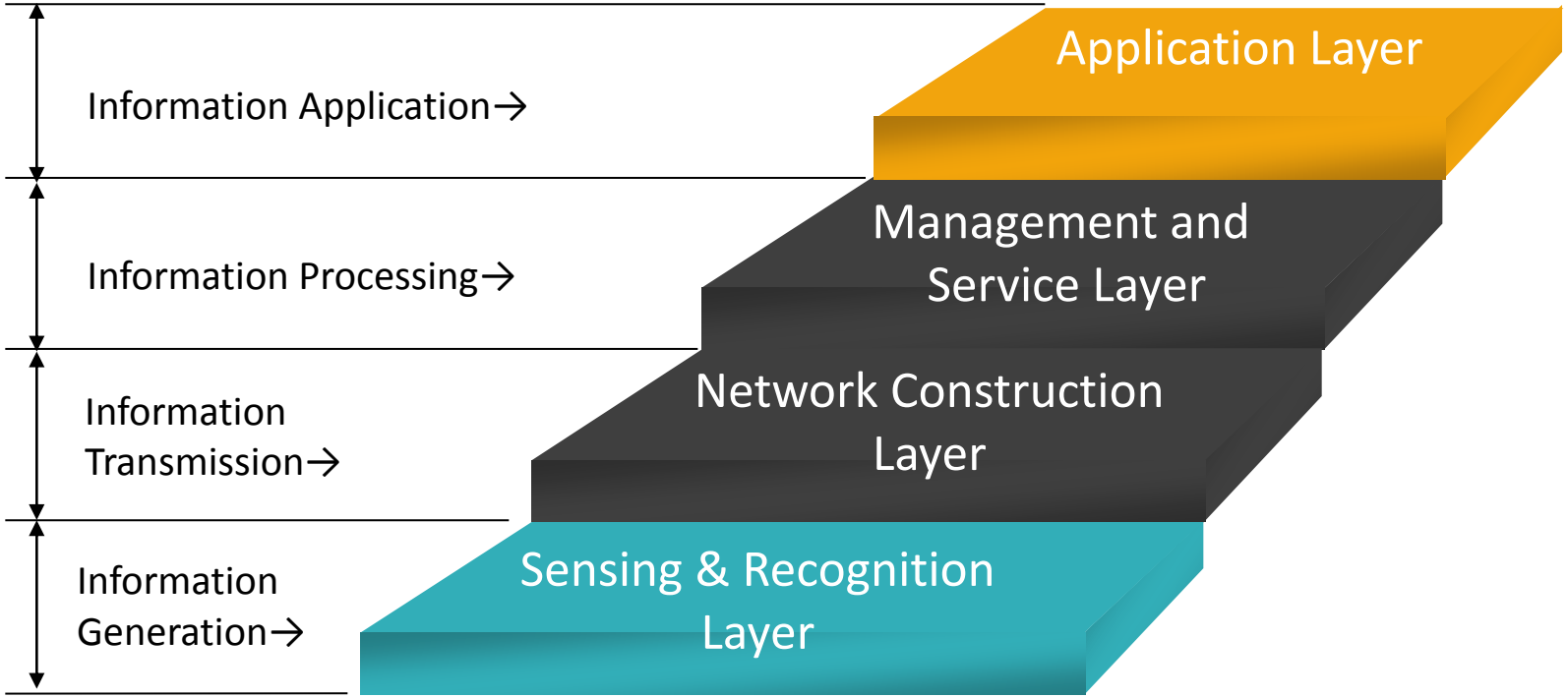
Connectivity and Communication



Devices – that are smart!


Driving Forces of IoT
Architecture of IoT
Typical Applications

Basic Architecture of IoT

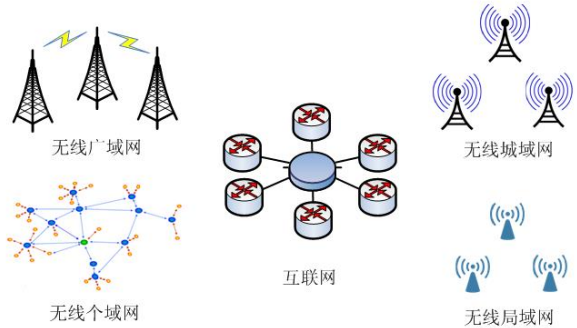


4-Layer Model of IoT

Applications

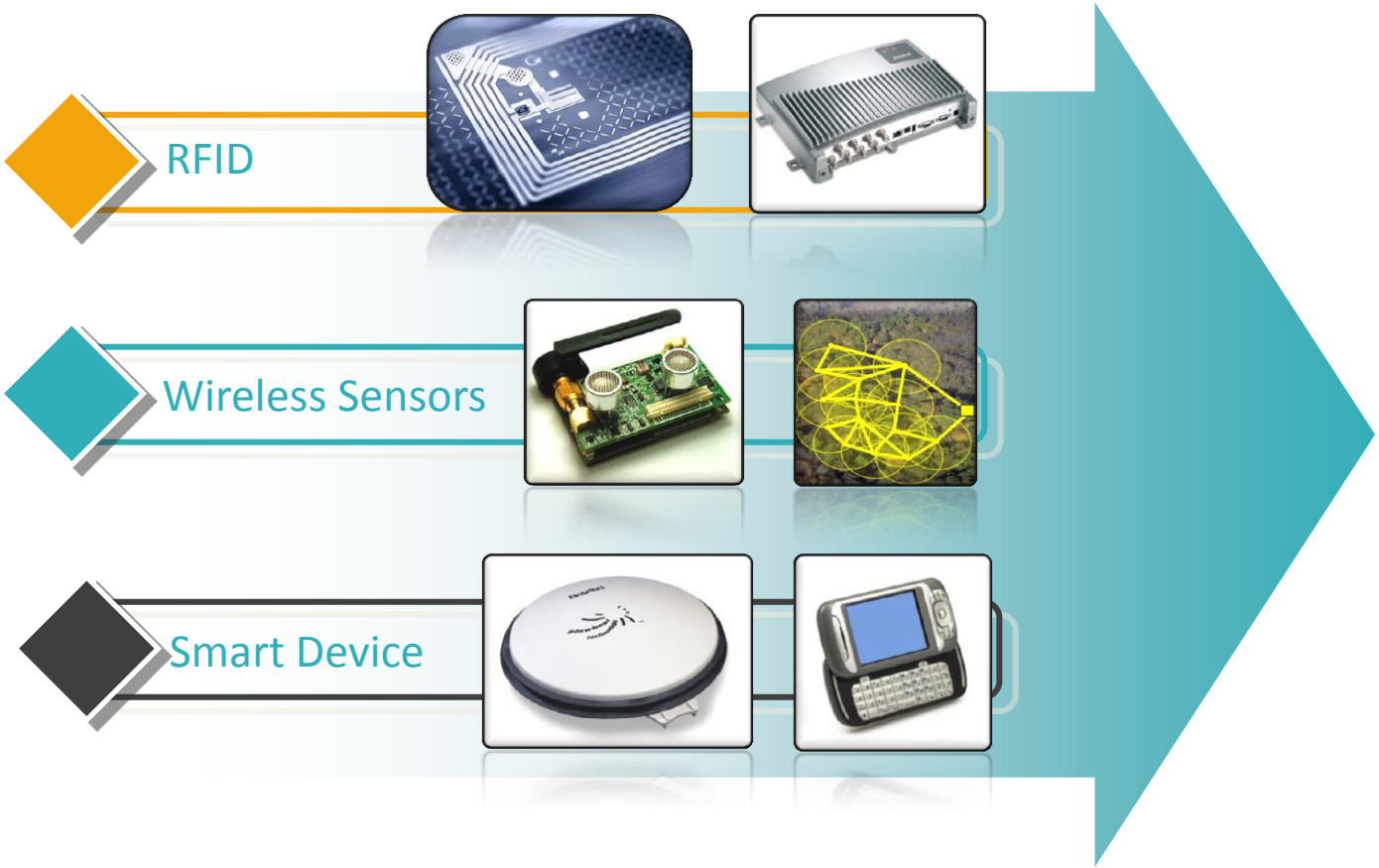
Information Processing

Network Construction



Sensing and Recognition

1) Sensing and Recognition Layer

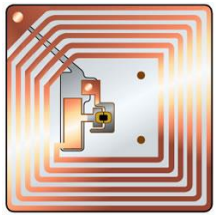


Sensing and Recognition Layer

- Through the sensing and recognition technology, the object can talk and publish information. This is an important part of the fusion of the physical world and the information world. It is the most unique part of the IoTs that distinguishes it from other networks.
- The "touch" of the IoTs is a large number of information generating devices located in the sensing and recognition layer, including information automatic generation devices such as RFID and wireless sensors, as well as smart phones, tablets, notebook computers, etc.
- Diversification of information generation is one of the important characteristics of the IoTs
- The sensing and recognition layer is at the bottom of the 4-layer model of the IoTs and is the basis of all upper layers

Example of Technology-1: RFID

- Basic components: The industry often divides RFID systems into three components: Tag, Reader and Antenna.
- Working principle: The Reader sends an electronic signal through the antenna. After receiving the signal, the Tag transmits the internally stored identification information. The Reader then receives and recognizes the information sent back by the Tag through the antenna. Finally, the Reader sends the identification result to the host.



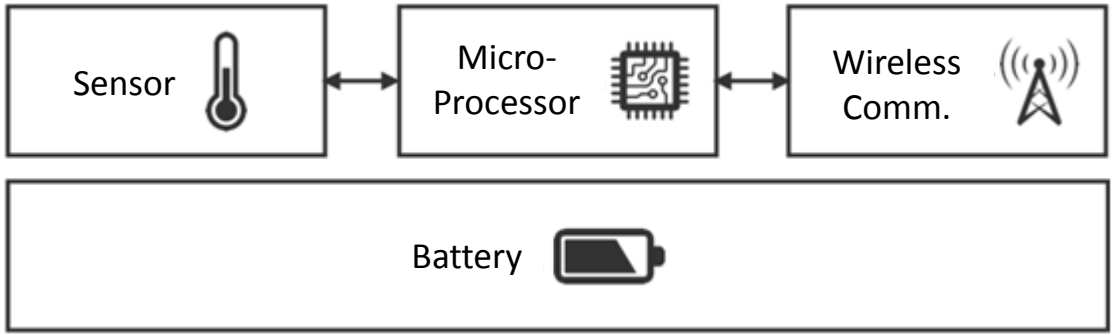
Tag

Reader

Antenna

Example of Technology-2: Wireless Sensor Networks

- Development history: sensor → wireless sensor → wireless sensor network (multi-hop wireless network composed of a large number of miniature, low-cost, low-power sensor nodes)



Example of Technology-2: Wireless Sensor Networks

- Sample Applications:
  - VigilNet: A system for military surveillance developed by the University of Virginia. Sensing nodes have the characteristics of self-organizing network n and multi-hop transmission
  - Mercury: A wearable medical monitoring sensor developed by Harvard University. The sensor has the characteristics of humanized design, high-precision sensing, continuous long-term data acquisition, etc.

VigilNet

Mercury

Example of Technology-3: Localization System

- Location information extension:
  - Spatial information → location + time at the location + object (person or device) at the location
- Positioning system and technology:
  - GPS satellite positioning
  - Cellular base station positioning (GSM/CDMA/3G)
  - Indoor precise positioning
- The challenge of positioning technology in the IoTs:
  - Precise positioning in heterogeneous network, complex environments
  - Large-scale application
  - Location Based Services
  - Information security and privacy protection issues caused by location information

Example of Technology-3: Smart Device

- Traditional smart devices:
  - Personal Computer (PC) / Personal Digital Assistant (PDA)
- New smart devices in the IoTs era:
  - Digital signage (real-time information interaction)
  - Smart TV (with full-featured Internet, personalized experience)
  - Smartphone

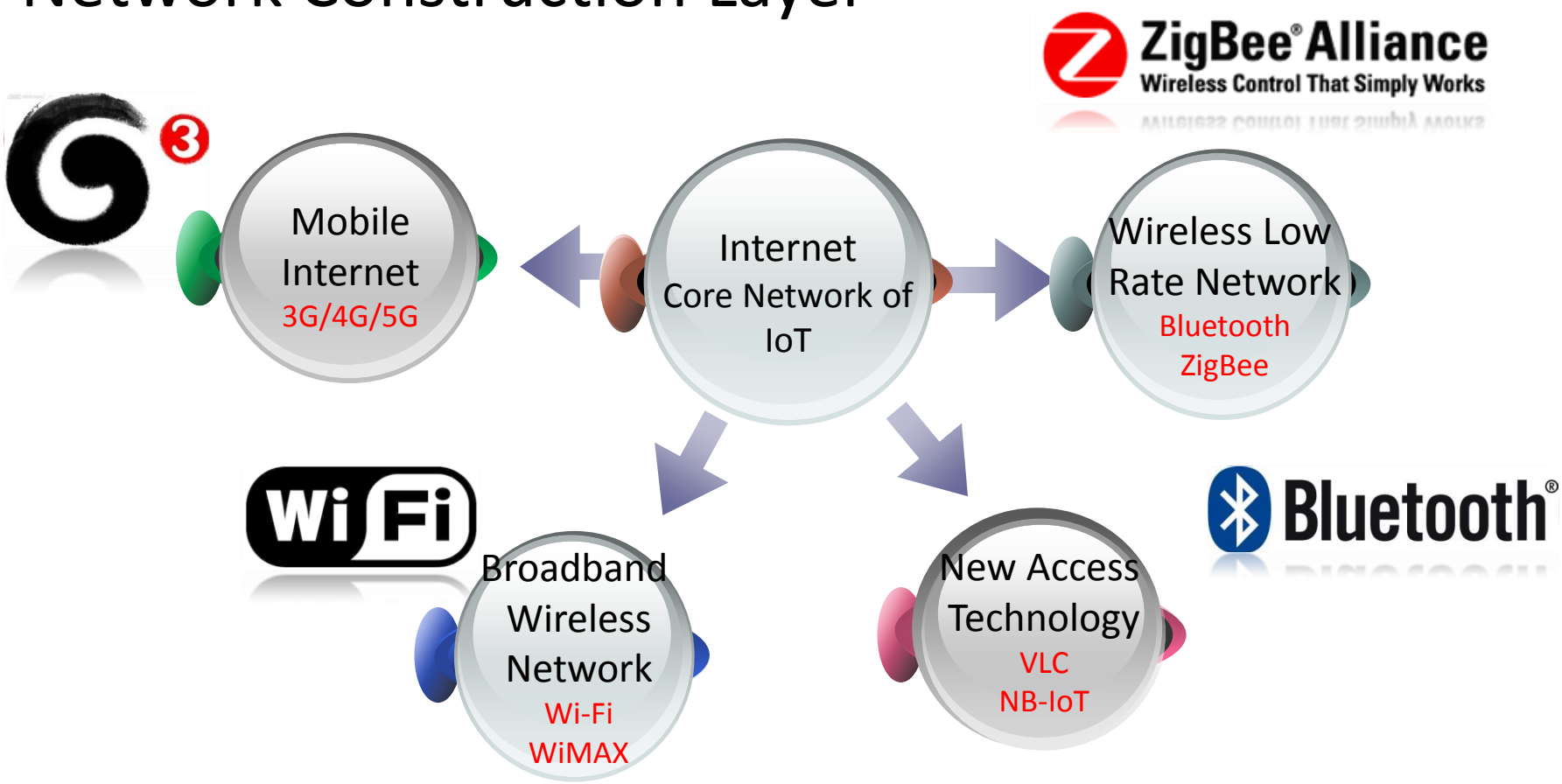
2) Network Construction Layer

- Network is one of the most important infrastructures of the IoTs

- What are the similarities and differences between the IoTs and existing networks? Is the IoTs the next generation of the Internet? What role does the wireless network play in the IoTs?

- The network construction layer connects the sensing & recognition layer and the management service layer in the 4-layer model of the IoTs, and has a strong link function to transmit upper and lower layers of data in an efficient, stable, timely and secure manner.

Network Construction Layer



Q: How Various Networks Applied to the IoTs?

- Internet: IPv6 clears the limit on the number of terminal devices that can access the network. Internet/telecom network is the core network, platform and technical support of the IoTs
- Wireless broadband network: Wireless broadband technology such as WiFi/WiMAX covers a wide range and has a fast transmission speed. It provides a high-speed, reliable, and inexpensive interconnection method for the IoTs
- Wireless low-speed network: Low-speed network protocols such as ZigBee/Bluetooth can adapt to low-rate, low communication range, and low computing power sources of lower-capacity nodes in the IoTs
- Mobile communication network: The mobile communication network will become an effective platform for transmitting information in a comprehensive, anytime, anywhere. High-speed, real-time, high coverage, and diversified processing of multimedia data to create conditions for object “touch” the network
- Emerging wireless access technologies: 60GHz millimeter wave communication, visible light communication, low-power wide area network (such as LoRa, NB-IoT) and other emerging technologies help solve the problem of limited spectrum resources and diverse application requirements for the IoTs

3) Management Service Layer

- The management service layer is located above the sensing & recognition and network construction layer. It is under the application layer and it is the source of the wisdom of the IoTs
- People often use “smart” term for IoT applications, such as smart transportation, smart logistics, smart buildings, etc., where the wisdom comes from this layer
- A large amount of information generated by the perceptual recognition layer is transmitted to the management service layer through the network layer, and needs to be effectively integrated and utilized
- The management service layer solves the problem of how data is stored, how it is retrieved, how it is used, and how it is not abused

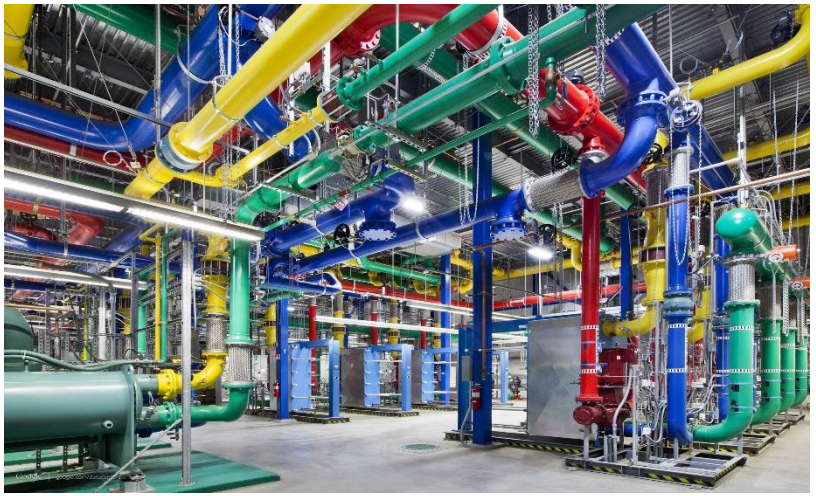
IoT and Big Data

- The IoTs will become an important source of big data, and big data will also provide a strong support for the development of the IoTs
- Networked storage is a way to store large-scale data, mainly divided into direct attached storage (DAS), network attached storage (NAS), storage area network (SAN)
- Challenge: only meet medium-sized business needs
- The data center includes not only computer systems and ancillary equipment (such as communication/storage equipment), but also redundant data communication/environment control equipment/monitoring equipment and security devices, which are large-scale system engineering. Provide timely and continuous data services with high security and reliability to provide good support for IoT applications
  - Typical data center: Google

Google Data Center

Servers and networks in the data center

(Yellow cable is fiber optic)



Data center cooling system

(The cold water in the blue water pipe and the hot water in the red water pipe)

Cloud Computing

- Cloud computing provides three levels of basic services for the computer industry and the IoTs:
  - Infrastructure as a Service (IaaS)
  - Platform as a Service (PaaS)
  - Software as a Service (SaaS)
- Cloud storage services provide ubiquitous access to electronic data, greatly simplifying cross-device management and consistency maintenance of data
- Cloud downloading guarantees data health and data transmission rate through cloud storage, thereby providing high-quality download service and reducing energy consumption at the user end
- With the support of cloud computing, users can flexibly rent cloud computing services, avoid infrastructure investment, use funds and time to provide better IoT services to customers, and make the Internet of Things more popular and efficient

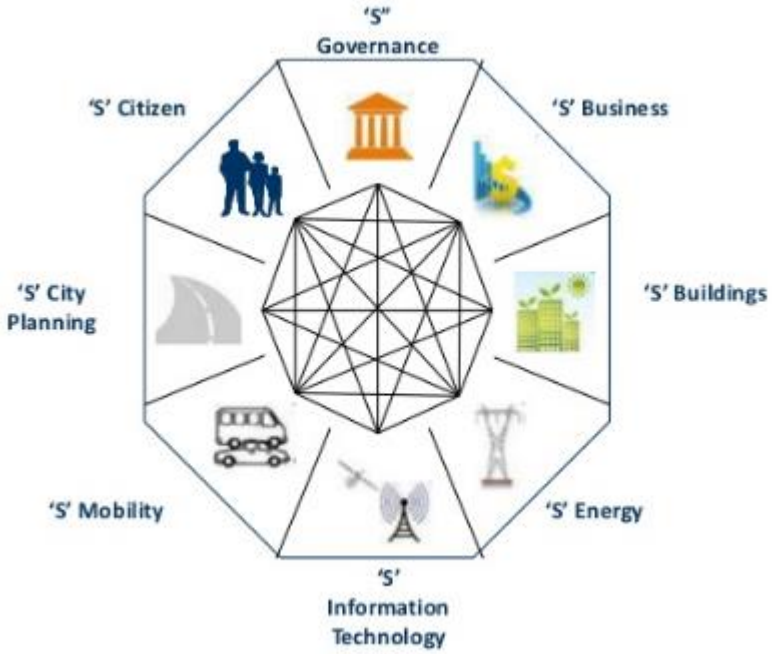
Information Security and Privacy Preservation

- RFID security
  - Key security and privacy concerns: eavesdropping, tracking, man-in-the-middle attacks, spoofing/replay/cloning, physical cracking, tampering with information, denial of service attacks, RFID viruses...
  - Protection means: physical security mechanism / cryptography security mechanism / PUF...

- Location privacy
  - Definition: The user's ability to control his or her location information: The user is free to decide whether to publish location information, who to post to, how to publish it, and how detailed the information is.
  - Protection means: institutional constraints, privacy policy, identity anonymity, data confusion

4) Application Layer

- Regardless of the technology, application is the key to success or failure
- The rich connotation of the IoTs has spawned a richer application of extension



4) Application Layer

- Traditional Internet has experienced data-centric to people-centric transformations. Typical applications include file transfer, email, the WWW, e-commerce, video on demand, online gaming and social networking
- IoT applications center on the "object" or the physical world, covering smart transportation, smart logistics, smart buildings, environmental monitoring and so on. IoT applications are currently in a period of rapid growth, with diversification, scale, and industrialization

Involved Components

Devices

send and receive data interacting with the

Network

where the data is transmitted, normalized, and filtered using

Edge Computing

before landing in

Data storage / Databases

accessible by

Applications

which process it and provide it to people who will

Act and Collaborate

To realize the development of the IoTs industry, a standards-based approach is needed

Development Trend

- Broader interconnection
  - Interconnected objects extend from people to objects
  - Extension the way of interconnection and interoperability
  - The number of connected nodes has surged
- More thorough sensing
  - Communication function enables sensors to work together
- Deeper intelligence
  - Multi-sensors realize the intelligence of "many strength“
  - Multi-dimensional sensing data to realize the intelligence of "preventing problems before they happen"
  - Big Data Mining Realizes the Intelligence of "Seeing the Mind"

Huawei IoT Strategy

Chip

IoT Chip

Ultra Low Power, High Performance

End

IoT Module LiteOS

Higher Energy Efficiency, More

Resource Saving, Lower Cost

Edge

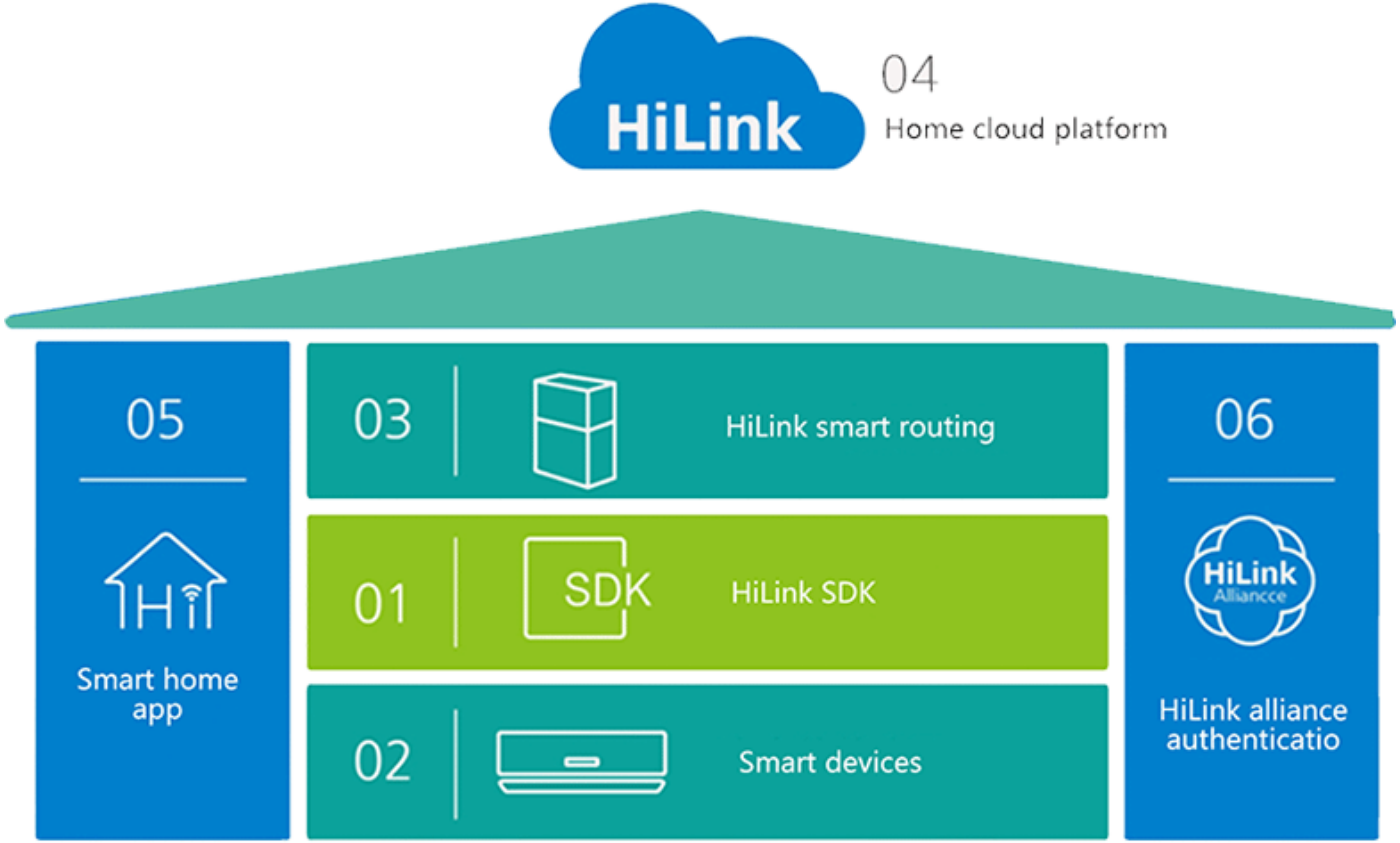
Router Edge Computing

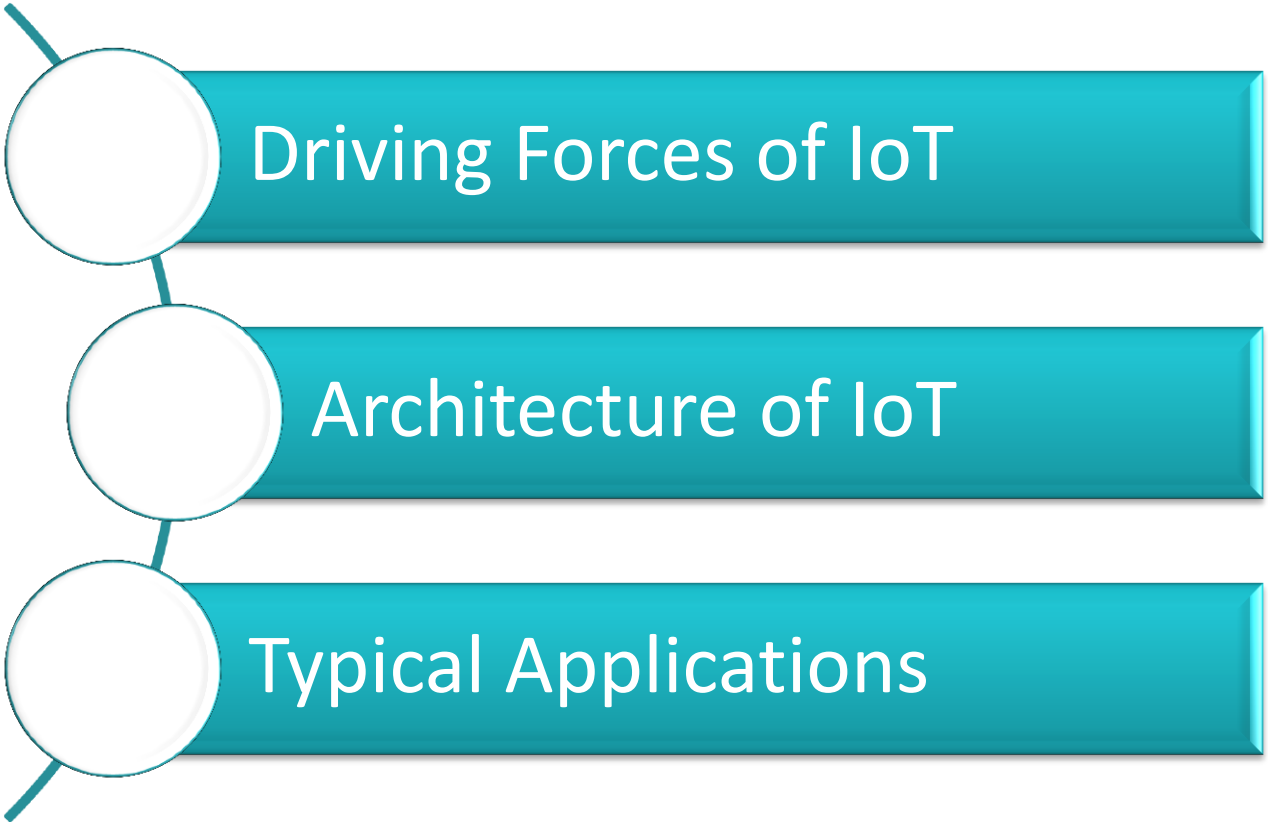
Cloud

IoT Cloud Platform

Cover 100+ Countries and Area

Huawei IoT Strategy




Driving Forces of IoT
Architecture of IoT
Typical Applications

Rapid Innovation → IoE Benefits $19T

Public Sector

$4.6T

Manufacturing

$3.9T

Retail

$1.5T

Oil + Gas

$504B

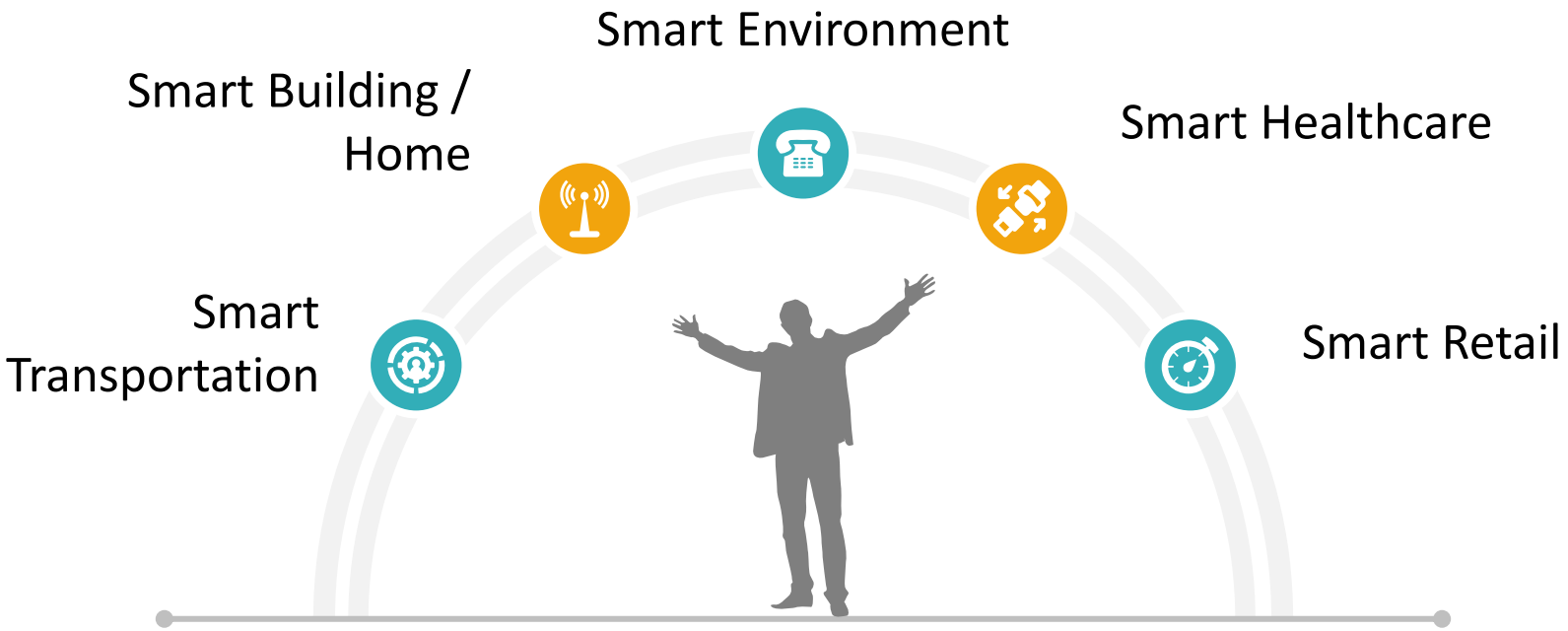
Finance

$1.3T

Healthcare

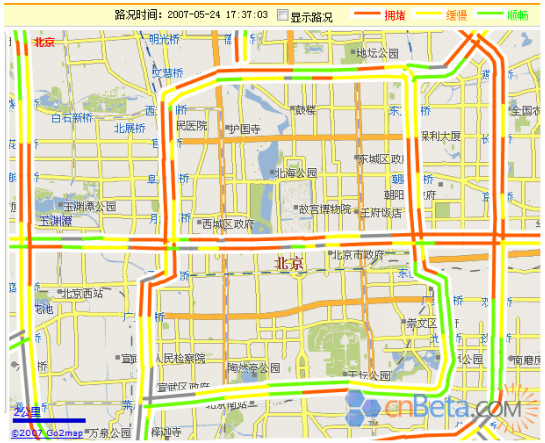
$1.1T

Typical Industry Applications



1-Smart Transportation

- Through the extensive application of IT technologies in infrastructure and vehicles, the safety, manageability, and transportation efficiency of transportation systems can be improved, while energy consumption and the negative impact on the global environment can be reduced.



Real-time traffic and navigation

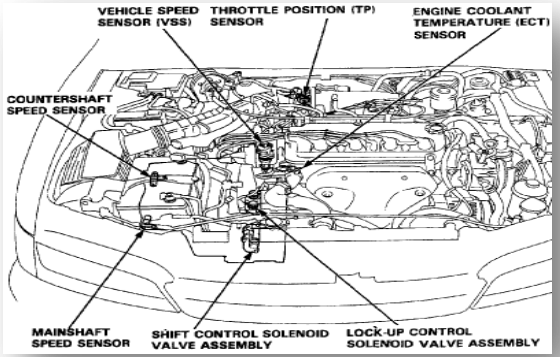
Electronics in Car

1-Opportunities and Challenges

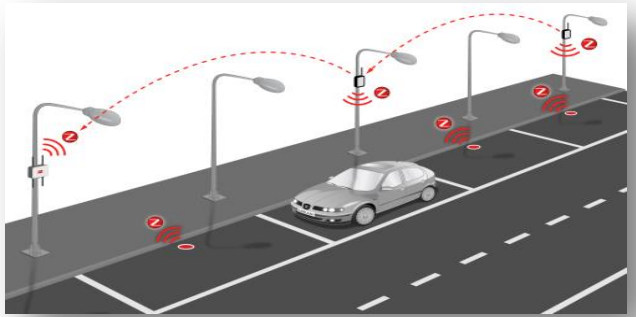
- Smart transportation is considered one of the most promising applications in IoT applications
- Compared with the other IoT applications, due to its special security requirements and the introduction of more sensing technologies, in addition to vehicles, it also needs to consider complex conditions such as roads, weather, and people.
- Therefore, intelligent transportation systems also face a large number of new challenges
  - Detection, sensing, and recognition technologies face challenges of high accuracy and low latency
  - Communication technology faces the challenge of high speed, low latency, and multiple ways of integration
  - Information processing and intelligent decision-making face challenges of massive, highly dynamic data, effectiveness, and real-time
  - Challenges of software security verification
  - The contradiction between standardization and flexibility.
  - In addition to technical challenges, there are many application challenges

1-Sensing and Recognition

- Sensing technologies in smart transportation systems are widely used for vehicle status detection, road and weather condition detection as well as traffic condition monitoring, vehicle cruise control, back-up monitoring, automatic parking, parking management, vehicle dynamic weighing, and etc.



Sensors within Vehicle

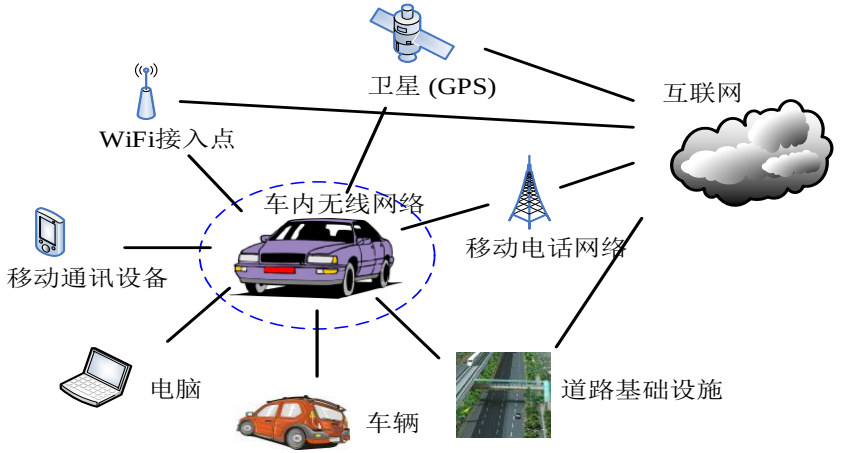


Road and Roadside Sensors

1-Wireless Communications

- Short-distance communication (less than several hundred meters)
  - Used to exchange information between vehicles and between vehicles and roadside facilities
- Long distance communication
  - Used to provide Internet access for vehicles, to facilitate vehicle service and multimedia entertainment information acquisition

The integration of multiple heterogeneous communication technologies means that software-defined radio design is required, and seamless integration of heterogeneous connections is required

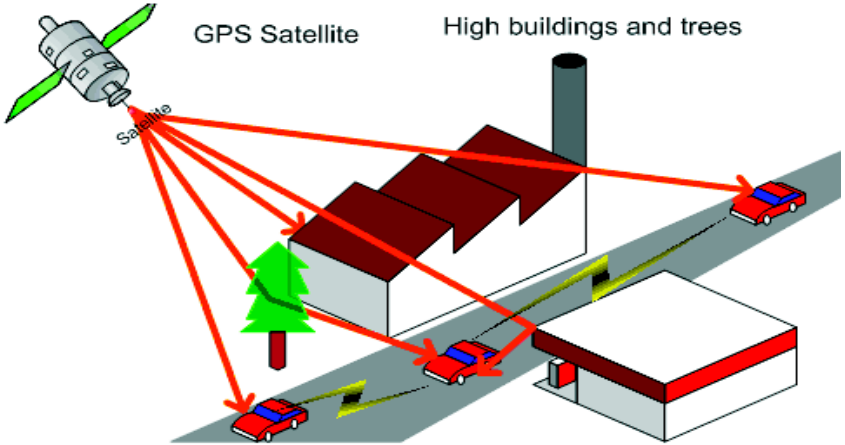


1-Computing Decision

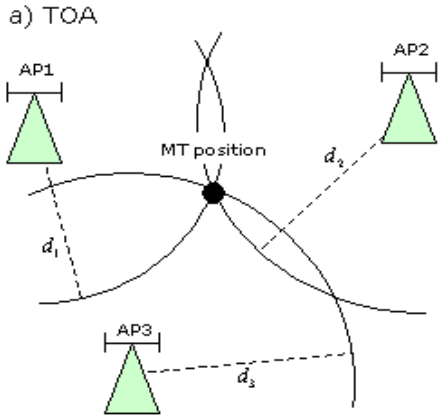
- Smart transportation requires a large amount of information processing and computing decisions. Based on the current vehicle and road conditions, it provides driver assistance information and even replaces the driver to intelligently control the vehicle
- Smart transportation also poses new challenges to data and logical processing:
  - Processing of sensor signals, such as the need to distinguish between dangerous and well-meaning obstacles
  - Predict future behavior of the other vehicles
  - Assessing threats during driving
  - Making decisions in ambiguous threat situations ...

1-Localization

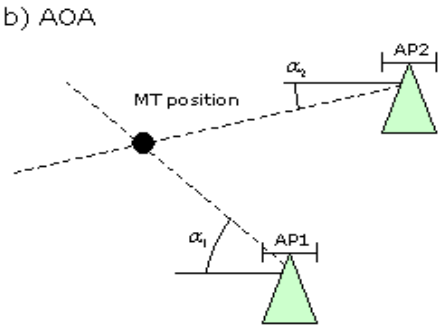
- Vehicle positioning is the basis of most smart transportation services (such as vehicle navigation, real-time traffic condition monitoring, etc.)



Satellite signals blocked by tall buildings and trees



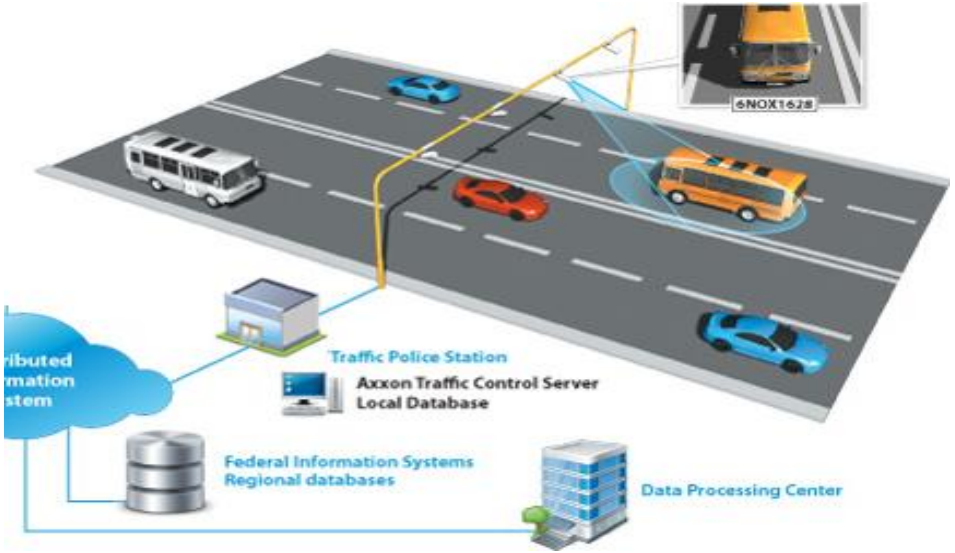
TOA localization



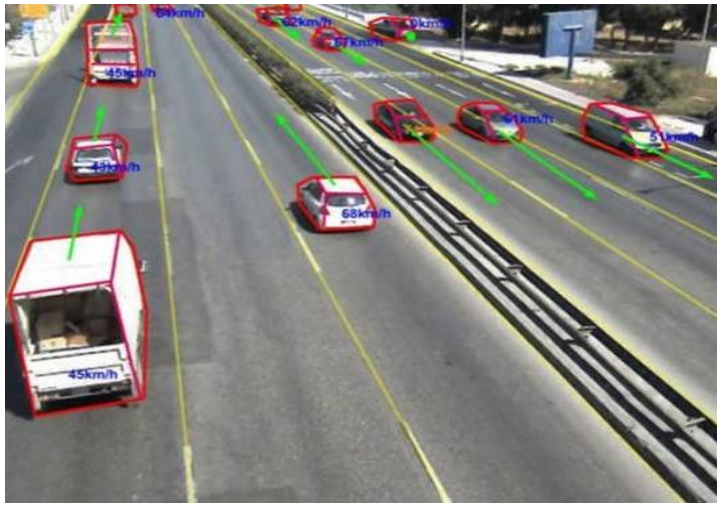
AOA localization

1-Video Surveillance Recognition

- Video camera equipment is often used for vehicle monitoring, such as traffic flow measurement and accident detection



Vehicle monitoring and identification system

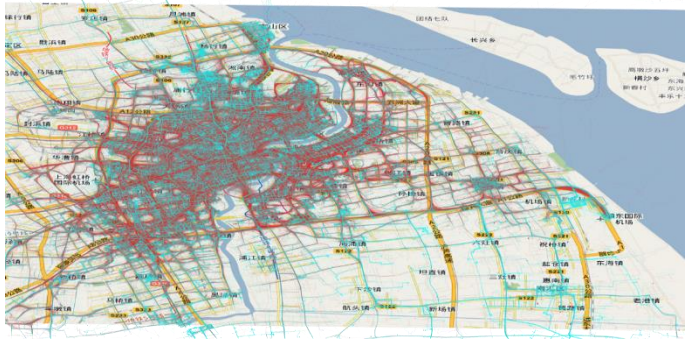


Vehicle identification

1-Detecting Vehicles and Equipment

- Some countries have begun to deploy so-called "detection vehicles", which are usually taxis or government-owned vehicles equipped with DSRC or other wireless communication technologies
  - Vehicles report their speed and location to the traffic operation management center. The management center analyzes these data to obtain a wide range of traffic conditions to detect the location of traffic jams
- At the same time, a lot of scientific research has focused on how to use smart mobile devices to obtain real-time traffic flow information

Monitoring Car



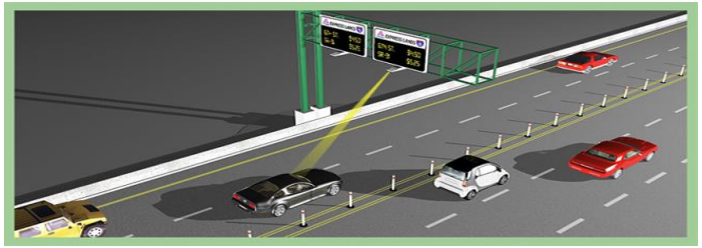
Taxi path tracking

Real-time traffic information

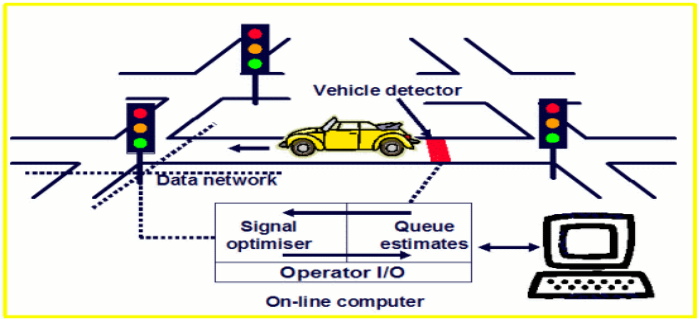
1-Traffic Monitoring and Management

- Smart traffic monitoring applications
  - Common smart traffic monitoring applications include: traffic flow monitoring, electronic police systems
- Smart traffic management applications
  - Common intelligent traffic management applications include: adaptive traffic signals, variable speed limit signs, automatically lit sidewalks, variable lanes, and intelligent ramp flow control

Variable speed limit sign / Lane sign



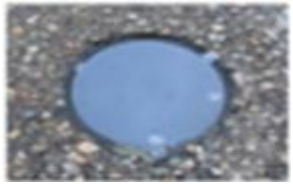
Intelligent Lane System

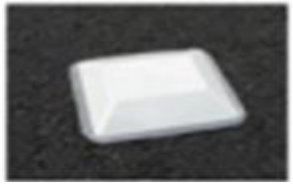


Intelligent traffic signal system

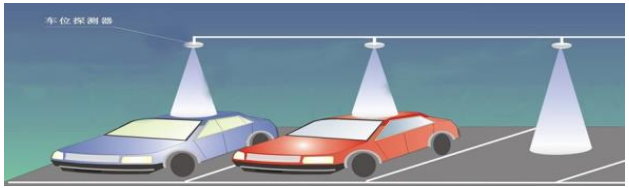
1-Smart Parking Management

- Real-time monitoring of parking spaces through sensor nodes such as ultrasonic and weak magnetic fields; real-time aggregation and storage of parking space information into the data cloud through ubiquitous wireless connectivity; guidance of drivers to the suitable nearby empty parking spaces via traditional electronic guidance cards or smart phones, on-board GPS, etc.





Weak magnetic sensor



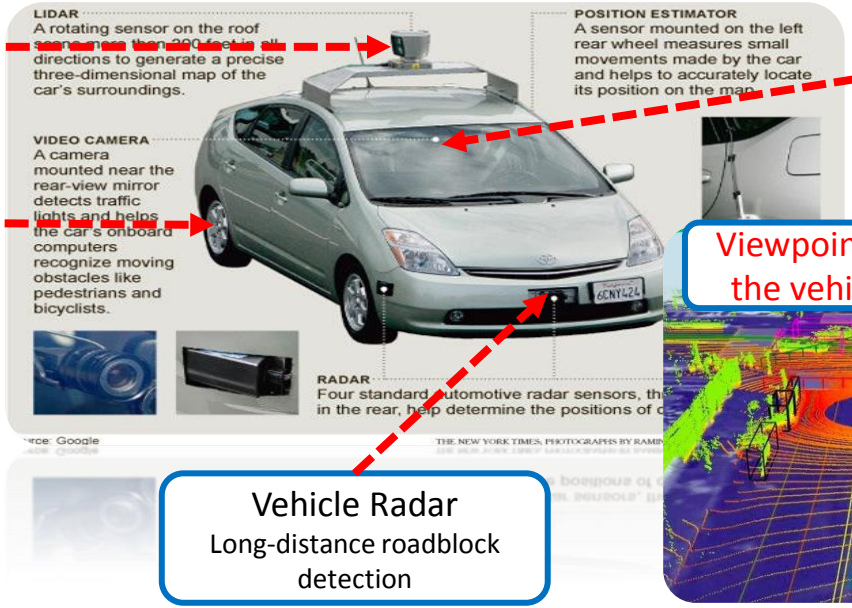
Ultrasonic ranging node

1-Auto Driving (1)

- Assisted driving
  - Through the video, radar, GPS and other equipment on the vehicle, and the communication between the vehicle and the vehicle and roadside equipment, collect road and vehicle information to assist the driver in making operational decisions.

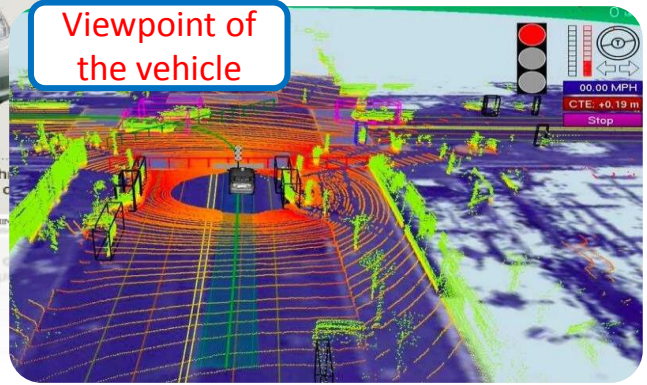
Laser Ranging
Accurately draw 3D terrain within 200 meters

Miniature sensor
Perceives small motions of vehicles to assist in precise positioning



Video camera
Detection of signal lights, pedestrians, vehicles

Viewpoint of the vehicle

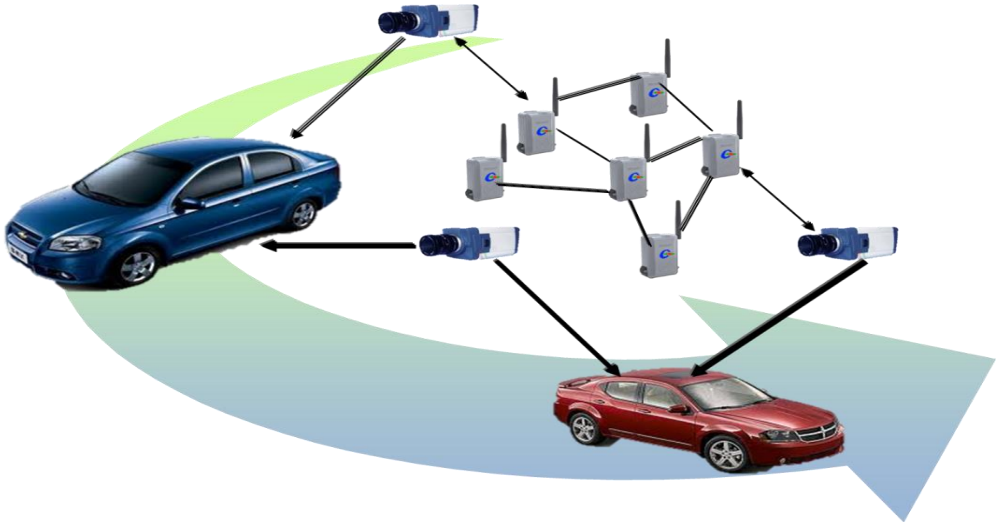


Vehicle Radar
Long-distance roadblock detection

Google auto-driving

1-Auto Driving (2)

- Smart driving
  - Intelligent roads and smart driving use roads as collectors, distributors, and decision makers of information to directly guide vehicles
  - On intelligent roads, various information sensing, processing and communication units will be deployed on the road and on the roadside.



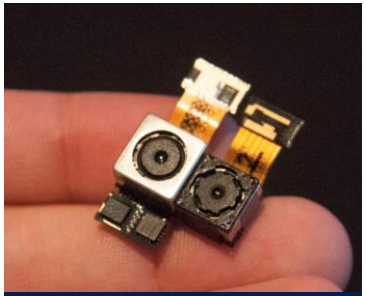
1-Other Applications

- Safety application
  - Such as automatic alarms for emergency situations, lane change assistance, intersection and traffic signal reminders, road condition reminders, roadblock reminders, etc.
  - Toyota ’s CICAS system (Cooperative Intersection Collision Avoidance System). Vehicles in each lane can receive traffic signal information of roadside equipment through on-board equipment, such as "red light for lane 1 for 4 seconds"
  - Roadside equipment based on DSRC technology intelligently controls traffic signals through maps and vehicle GPS information, and issues timely warnings to dangerous vehicles
- Comfort applications
  - Such as Internet access services in the car, and download and online viewing of music movies
  - Chat or interactive games via short-range communication technology
  - Introduction and inquiry of attractions, restaurants and shops along the way
  - Automatically adjust the environment inside the car, etc.

Invisible Sensing
of Vehicle Steering with Smartphones

Dongyao Chen, Kyong-Tak Cho,
Sihui Han, Zhizhuo Jin, Kang G. Shin
ACM Mobisys 2015

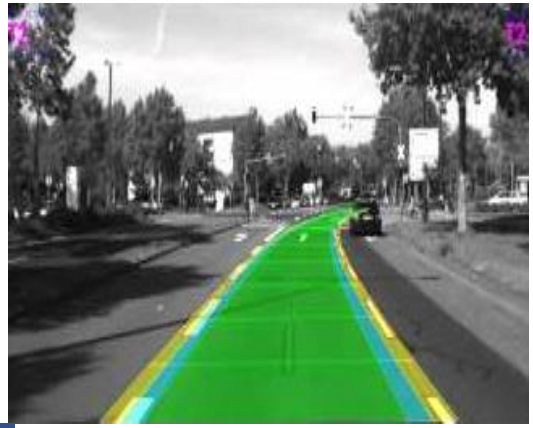
Motivation



Camera is useful in many applications

Lane marker detection

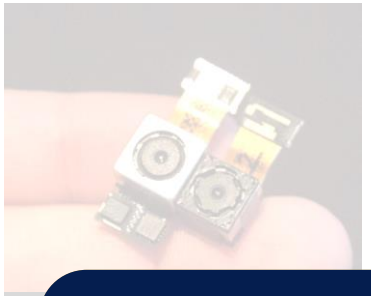
- For lane departure warning system
- Detect car maneuvers



Autonomous vehicle

- Detect lane markers
- Detect pedestrians and objects on road

Motivation



Lane marker detection

- For departure warning system
- Detect car maneuvers

Seeing is Believing

Camera is widely used in driving assistant systems

- Detect lane markers
- Detect pedestrians and objects on road

Performance of Camera

Does camera always work?

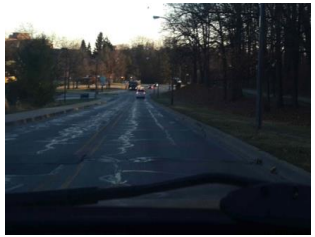
Lighting

Weather

Pavement

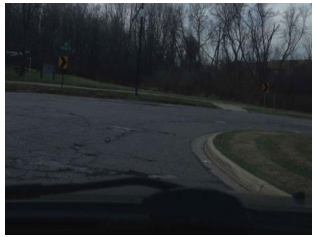
Placement

Heavy Shadow



No Lane

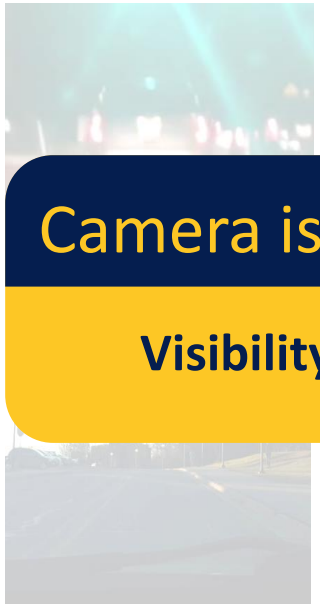
Sunlight Reflection



Sharp Turn

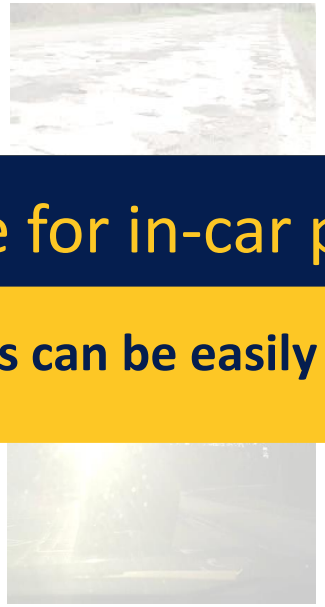
Performance of Camera

Does camera always work?



Heavy Shadow

No Lane



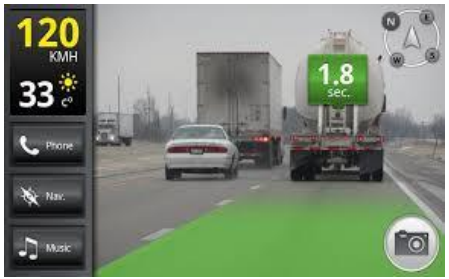
Sunlight Reflection

Sharp Turn

Camera is not reliable for in-car purpose

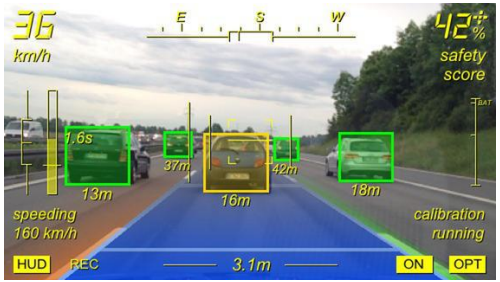
Visibility of road objects can be easily distorted

Sole-reliance on Camera

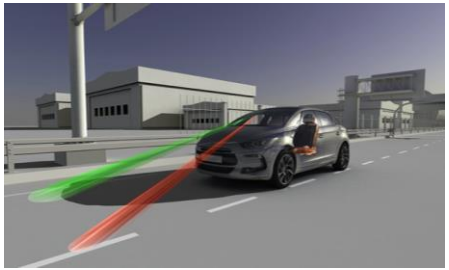


iOnRoad app

BlackSensor app

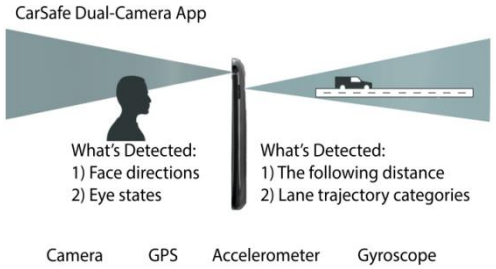


Augmented Driving app



Citroën DS5 LDW System

Volvo CX90 LDW System



CarSafe app

Sole-reliance on Camera

Augmented Driving app

Volvo CX90 LDW System

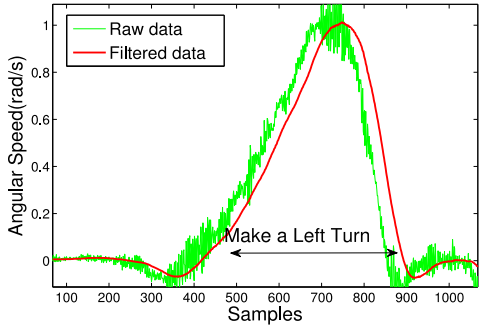
CarSafe app

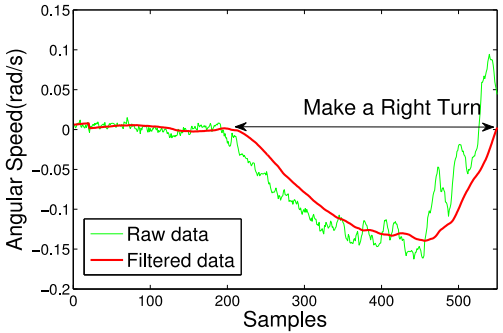
Our Goal: Reliability!

Sense the maneuvers w/o using camera

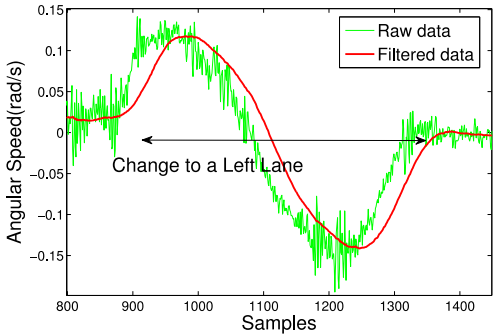
Signatures in Vehicle Steering

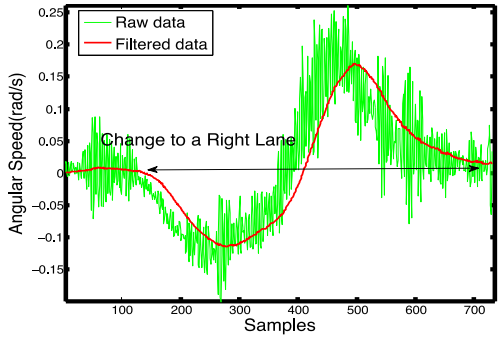
- Gyroscope reading in left & right turns





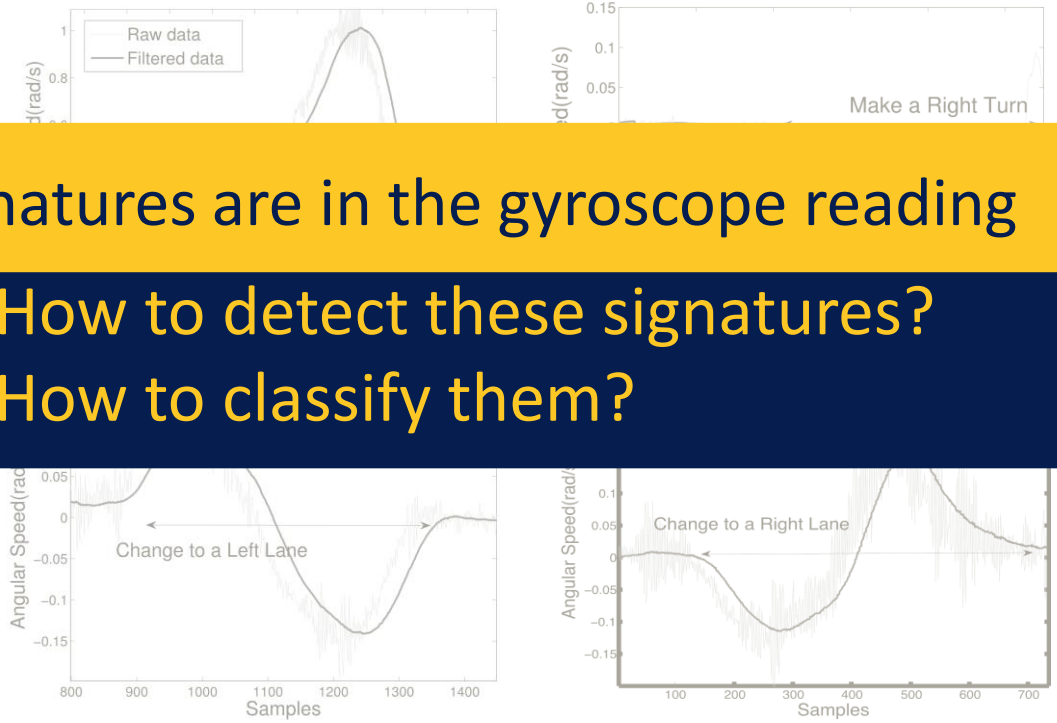
- Lane changes





Signatures in Vehicle Steering

- Gyroscope reading in left & right turns

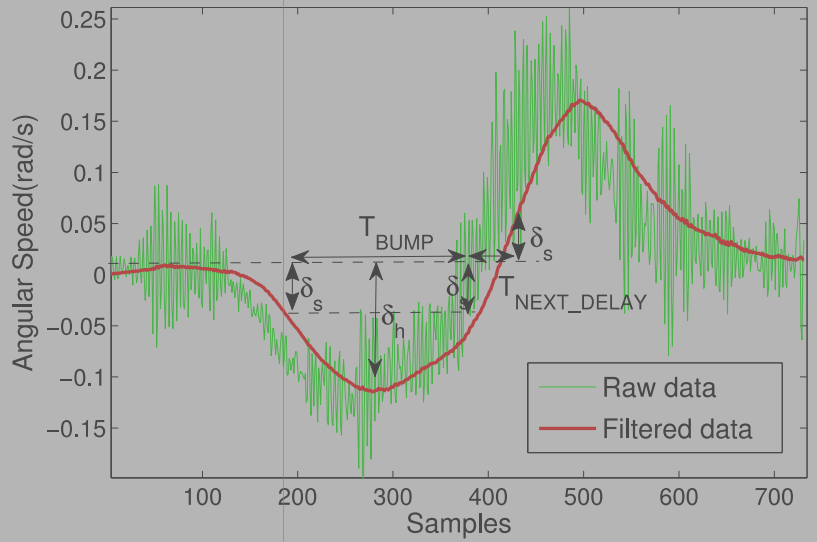


Signatures are in the gyroscope reading

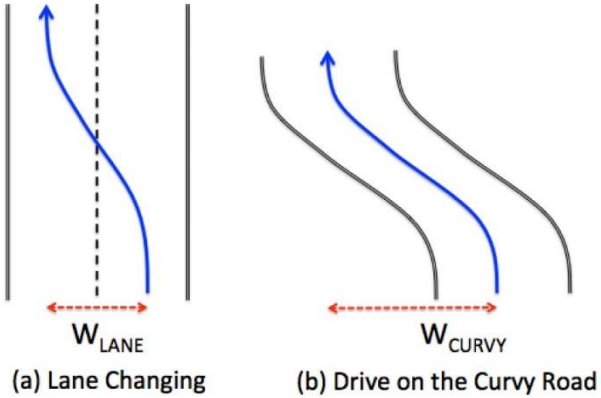
- How to detect these signatures?
- How to classify them?

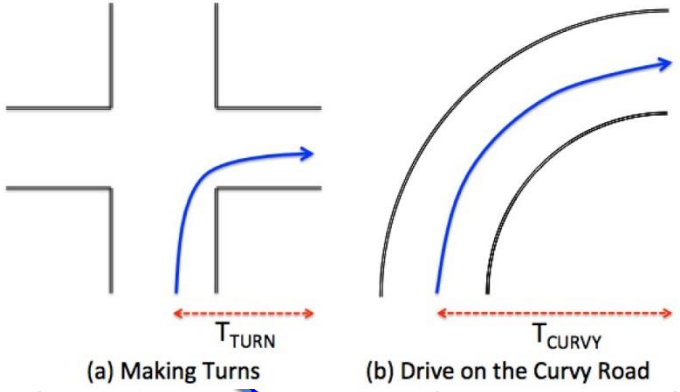
Bump Detection

- Bump detection
  - No bump → One bump→ Waiting for

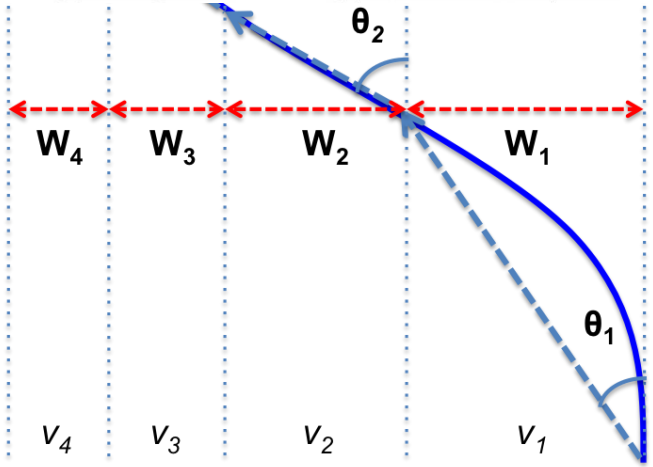


Maneuver Differentiation





- Horizontal displacement:
  - Integrate horizontal displacement at each reading sample

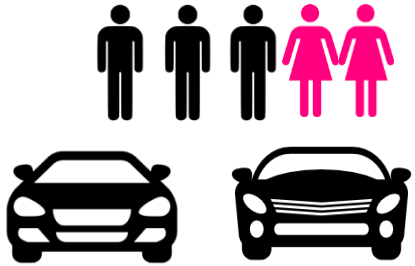


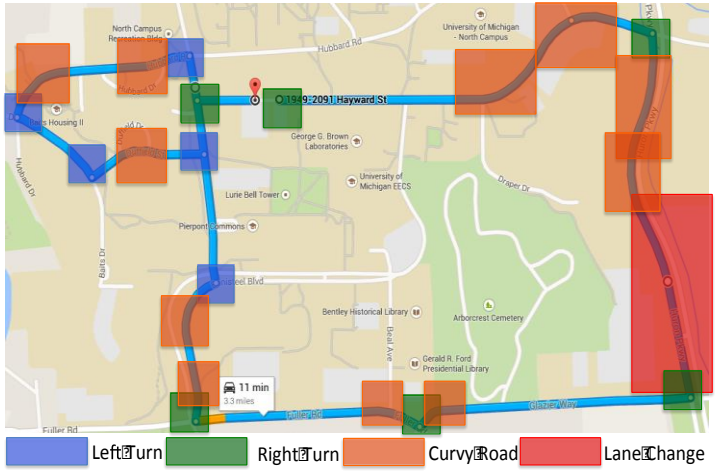
V-Sense: Highlights

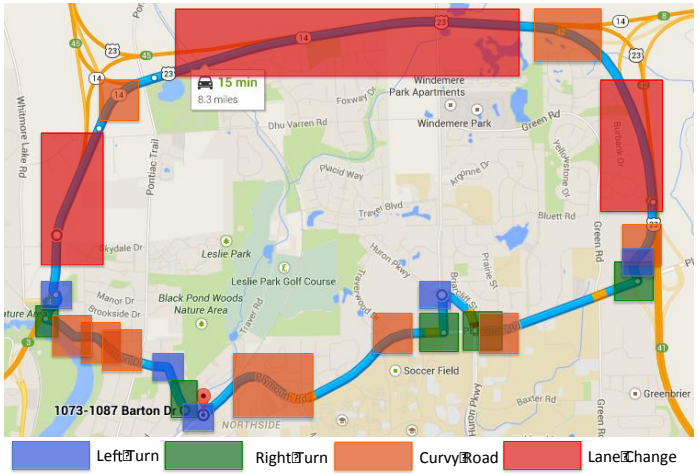
- Camera-free
- Detect steering maneuvers just using smartphone
- Differentiate turning, lane changing, and driving on curvy roads

Evaluation

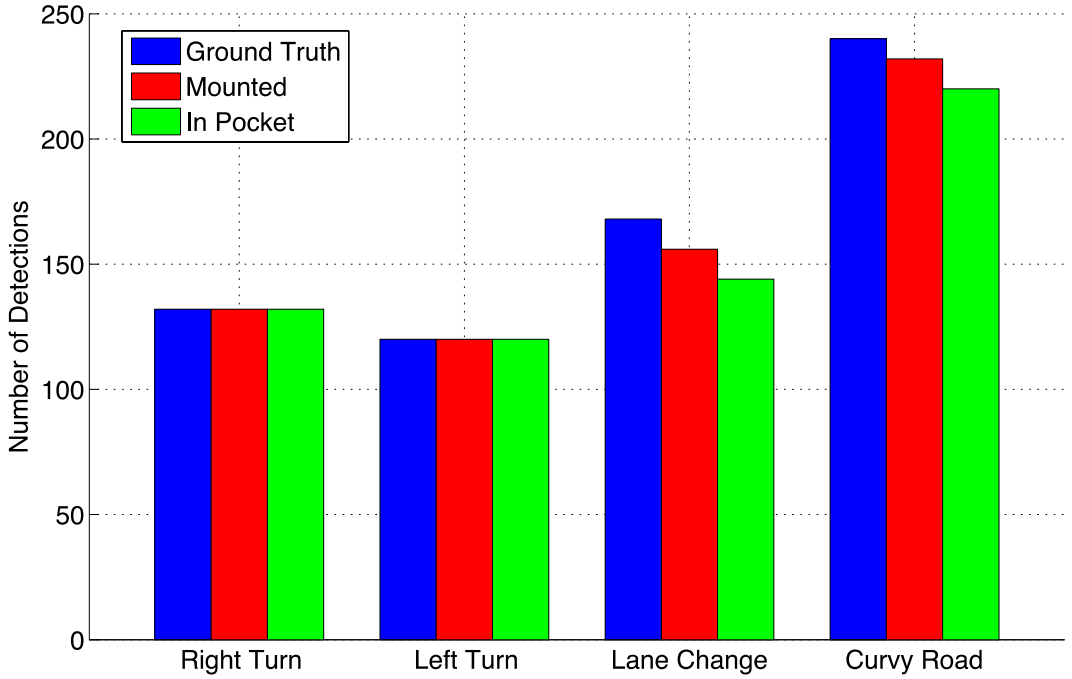
- Experiment setup:
  - Implemented V-Sense on Samsung Galaxy S4 and S3
  - Total 40h test



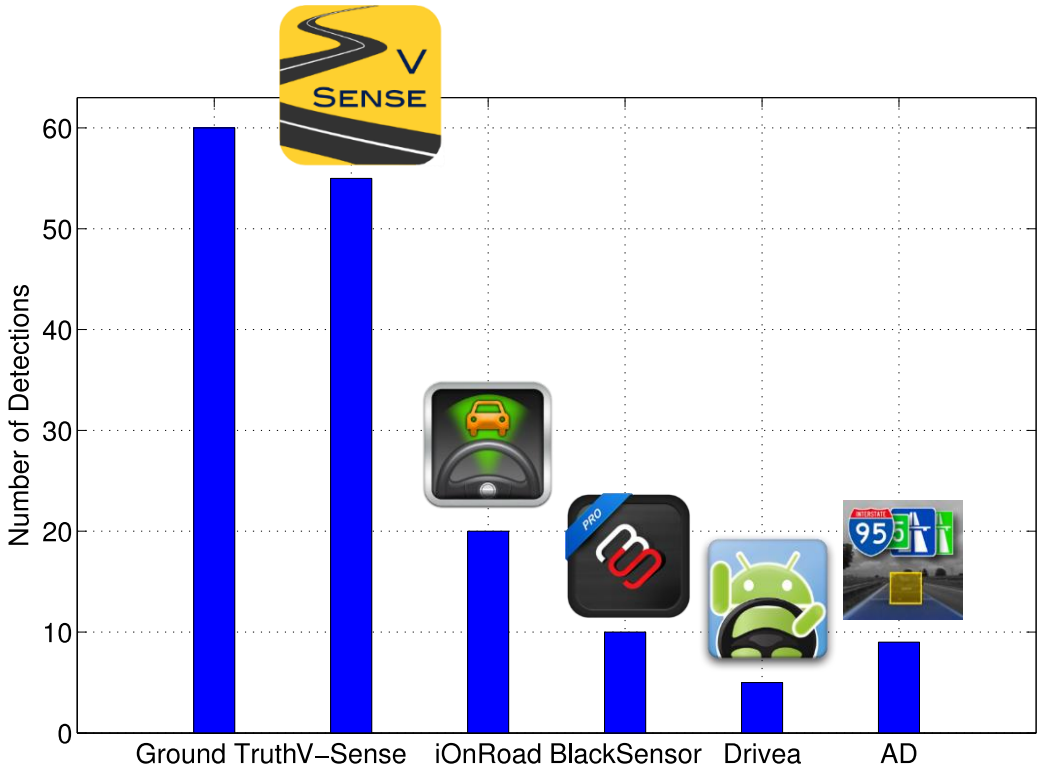




Evaluations: Accuracy



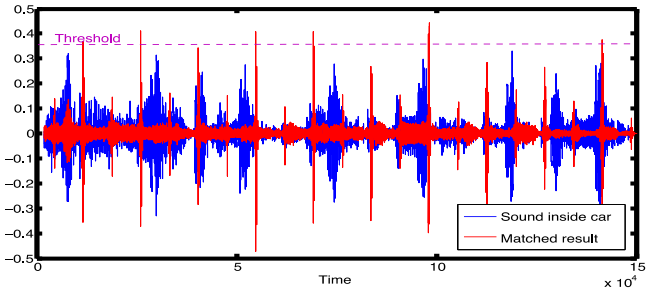
Evaluations: Comparison



Application Scenario I: Detecting Unconscious Turn

Application Scenario I: Detection of Careless Steering

Extracting sound from background noise



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V SENSE

=

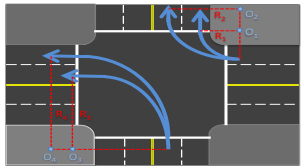
Instant warning of unexpected lane departure

Application Scenario II: Fine-Grained Lane Guidance

Application Scenario II: Fine-Grained Lane Guidance

Navigation APP

+



InterHelper

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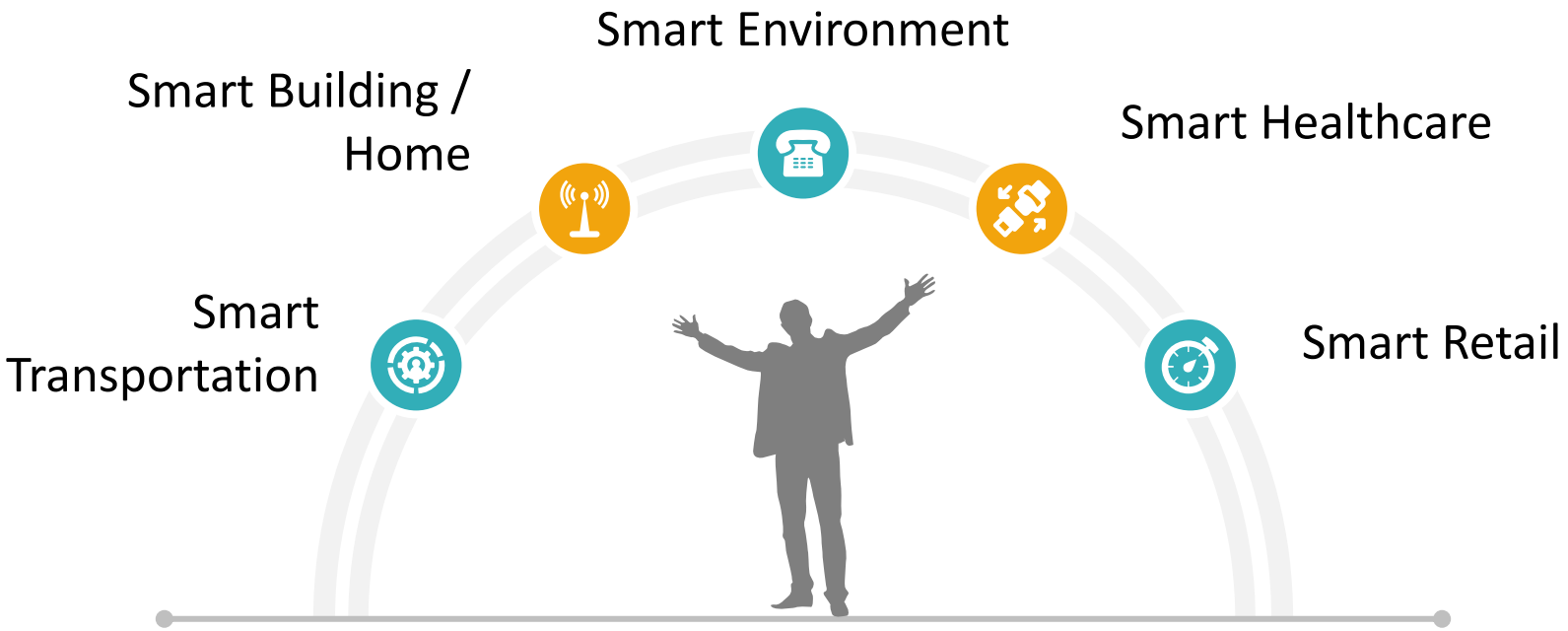
Instantly know which lane you are driving in

Brief Summary

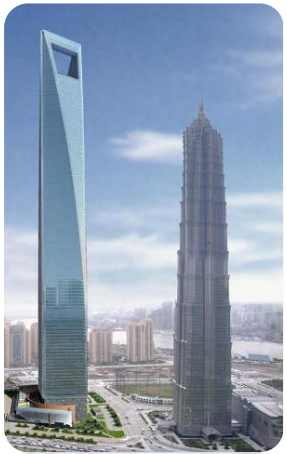
- Proposed V-Sense, a camera-free steering sensing applications on smartphone
  - Differentiate between
    - Lane Change
    - Left/Right Turn
    - U-Turn
    - Driving on Curvy Roads
- Two proof-of-concept applications

Typical Industry Applications



2- Smart Building / Home

- The Internet of Things technology brings new power to green buildings. By establishing a building equipment monitoring network with energy saving as the goal, various equipment and systems are integrated to form an IoT application system centered on intelligent processing, which effectively provides strong support for building energy conservation


2- A Brief History of Smart Home Development

01

1997

Bill Gates' mansion uses enabling furniture, launches the whole idea

02

2007

The first iPhone is released, the mobile phone enters the era of intelligence

03

2010

TCL releases the first Android-based smart TV

04

2014

Amazon releases Echo speakers to address voice input; Google acquires Nest for $ 3.2 billion

05

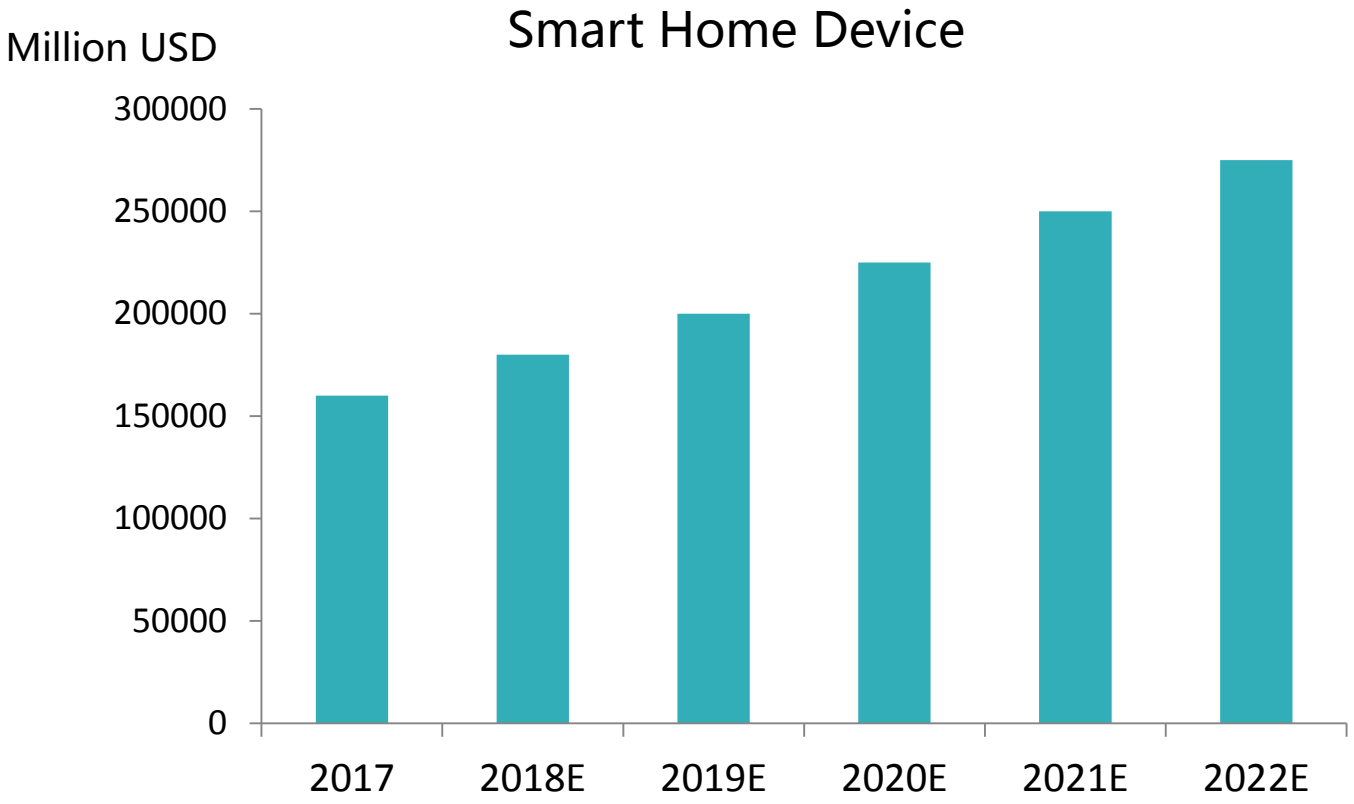
2018

Amazon acquires Ring, a smart security vendor

06

More to Come

2- Smart Home Market Size



Internet+ Exploration for Hardware

- Consumer Electronics

  Smart phones, smart watches, smart TVs, smart speakers, game consoles, set-top boxes, routers

- Consumer electronics

  Refrigerator, washing machine, rice cooker, sweeping robot, air conditioner, air purifier, water purifier

- Smart home furniture

  Electronic locks, smart curtains, smart lamps, smart kitchenware, smart smoke detectors, home cameras

Smart Home Platform

Appliance manufacturers

Haier

SAMSUNG

Midea

GREE

TCL

Internet-based Company

AWS

Microsoft

HUAWEI

Google

阿里云

Innovative enterprise

BroadLink

VIOMI云米

物联云平台 云智易

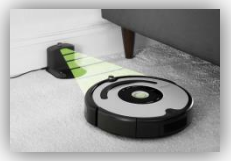
tuya 涂鸦智能

APP: Intelligent Control

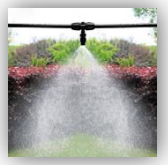
2- Voice Assistant Drives --- from Touch to Voice Control

Amazon Alexa Smart Eco-System


Smart socket


Sweep floor robot

Smart sprinkler




Camera

Intercom

Smart switch

Router

Lighting

Locker

Air purifier

amazon alexa ENABLED

2- Xiaomi "Xiao Ai" Voice Assistant

switches house status in one sentence

Hub: Smart Speaker

Get Up

Music-Alarm

- Curtain motor open curtains
- Ceiling light on
- Broadcast weather, road conditions, schedule reminders
- Open egg-cook socket
- Turn on water heater
- Turn on the rice cooker
- Broadcast the information of the subscription

Leave Home

Bye-Bye

- Ceiling light off
- Air purifier off
- Gateway turns on alert mode
- Sweeping robot start
- TV off
- Air conditioning off
- Camera start
- Turn off switch on the wall

Back Home

I am back

- Turn on the TV
- Air-conditioning partner turns on air conditioning
- Sweeping robot back to charge
- Turn on switch on the wall
- Turn off the camera

Sleep

Good-night

- Query time
- Curtain motor close curtains
- Air purifier sleep mode
- Wall switch off
- Air conditioning sets sleep temperature
- Gateway turns on alert mode

2- Interaction: Reactive Response → Proactive Cooperation

reactive response

Need actively trigger

Phone Control

Voice Control

Self-sensing trigger

Smart Lamps, Cameras

Smart Locker

proactive cooperation

Smart fridge recommended recipes

Smoker adjusts suction force

Smart washing machine automatically adds washing powder, adjusts strength/mode

2-Traditional Home Appliance Manufacturers

Value-Added Products

- The first step is to add Wi-Fi to the product
  - e.g., the air conditioner of Midea has the function of "WiFi intelligent control"
- The second type of intelligence is to make some optimization
  - e.g., the IH rice cooker (Midea) can identify the rice species, intelligently select heating curve (the price is 2.5 times of the one from ordinary rice cooker)
- Empower product with new features, such as artificial intelligence, voice interaction, A/V entertainment
  - e.g., JD and Midea jointly developed a smart refrigerator with image recognition technology, identify the type of ingredients, record user diet data (the price is 44% higher than the average multi-door refrigerator)

2- Xiaomi: Investment + Platform-Driven “Remote Control E-commerce”

- "Zero" to "first-batch" users: fans (bring their own traffic)
- "First-batch" to "N-batch" users: "remote control e-commerce" mode (precise sales channels)
  - Remote control e-commerce: refers to the characteristics of remote control (high frequency of use, very close to users, full understanding of usage habits) of intelligent hardware into an e-commerce channel
- 200 types of Xiaomi IoT products, most can be accessed to Mijia APP for controlling
  - More than 1.4 million users have more than 5 Xiaomi IoT devices at the same time

Self-developed Products

Smart TV+ Xiaomi Box

Smart Speaker

Laptop

Router

Eco-System Corp.

R

Sweeping robot

Drone

Air purifier

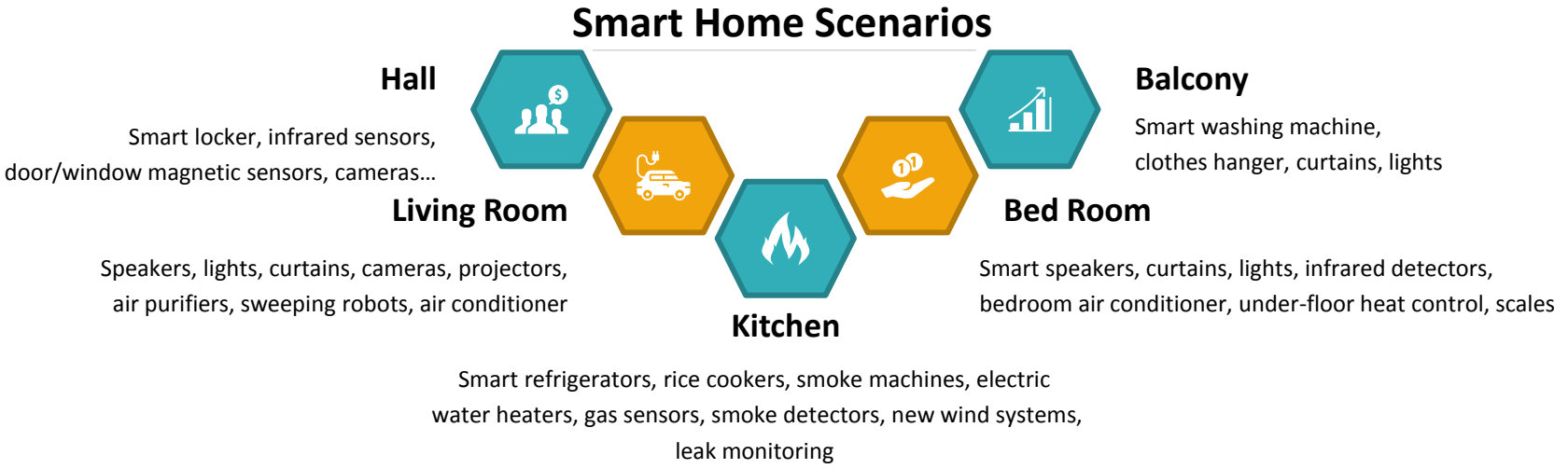
Water purifier

Rice Cooker

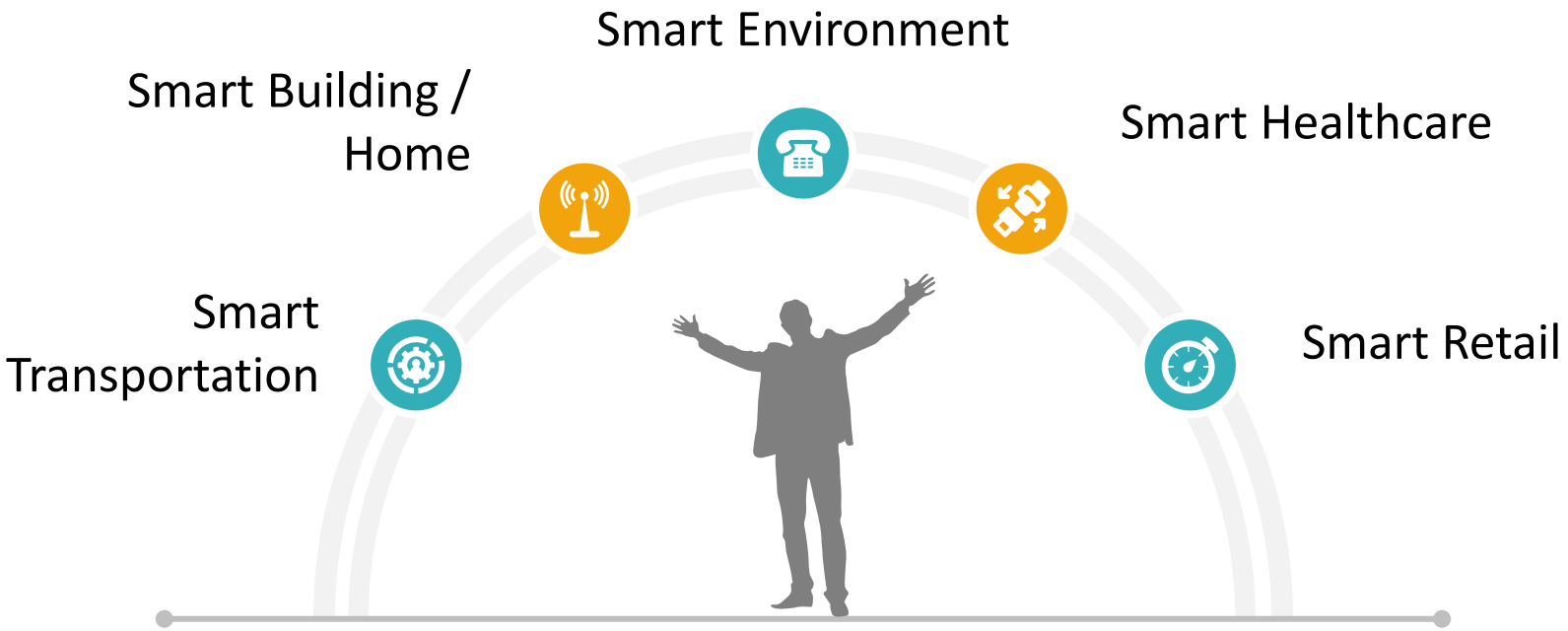
Smart Lamp

2- Smart Home of the Future: AI Empowered

- A truly smart home system requires a mature AI to
  - Control almost all of the smart products for intelligent application scenarios that connect and interact
  - Identify the functions of all types of smart products at home and integrate them to achieve the new services
  - Ability to learn on your own and adapt to users' personalized needs

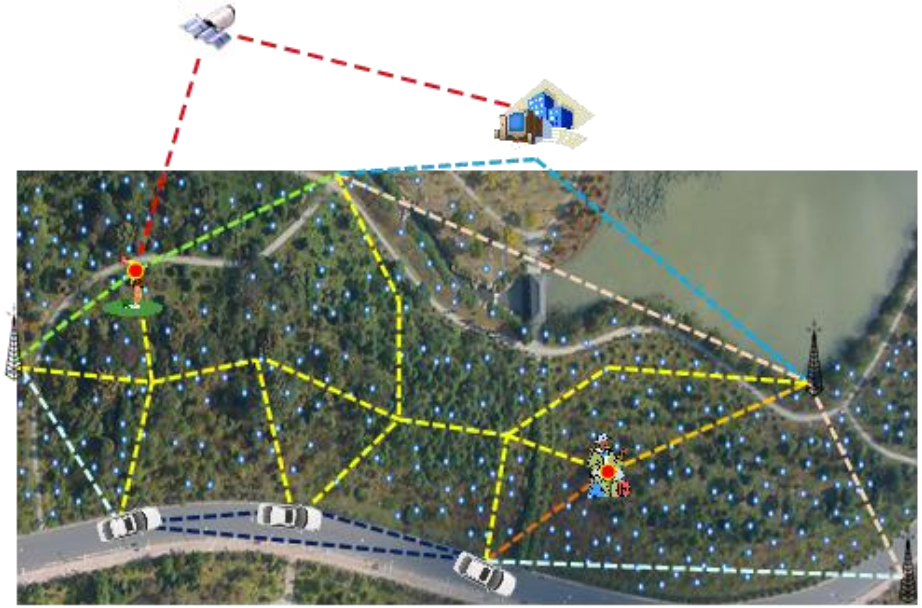


Typical Industry Applications



3-Smart Environment

- Through the detection of environmentally affecting material content, emissions, and various environmental state parameters, track changes in environmental quality, determine environmental quality levels, and provide basic information, method guidance and quality assurance for environmental management, pollution management, disaster prevention and mitigation



3-Concept of Environmental Monitoring

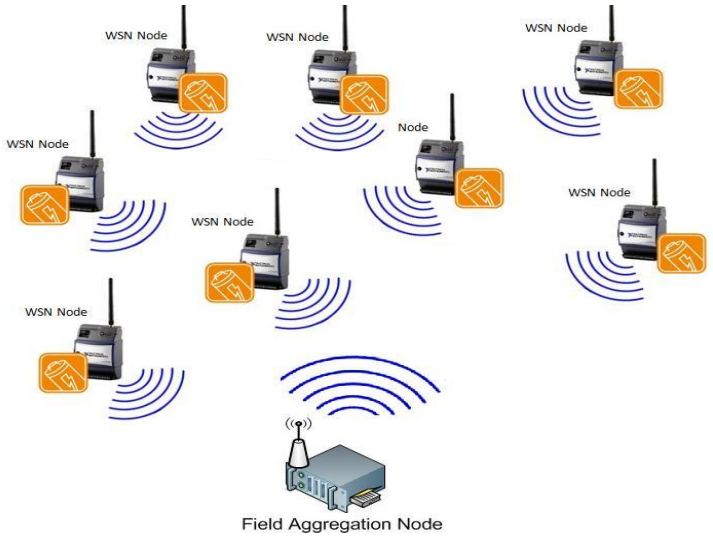
- The purpose of environmental monitoring: detect state parameters, track quality changes, and determine quality levels
- Environmental monitoring objectives: to provide basic information, method guidance and quality assurance for environmental management, pollution control, disaster prevention and mitigation
- Objects of environmental monitoring: natural factors, human factors, other factors that pollute the environment, and biological and ecological changes
- Different stages of environmental monitoring:

3-Development of Environmental Monitoring

- Experience-based observation
  - Understanding natural laws from natural factors
  - Incomplete, inaccurate, and un-objective reflection of natural laws
- Systematic scientific monitoring
  - Passive monitoring of heavily polluted locations in the 1950s
  - In the 1970s, the monitoring range was extended to discrete measurements including other physical factors
- Automatic monitoring
  - Computer control and auxiliary processing
  - Monitoring environment has breadth, frequency and depth
- Wireless sensor network

3- Advantages of Wireless Sensor Networks

- Wireless sensor network (WSN) technology has the characteristics of wide monitoring range, long duration, strong sensing ability, and timely information transmission. It is particularly suitable for playing a role in large-scale and complex environmental monitoring fields, and has become a bridge between the physical world and the mathematical world
  - Large-scale monitoring
  - Long-term unsupervised monitoring
  - Complex event monitoring
  - Synchronous monitoring



3- WSN System and Deployment

- Application scenario
  - Biological habit monitoring
  - High-risk disaster area monitoring
- Deployment requirements
  - Long-term continuous & fine-grained observations
  - No human intervention in the observation process

3- WSN System and Deployment

-- Great Duck Island System

- UC Berkeley 2002
- Great Duck Island
- 32 MICA nodes
- Data collection:
  - Temperature, humidity, light and atmospheric pressure
- Objective:
  - Continuously monitor the habits of petrels during the breeding season and collect relevant environmental data for zoologist analysis
- Significance:
  - WSN technology is first applied to environmental monitoring in real environments
  - Reveals various engineering and scientific challenges facing WSNs in outdoor environmental applications

大鸭岛传感器网络节点和部署环境

3- WSN System and Deployment

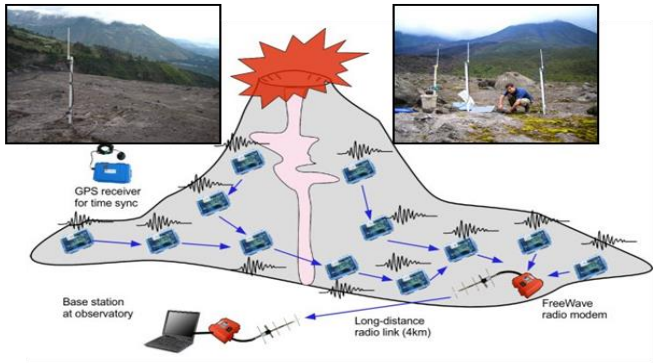
ZebraNet

- Princeton University 2004
- Central Kenya
- Data collection
  - Collect fine-grained zebra herd position information by bundling GPS sensors o n zebras
- Objective
  - Long-term tracking of zebra herd migration

3- WSN System and Deployment

- Harvard 2004
- Around active volcano in Ecuador
- 16 nodes
- Capture 229 earthquakes, volcanic eruptions and other seismic wave events in 19 days
- Data collection
  - 100 Hz frequency continuous acquisition of seismic wave and sound wave intensity, etc.
- Objective
  - Exploration of transmission reliability, data verification and calibration during high frequency data acquisition

Volcano monitoring



厄瓜多尔火山监控传感网部署环境

3- WSN System and Deployment

Natural climate monitoring

- University of Basel, University of Zurich and Federal Institute of Technology Zurich 2006
- Swiss Alps
- Data collection:
  - Climate conditions, geological structures and surface environment
- Objective:
  - Study the environmental impact of climate and predict natural disasters such as avalanches and landslides in advance

PermaSense系统部署

3-Challenges -1

- The actual scale and runtime that system achieves is far from the original target when WSN was proposed

System	Institute	Scale	Deployment period	Deployment	Power supply
VigilNet	University of Virginia	200	3-6 months	Outdoor	Battery
Motelab	Harvard Univ.	190	years	Indoor	Battery
SensorScope	Lausanne Institute of Technology	97	6 months	Outdoor	Battery
Trio	University of California, Berkeley	557	4 months	Outdoor	Solar cells

3-Challenges -2

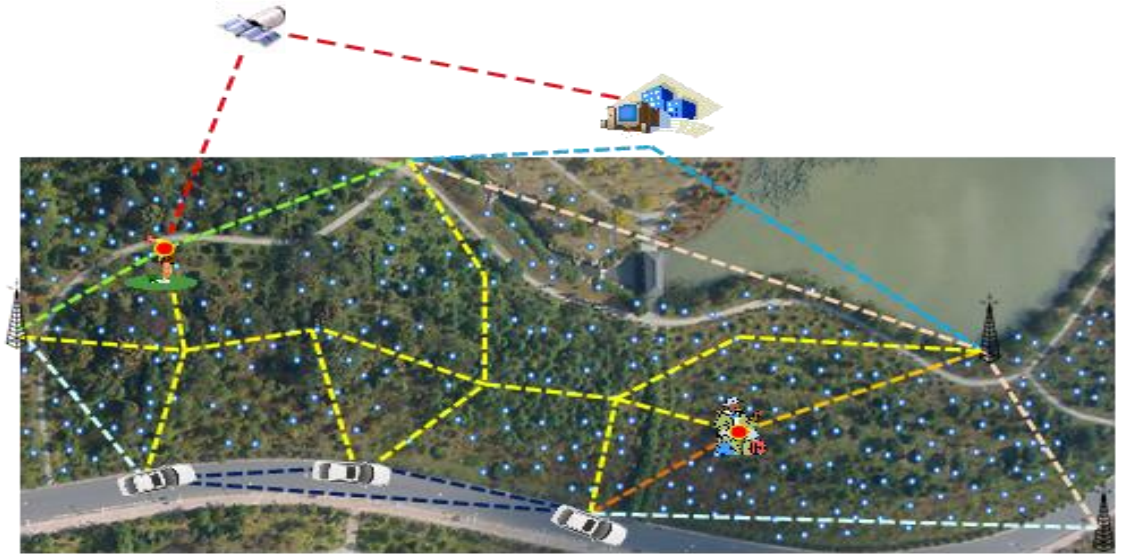
- The difficulties faced by large-scale long-term and stable WSN systems can be summarized as:
  - Sensing deharmony: Two core functions of WSN, i.e., transmission and sensing, are mismatched
  - Miscalculation: difficulty in network management
  - Model in-use: most existing research work is based on idealized model assumptions

3-Carbon Monitoring WSN: Application Background

- Addressing global climate change and maintaining a natural ecological balance:
  - On 16 February 2005, the Kyoto Protocol entered into force, explicitly stating that the share of carbon emission reductions could be offset by increasing carbon sequestration potential through effective management of ecosystems such as forests. Determining the role of forest in global CO2 mitigation
  - On September 22, 2009, President Hu Jintao proposed to use “forest carbon sinks” to mitigate climate change at the G20 summit in New York
  - On December 18, 2009, Premier Wen Jiabao at the Copenhagen Climate Change Conference

3-GreenOrbs - 1

- GreenOrbs:
  - Long-term large-scale monitoring of the Earth's environment centered on carbon sinks and carbon emissions
- Institutions
  - Tsinghua university
  - HKUST
  - Xi'an jiaotong university
  - Zhejiang Agricultural and Forestry University
- Composition
  - WSN
  - Vehicle network
  - Mobile 3G
  - Internet



GreenOrbs System Deployment (forest region)

3-GreenOrbs - 2

- One of the largest and longest running WSN applications in the world
- Location:
  - Tianmushan Nature Reserve in Zhejiang Province, the campus of Zhejiang Agricultural and Forestry University and Wuxi New Area
- Nodes
  - More than 2000
- Self-org multi-hop：
  - More than 20 hops
- Running time
  - More than 20 months

GreenOrbs System Deployment (Science Park)

3-GreenOrbs - 3

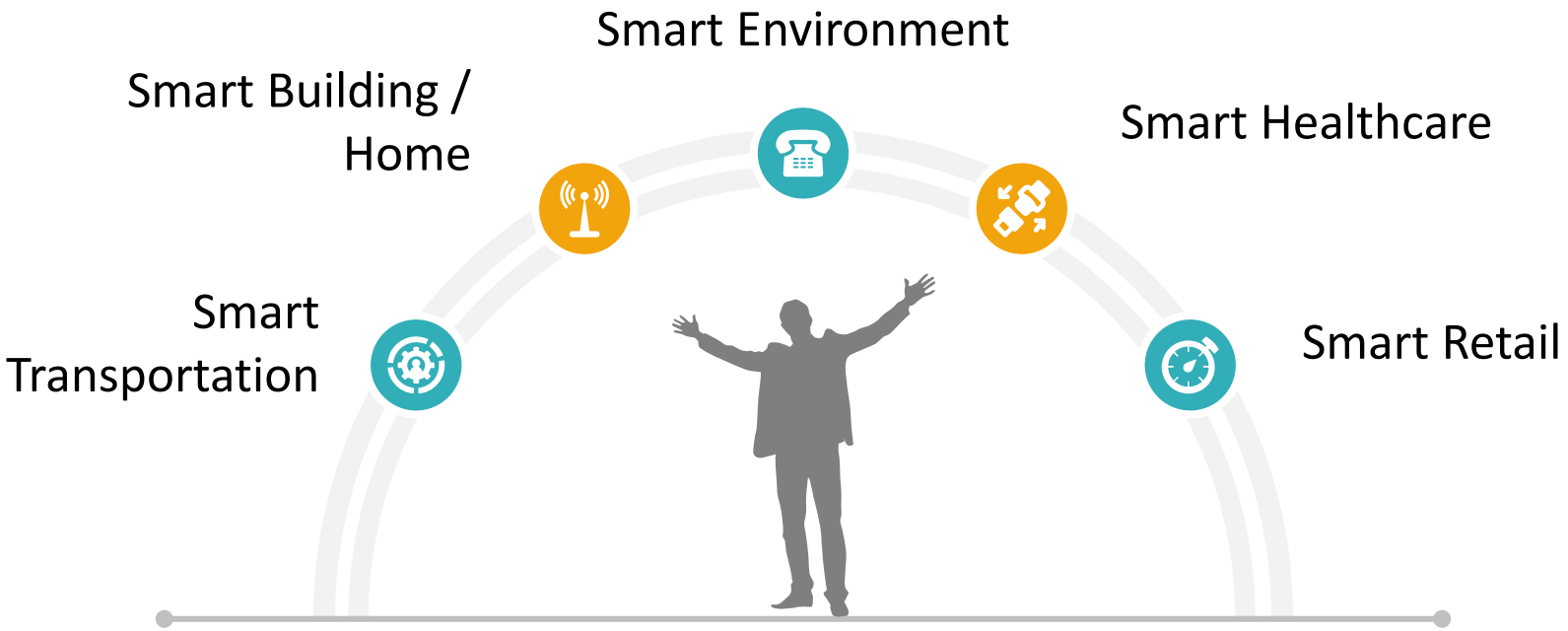
Sensing Node of GreenOrbs

Real-time display of the sensing data

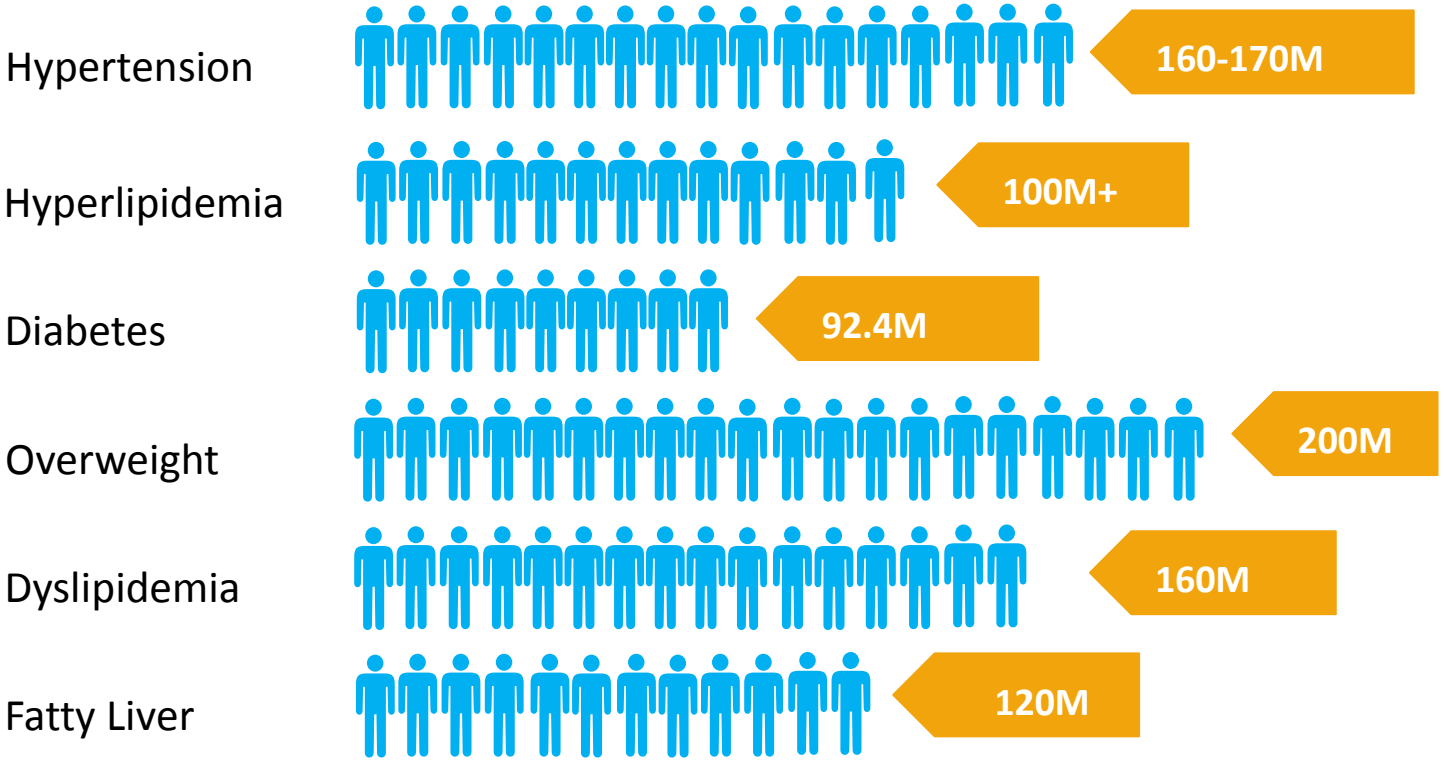
3-GreenOrbs - 4

- Research topic:
  - How to combine multi-dimensional information (such as node physics with logic) to design post-IP addressing methods based on environment fingerprint, event, and similarity
  - Build a multimodal sensing data model that supports quantitative fusion management
  - Study self-guided multi-grain diagnostic evaluation strategy for WSN, realize common sensor network diagnostic tool
  - study the method of localization error control for large-scale networks
  - Study on regionalized carbon concentration measurement and carbon emission monitoring

Typical Industry Applications

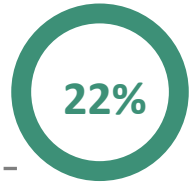


Health Related Big Data in China



Patients are Getting Younger

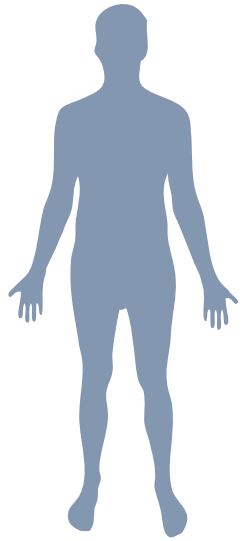
Middle-aged Chinese die of heart and brain disease



Intellectuals are on the verge of "being overworked"

White-collar workers suffer from sub-health

- Young women are easy to get gynecology, cardiovascular and cerebrovascular diseases
- Young men face sudden death, fatigue and cancer
- The prevalence of chronic diseases
  - Accounted for 83% of all deaths



- 35-46 years old patients died of Cardiovascular disease: China 22% vs. USA 12% (2013 - 2014)
- China has spent 300 billion RMB per year on the treatment of cardiovascular and cerebrovascular diseases

From: Healthcare Forecast Report 2020
China Talent Development Report

Technology Empower Medicare Development

Wearable

Novel Material

Internet +
Big Data

3D Printing

Mobile Internet

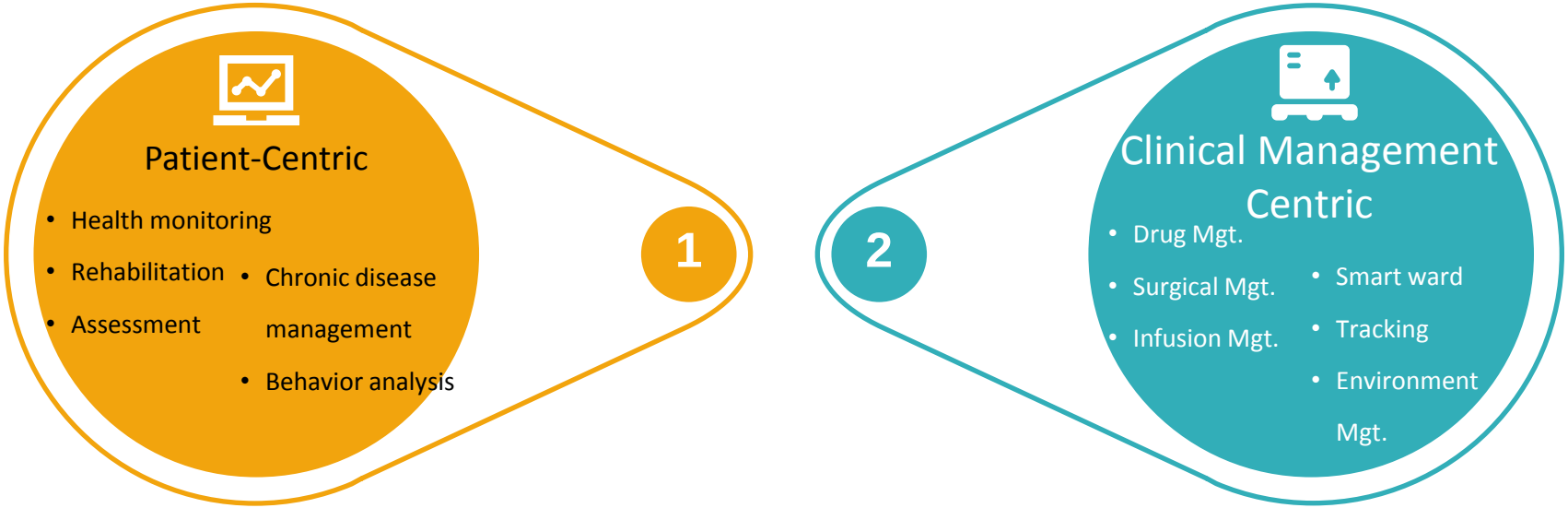
AI Technology

IoT

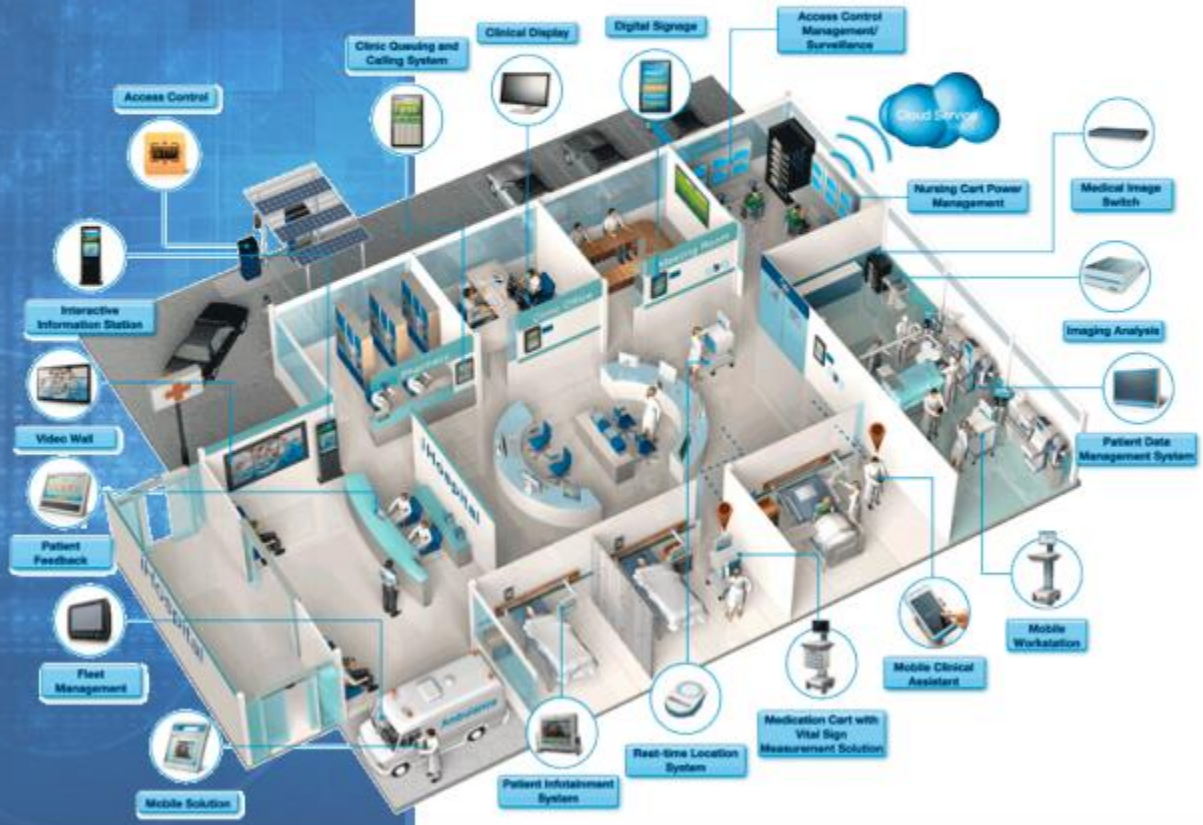
Application Space of the Medical IoT

The empowerment of IoT technology for the health industry can be seen from

- **Patient-centered health management:** disease risk prediction, disease diagnosis, treatment, and post-treatment rehabilitation/chronic management
- **Centered on medical clinical management,** including personnel/equipment positioning/ tracking/ management, drug management, surgical management, infusion management, physiological signs monitoring, smart wards, etc.



Smart Hospitals in the World



- **Sunshine Coast University, Queensland**
- **NHS University Colleague London Hospital**
- **The Cleveland Clinic**
- **South Glasgow University Hospital, Scotland**
- **Humber River Hospital, Canada**

Australia SCUH's Digital Hospital Elements

Navigation

- Physical and digital maps
- Color-coded wards and strips on the floors

Patient Rooms

- Tall windows with landscaped gardens
- Magnet-operated blinds Instead of doors for quieter environment

Indoor Lighting

- Bright, ambient indoor lighting
- Sensitive to movement with no manual switches

Scalability

- Planned capacity for 40,000 IT touchpoints to scale up digital capabilities
- May support double bed capacity from 450 beds to 900

NHS UC London Hospital - Decision Making using AI

NHS
University College London Hospitals
NHS Foundation Trust

Smart A&E Triage

- AI-supported case triage through analysis of thousands of similar scenarios
- Identify patterns in the initial presentation of symptoms
- Single out 20% cases with serious conditions for fast-track scan and swift diagnosis

Data Analytics & AI

Process Optimization

- AI & ML on large existing data sets on how people move through the departments of the hospital
- Track down operation bottlenecks, hurdles and downtime
- Improve operational and care efficiency

NHS University College London Hospitals

8 Hospitals, 500,000 outpatients & 100,000 inpatients in 2010

John Hopkins Hospital, US - Command Centre in Action

Staffing

- 24 staff members from various departments & professions
- Empower to make decision & take actions on service bottlenecks, staff shortage, and operational risk

Technology

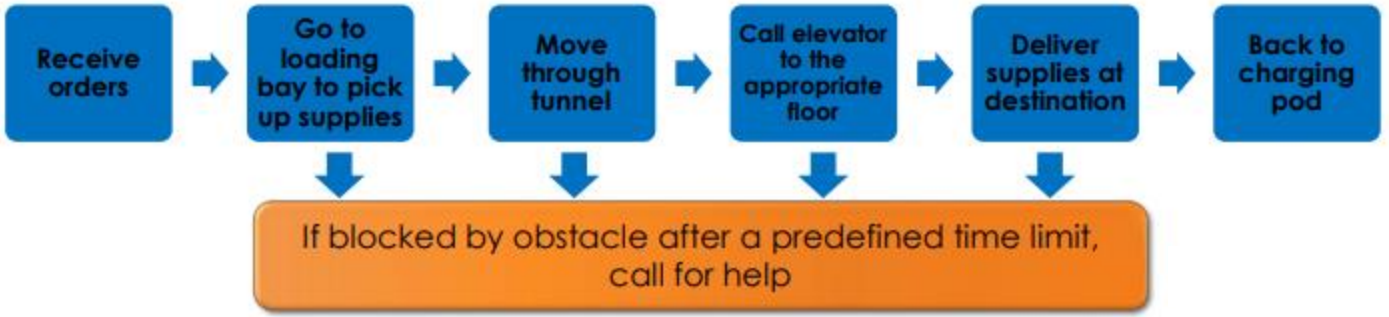
- Interface with all major IT systems
- Predictive analytics & effective data visualization
- Wall-mount monitors & dashboards

Benefits

- 60% capacity increase in patient transfers
- Access block shortened by 30%
- 21% more patients could be discharged before noon

South Glasgow University Hospit
Robotics in Action

- **26 robots** to move medical equipment, linens, food, and waste
- **Dedicated underground tunnel and elevator** for robots to transport supplies
- **Dedicated charging bay and loading bay** required
- Performing 10% of the hospital's operations tasks and expected to rise to 25% by 2025
- The robot's workflow:



Canada HRH's Key Technology Components

Touch-screen bedside terminals

- Patients can control over their environment, e.g. light, ambient temperature
- Can also use video call for real-time communication with staff, family and friends

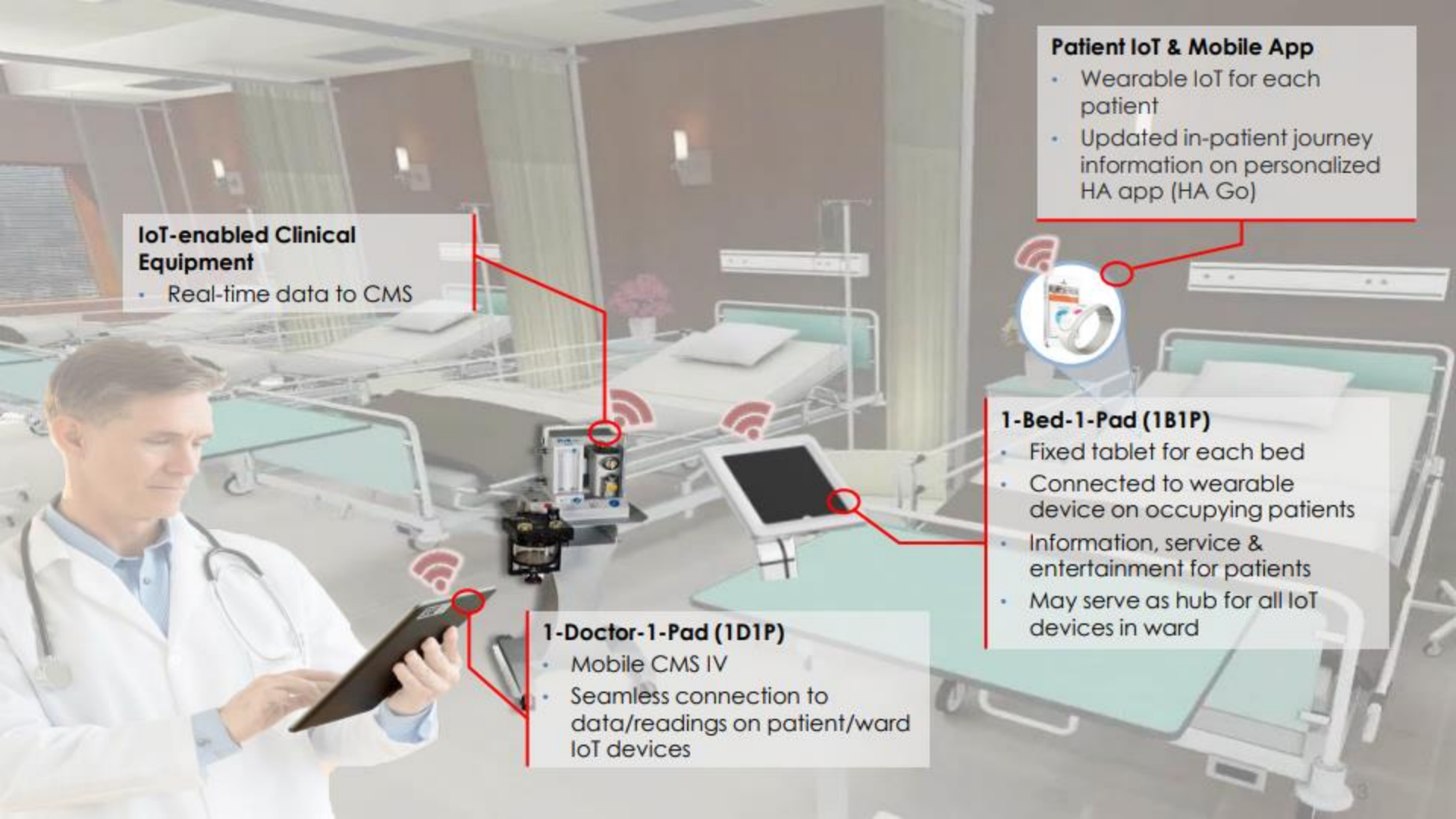
Automated Guided Vehicles (AGVs)

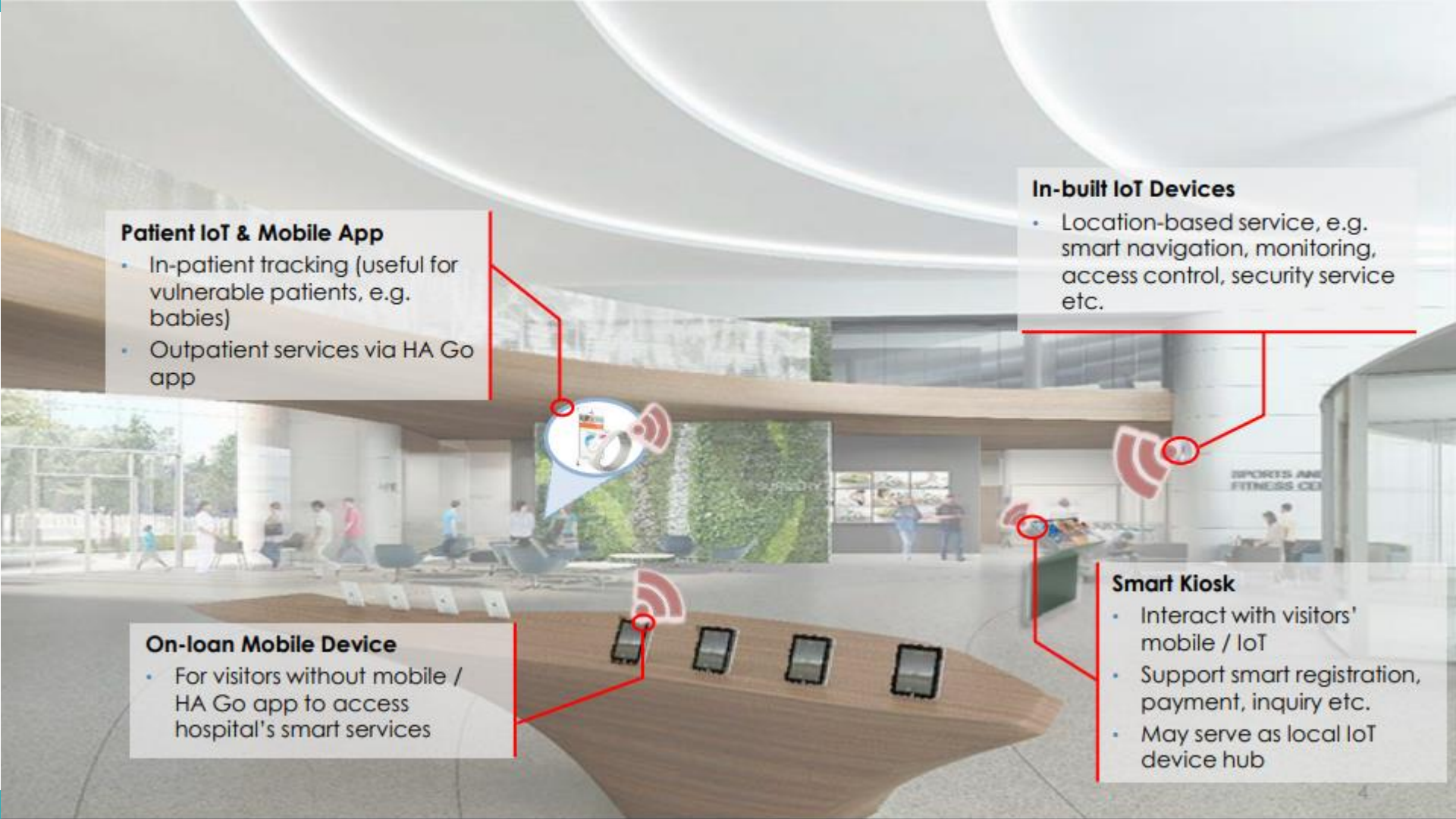
- Streamline delivery of medication, food services and housekeeping
- Interact with staff to let them know when the requested services have been delivered

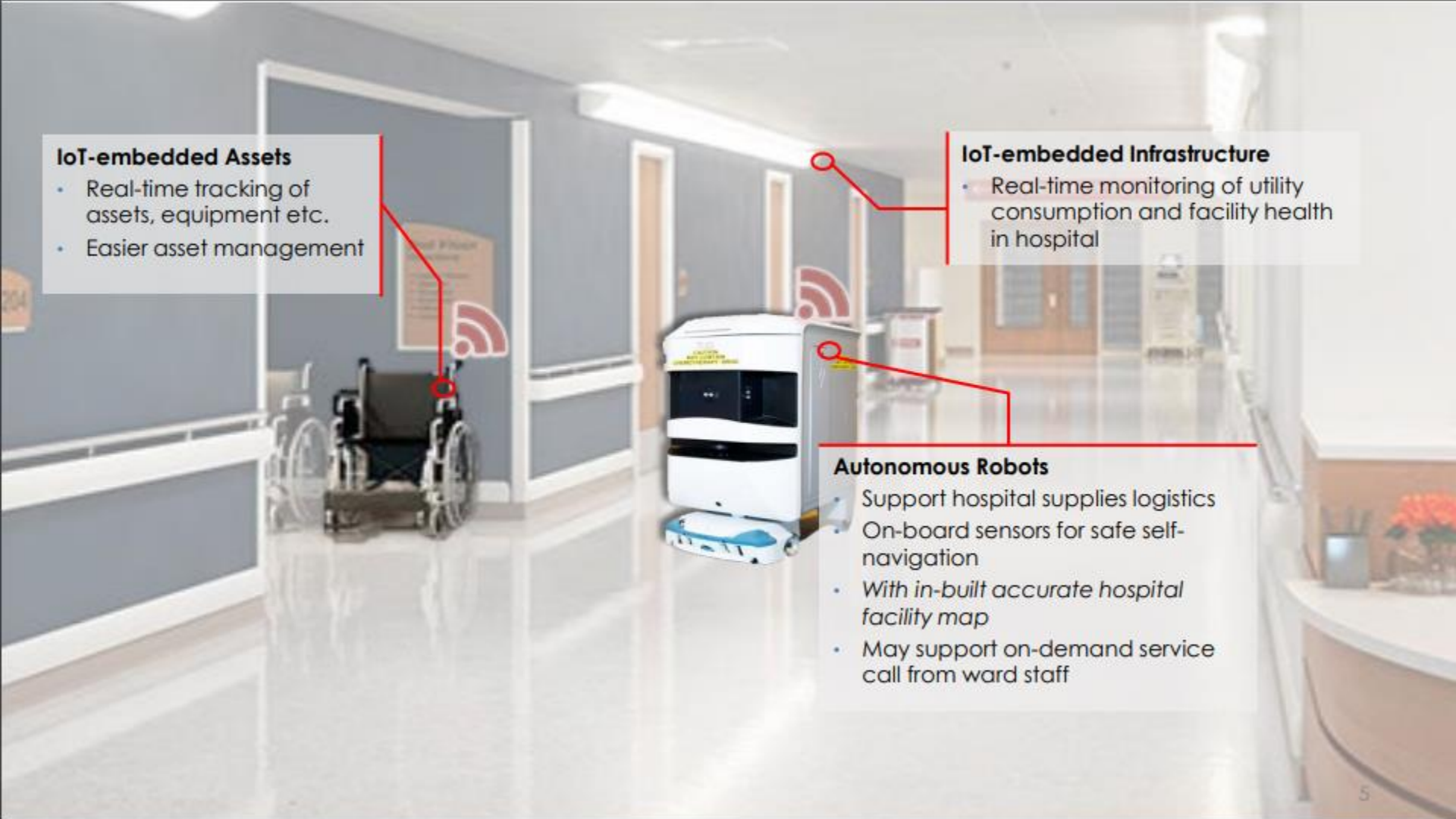
Real-time locating service

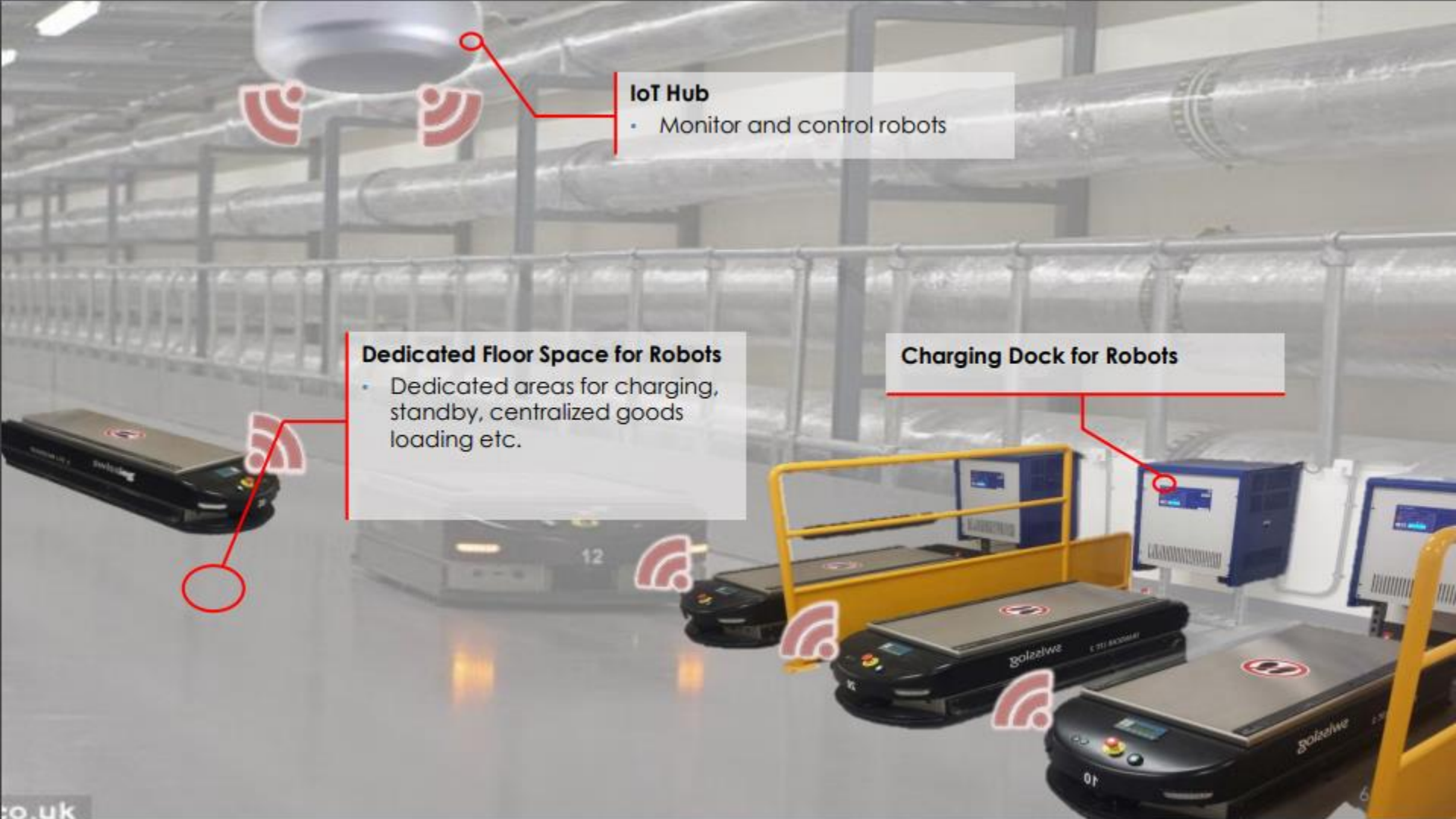
- Track patients, staff and assets
- Focuses on asset management, patient wandering, infant abduction and staff duress

Vision of Hong Kong Hospital Authority (HA)


Patient IoT & Mobile App
• Wearable IoT for each patient
• Updated in-patient journey information on personalized HA app (HA Go)
IoT-enabled Clinical Equipment
• Real-time data to CMS
1-Bed-1-Pad (1B1P)
• Fixed tablet for each bed
• Connected to wearable device on occupying patients
• Information, service & entertainment for patients
• May serve as hub for all IoT devices in ward
1-Doctor-1-Pad (1D1P)
• Mobile CMS IV
• Seamless connection to data/readings on patient/ward IoT devices

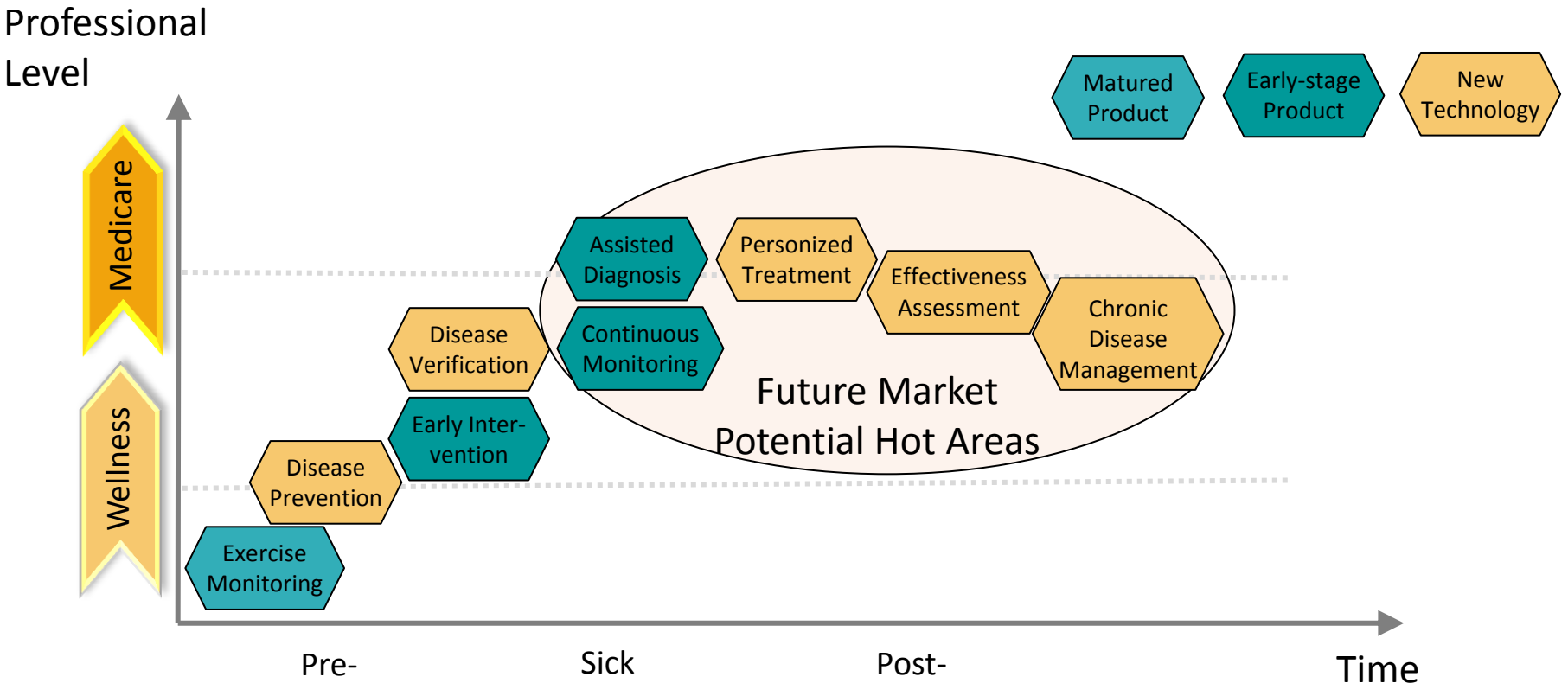

Patient IoT & Mobile App
In-patient tracking (useful for vulnerable patients, e.g. babies)
Outpatient services via HA Go app
In-built IoT Devices
Location-based service, e.g. smart navigation, monitoring, access control, security service etc.
On-loan Mobile Device
For visitors without mobile / HA Go app to access hospital's smart services
Smart Kiosk
Interact with visitors' mobile / IoT
Support smart registration, payment, inquiry etc.
May serve as local IoT device hub


IoT-embedded Assets
Real-time tracking of assets, equipment etc.
Easier asset management
IoT-embedded Infrastructure
Real-time monitoring of utility consumption and facility health in hospital
Autonomous Robots
Support hospital supplies logistics
On-board sensors for safe self-navigation
With in-built accurate hospital facility map
May support on-demand service call from ward staff


IoT Hub
• Monitor and control robots
Dedicated Floor Space for Robots
• Dedicated areas for charging, standby, centralized goods loading etc.
Charging Dock for Robots


Centralized Command Centre(s)
• Dashboards with real-time relevant information and alerts
• Monitoring all patients, clinicians, equipment, robots, facilities etc. in the hospital
• AI-based decision support & action triggering
Centralized Experts
• Centralizing professionals and their expertise
• Monitor overall hospital's operations
• Remote advice / instruction provision to local staff

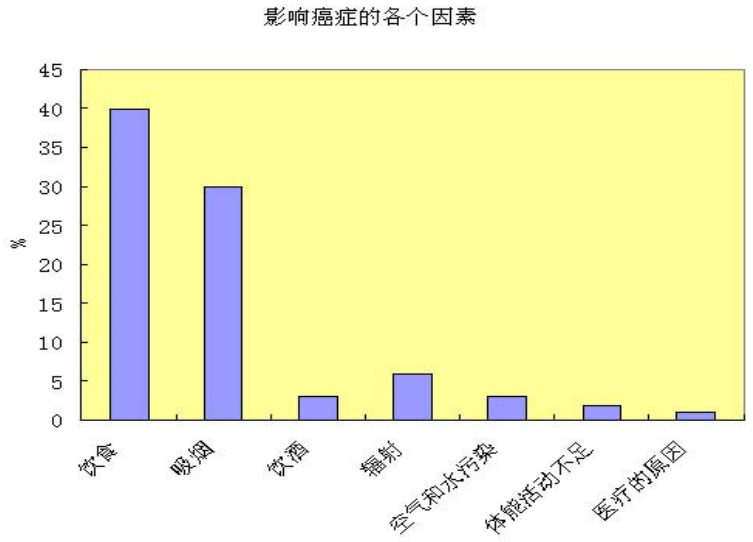
Application Scenario for IoT in Healthcare



From: 动脉网

The Importance of Healthy Lifestyle

- 75% of cancers are associated with lifestyle
- With proactive prevention and intervention, at least 40% of the tumors can be prevented
- In the cause of chronic diseases
  - Genetic factors 15%, social factors 10%, climatic 7%, medical conditions 8%, and personal life style 60%



Life-cycle Health Management Solution

- Monitor user health-related **life behaviors** (eat, sleep, walk)
- Monitor key **vital signs** (blood pressure, blood sugar, ECG, urination, breathing)
- Evaluate the effectiveness of the treatment plan (medical treatment plan: medicine, rehabilitation, surgery, etc.)
- Health management platform provides **personalized treatment plan** data support for doctors
- Intelligent IoT equipment monitors key vital signs in real time, providing a basis for doctors to adjust treatment plans

Good Sleep

Background and Motivation

Necessity 3000 deaths are related to OSAS (Sleep Apnea) each day in the world 20 percent of sudden death are caused by OSAS

Patient 50 million people in China are suffering from OSAS

Treatment The best way to cure OSAS is to adopt sleep monitoring

Lack of Knowledge and Diagnosis

PSG----Golden Principle

Polysomnograph is a comprehensive recording of the bio-physiological changes that occur during sleep, which is commonly used for testing insomnia and OSAHS. The PSG monitors many functions including arterial oxygen saturation, electroencephalogram (EEG), eye movements (EOG), muscle activity or skeletal muscle activation (EMG) and heart rhythm (ECG) during sleep

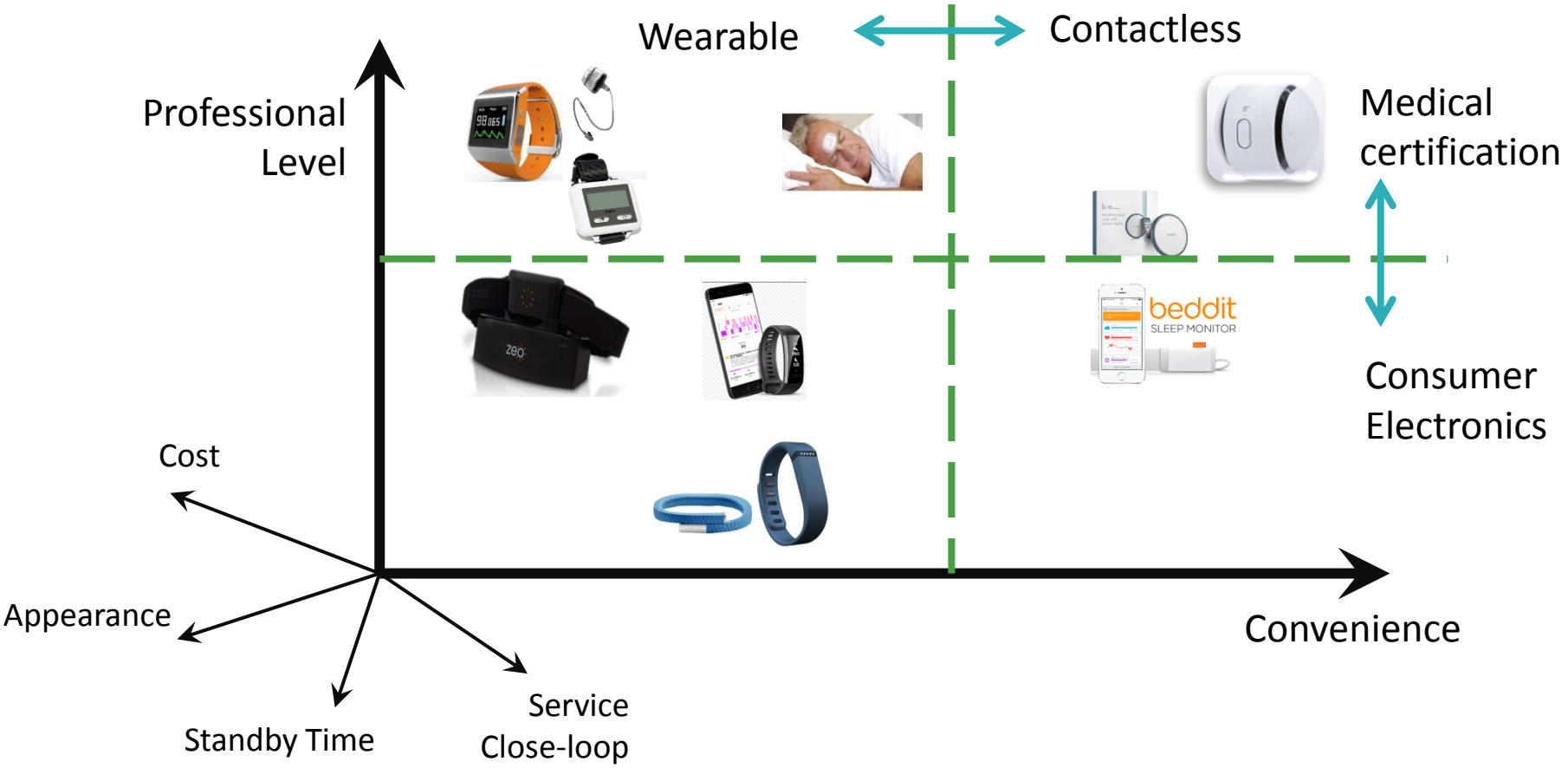
Disadvantage

1. A PSG requires dozens of lead wire attachments to the patient. The operation is complicated for medical staff
2. The testing cost is high for patients
3. It may interrupt the sleep of the patients, which may produce physiological and physical stress to patients

93% of male patients and 82% of female patients suffering from OSAS miss the most suitable time for treatment due to lack of proper diagnosis. Some are unwilling to take monitoring due to the interference and inconvenience.

Hence, portable and convenient instrument is needed

Remote Sleep Monitoring Solutions



UP: Technology and Products are the Foundation

- In 2011, when the wearable concept was emerged, Jawbone entered the field, releasing the UP series of health sports bracelets
- Jawbone raised in total of $900 million (with 13 rounds), with a peak valuation of $3 billion
- Jawbone's UP series bracelets are always stranded by the market because they are not fully functional and have nothing new
  - First-generation UP bracelet, quickly removed due to bug
  - In 2012, the new version of the UP bracelet cannot support wireless synchronization
  - In 2013, the UP24, despite the addition of wireless sync, lost its original promised waterproofing
  - Competitors have started to provide screens, automatic sleep recognition and motion status for sports bracelets

- Ring market is not very good
  - About a third of fitness rings are abandoned in just six months, according to market research
  - More than half of fitness ring buyers end up abandoning the device, according to the Journal of the American Medical Association

In 2017, Jawbone launches bankruptcy liquidation process

Zeo: Cannot only focus on Technology

- Zeo was founded by three Brown University students who are trying to use sleep science and technology to improve people's quality of life
- Launched Zeo Personal Sleep Advisor in June 2009 and a sleep management app in 2011
  - User wears a special headband and can track different stages of sleep, such as light sleep, deep sleep, and rapid eye movement, through sensors that measure brain waves
  - Data is sent to the user's smartphone
- The company raised more than US $ 30 million in eight years and remains bankrupt

- Problems
  - Product problem: discomfort when wearing and affecting sleep
  - Unclear market positioning and target user group’s needs
    - Positioned for self-management ←→ Consumers don't seem to care about monitoring accuracy
      - FitBit and Jawbone Up and other wrist movement recording devices have built-in accelerometers to determine the user's sleep and wake cycles
      - Research published in the Journal of Sleep Research points out that Zeo's analysis data is close to authoritative data from the sleep laboratory
    - Sleep monitoring from ordinary wearable devices is a toy from doctors’ perspective

Huawei: Consumer Product with Professional Analysis Capabilities

Huawei Honor Bracelet is the first industrial wearable solution based on PPG for sleep staging monitoring

- Huawei's TruSleep sleep monitoring technology is based on CPC technology from the CDB Center at Harvard Medical School
  - Professional guarantee: CardioPulmonary Coupling technology has passed FDA and CFDA certification
  - Theoretical basis: CPC theory is based on ECG signals.
  - Technical breakthroughs:
    - The extraction of the heart rate signal by the wearable device is based on photoelectricity, which is highly interfered. The technological breakthrough has made the photoelectric heart rate as accurate as the ECG
    - Honor 4 is the first to achieve sleep without heart rate measurement (avoid green light at night)
    - Screening for sleep apnea disorders: respiratory quality

Positioned as consumer electronics product, the significance of independent monitoring?

Oranger: Focus on Medical Grade Product

- Positioned as "Medical Devices + Medical Services", the products of the Oranger are medical-grade products that have been certified by the CFDA
- In 2014, launched the first product-hysteresis monitoring watch (i.e., the orange pulse oximeter), which is a new type of portable diagnostic equipment developed for OSA
- By monitoring the blood oxygen level of the patient while sleeping, a continuous indicator of blood oxygen is generated to form a monitoring report, from the respiratory disease to the chronic disease management
- Clear sales channels: through multiple channels such as top hospitals, primary hospitals, medical examination centers, and etc.

The Internet + attributes are not strong. The experience of the end user needs to be improved

SomnaPatch: Professional Sleep Breathing Monitoring

- Wearable patch SomnaPatch can effectively detect different degrees of sleep apnea
  - Disposable patch that has been approved by the US FDA
  - The SomnaPatch device is placed on the forehead and has a section that fits the nose
  - The patch weighs less than 1 ounce and can record human blood oxygen saturation, nasal pressure, pulse, breathing effort, sleep time and body position
  - Clinical trial results are consistent with 87% of standard laboratory PSG monitoring results

Merchant pointed out that most home sleep diagnostic devices are difficult for users to operate, while may affect the sleep quality of patients. SomnaPatch is comfortable and convenient to use, and will not negatively affect sleep.

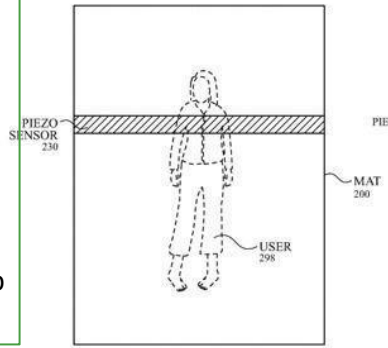
Comfortable and convenient, can we work harder?

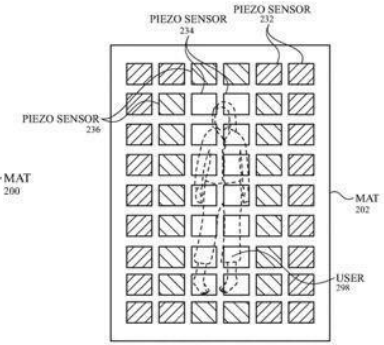
Beddit: Contactless Health Monitoring

- In 2017, Apple acquired Finnish sleep monitoring hardware company Beddit, and in December 18 introduced Bedsit 3.5, which is exclusive to IOS.
  - Beddit 3.5 uses a piezo film monitoring process, which generates electrical signals after pressure contact between the upper and lower conductive films, and induces micro-vibrations of the human body.
  - The back of the strap is black non-slip fabric, which can "grasp" the mattress surface to prevent monitoring failure due to displacement Can
  - Only for single person sleep monitoring

Apple applies for two patents at the end of 2018

- The core principle is to place a piezoelectric film on the bed to monitor the contact points between the user and the bed, and analyze the movement and quality during sleep
- Two sleep solutions:
  - A thin long strip is placed on the user's chest
  - The sensor array is covered throughout the bed and the sensors are divided into separate units
    - Induction matrix is dense and widely distributed to monitor more sleep indicators





EarlySense: Contactless towards Medical Grade

- As an Israeli medical technology company founded in 2004, it has raised a total of 106 million US dollars
  - The core product is a contactless sensor system that can be embedded in the bed, and can continuously monitor the respiratory rate, heart rate and movement without contact
  - Both sensors have been approved by the US FDA, and the products can be used in medical institutions or homes
  - EarlySense's sensor products can be used in hospitals or homes. Hospital equipment solutions are priced at thousands of dollars per bed, and home consumer devices are often at hundreds of dollars
  - In January 2017, EarlySense launched the first clinically proven contactless home health and sleep monitor LIVE, providing users with a low-voltage inductive sensor disk and a LIVE + mobile APP with remote access permissions.

For individual patients and their families, contactless bed monitoring products are undoubtedly a good choice

MegaHealth: Wireless-based Contactless Solution

- Wireless sleep breathing monitor "Dream Plus"
  - The instrument can be placed directly on the bedside, connected to a Wi-Fi network, and the arrow on the instrument can be adjusted to the patient's chest to detect whether there are breathing disorders such as sleep apnea and hypopnea
  - Using ultra-wideband (UWB) bio-radar monitoring technology to detect chest-abdominal motion caused by breathing, and obtain breathing, full body movement and other information in radar echoes, thereby achieving non-interfering monitoring of sleep breathing disorders
  - Patients do not need to experience the electrodes on the head, making it difficult to fall asleep
  - Product features: anti-interference
    - When multiple person sleep together, they will search for the target, lock the closest human target, and filter out other interference information

"Dream Plus" received CFDA certification in April 2017, demonstrating that it is a serious medical grade product

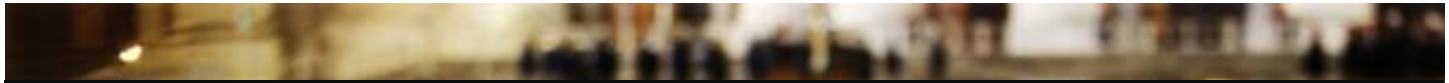
Contactless + Medical-grade + Affordable Price ?

Contactless Sleep Apnea Diagnosis on Smartphones

Rajalakshmi Nandakumar, Shyam Gollakota, Nathaniel Watson M.D.


Can we enable contactless sleep apnea diagnosis on a smartphone ?

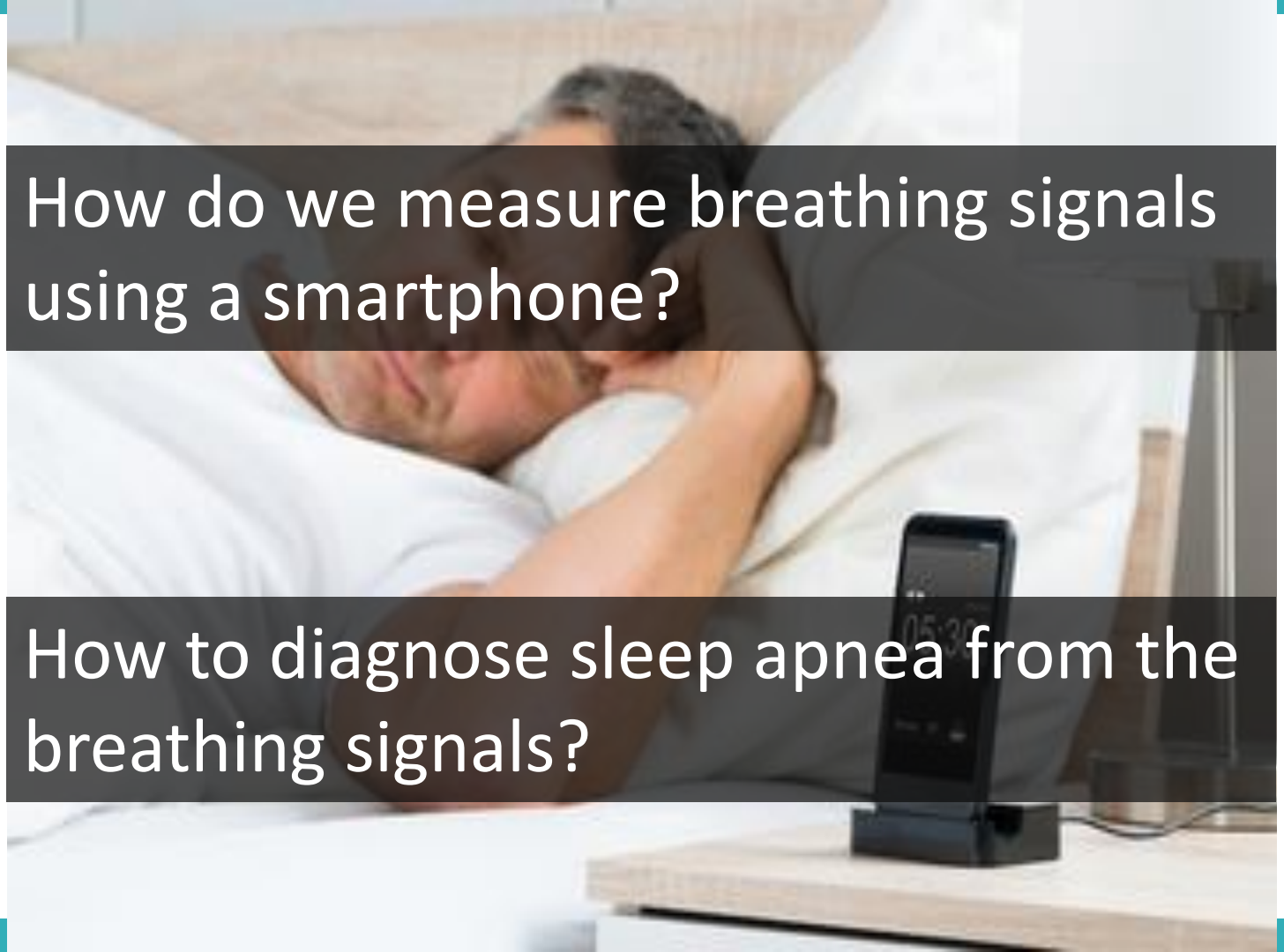
ApneaApp

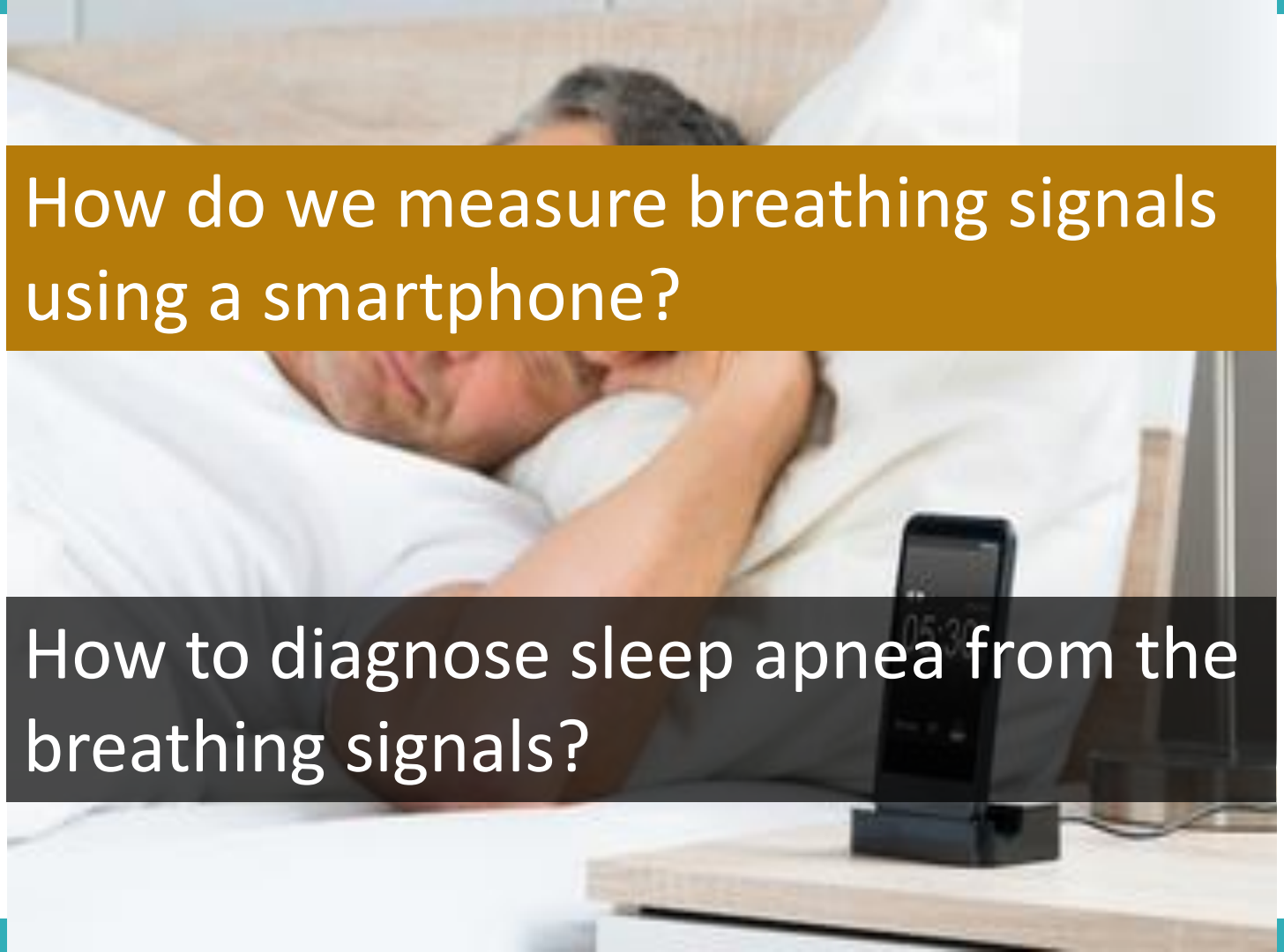


Introduces the first contactless system that measures breathing signals on a smartphone

Detects sleep apnea events (e.g. central apnea, hypopnea, obstructive apnea) from the breathing signals

Evaluated in a clinical study with 37 patients over 296 hours


How do we measure breathing signals using a smartphone?
How to diagnose sleep apnea from the breathing signals?


How do we measure breathing signals using a smartphone?
How to diagnose sleep apnea from the breathing signals?

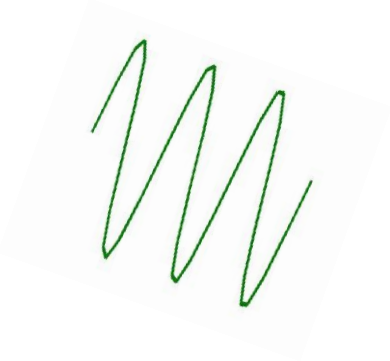
Challenge: Breathing Motion is Very Minute

Radar Approaches Infeasible on Smartphones

Centimeter resolution requires expensive ultra-wideband (1—2 GHz) radio signal processing

Requires custom, expensive multi-antenna hardware

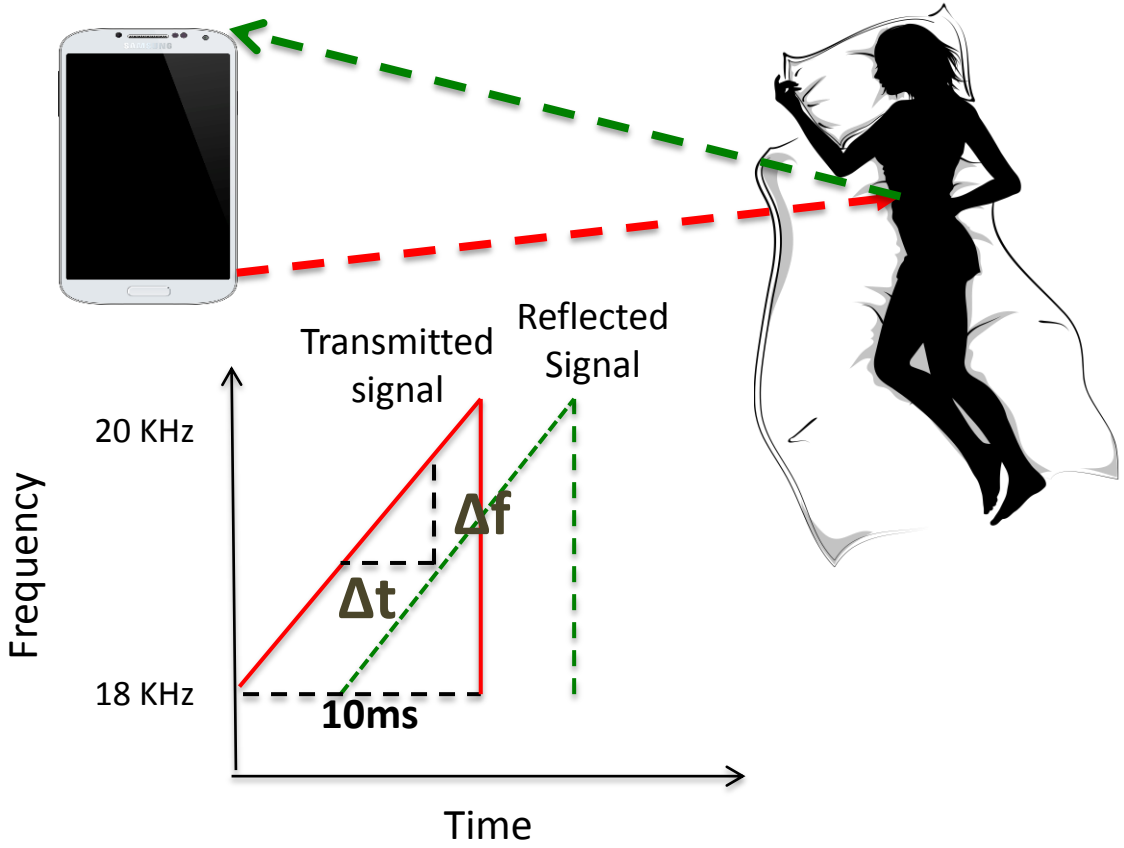
Key Idea: Transform Phone into Active Sonar



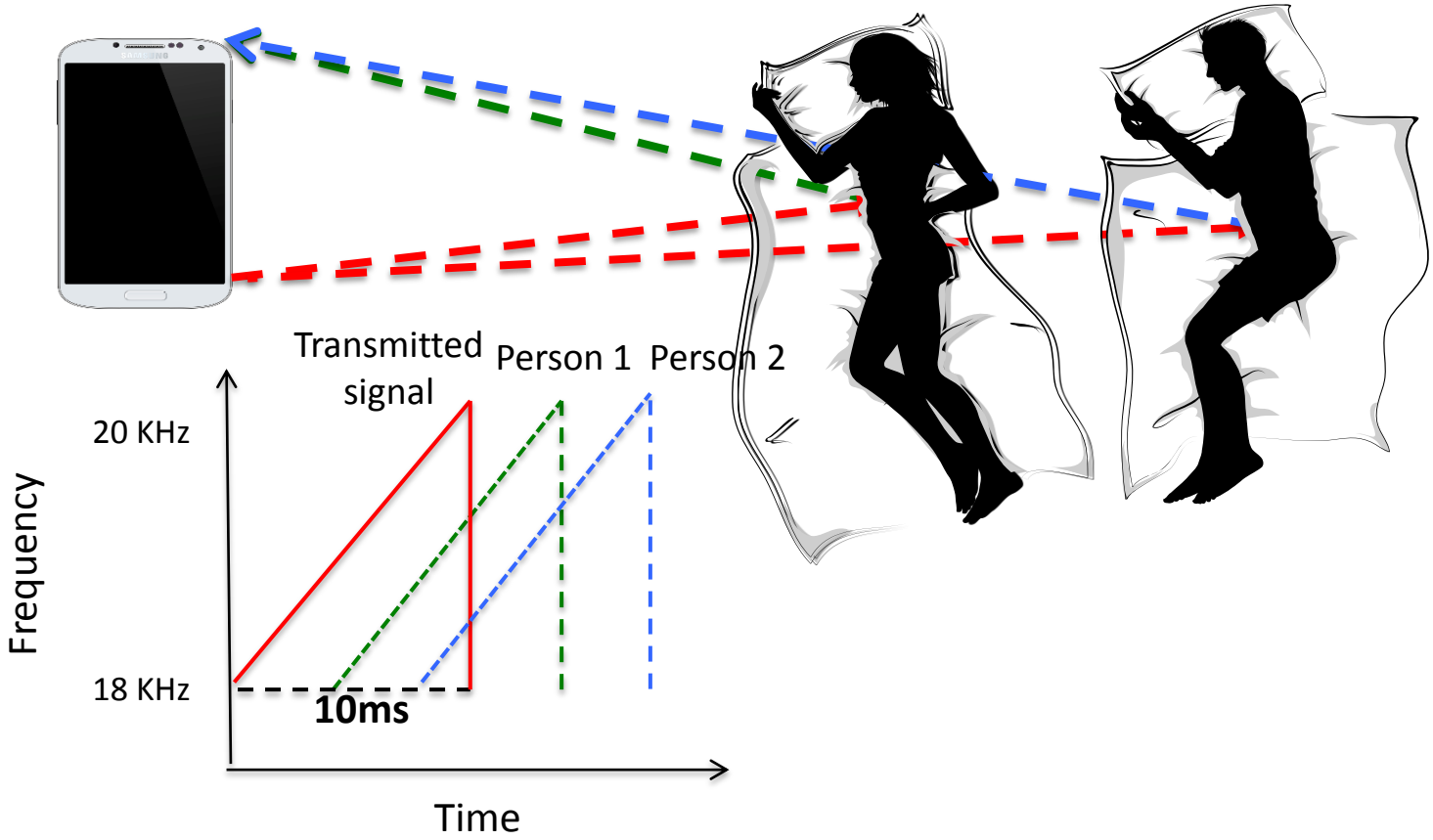
Breathing Motion

Achieves 0.71 cm resolution using only 48 kHz acoustic signals!

System Design

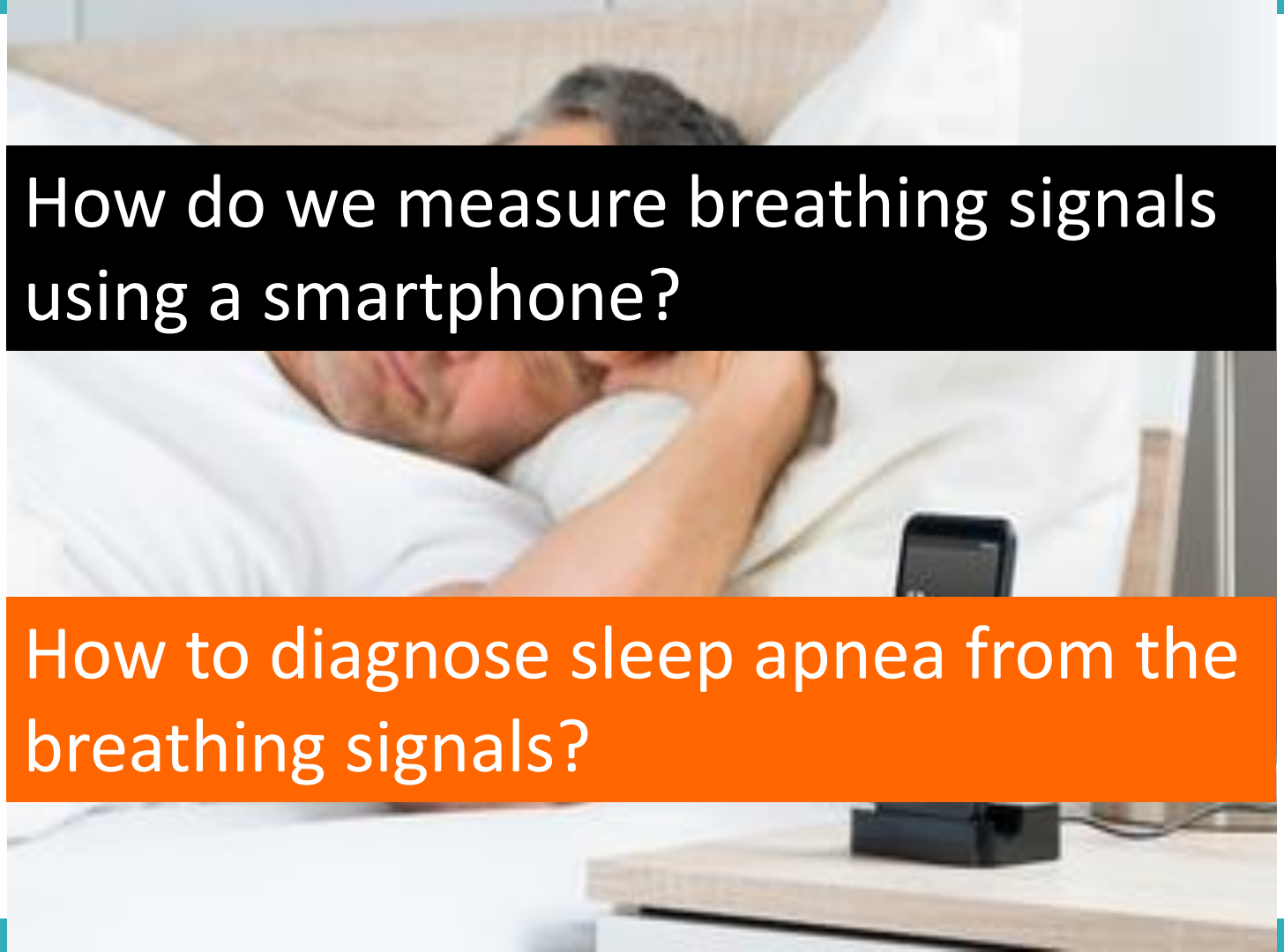


System Design



ApneaApp’s Processing Algorithm

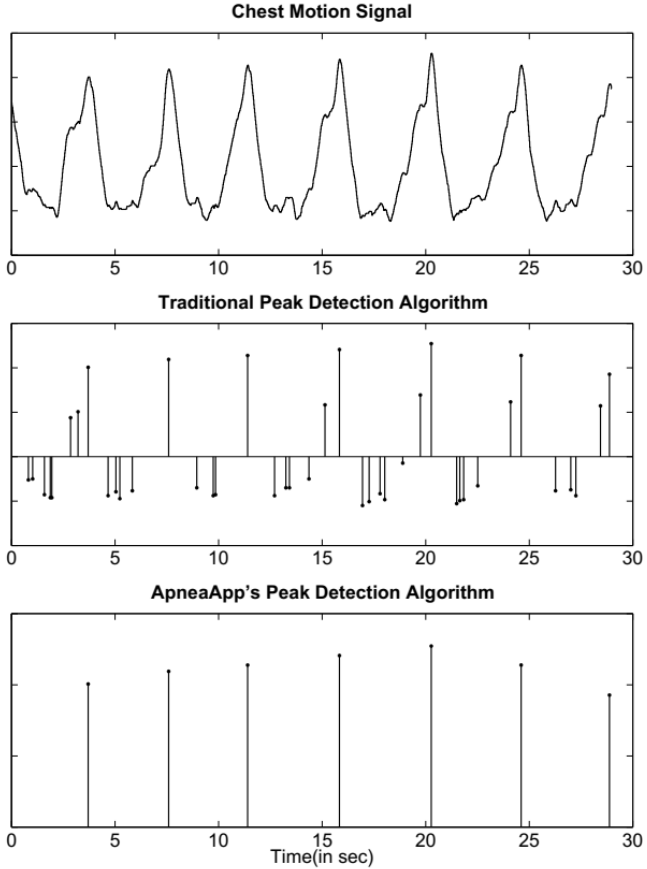
- Start at zero distance and search for breathing motion at increasing distances
- Stop search when 0.2 - 0.3 Hz periodic signal is found
- With multiple people, continue search till max distance



How do we measure breathing signals using a smartphone?

How to diagnose sleep apnea from the breathing signals?

Peak Detection Algorithm



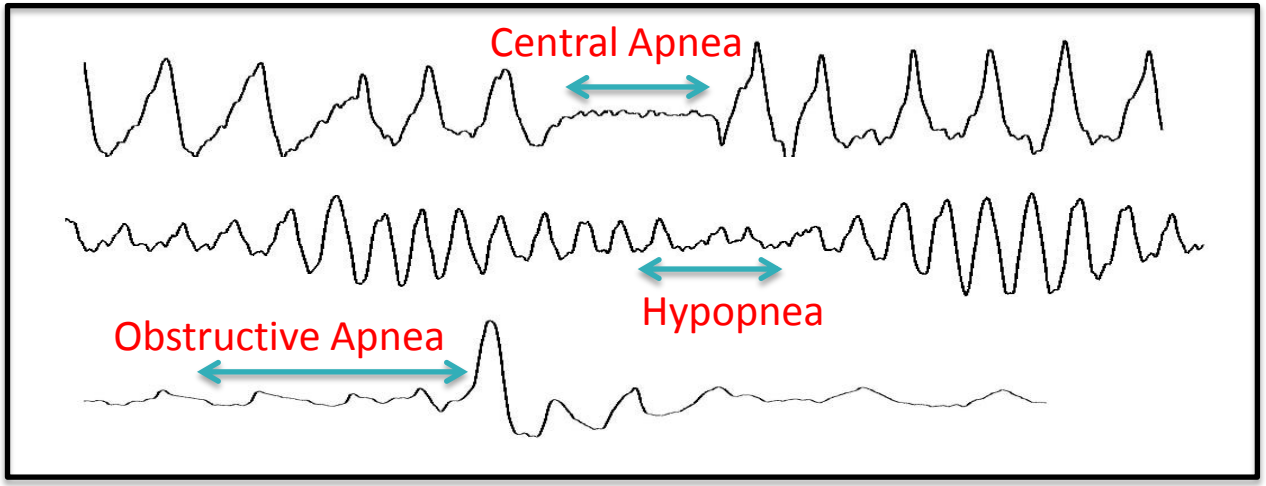
Simple peak detection results in false peaks

Use thresholds for min. distance between peaks and min. peak amplitude.

Apnea Event Detection

1. **Central Apnea** : Distance between consecutive peaks > 10s
2. **Hypopnea** : Peak below a threshold, but still periodic
3. **Obstructive Apnea** : Sudden spikes. Amplitude increase > 50%

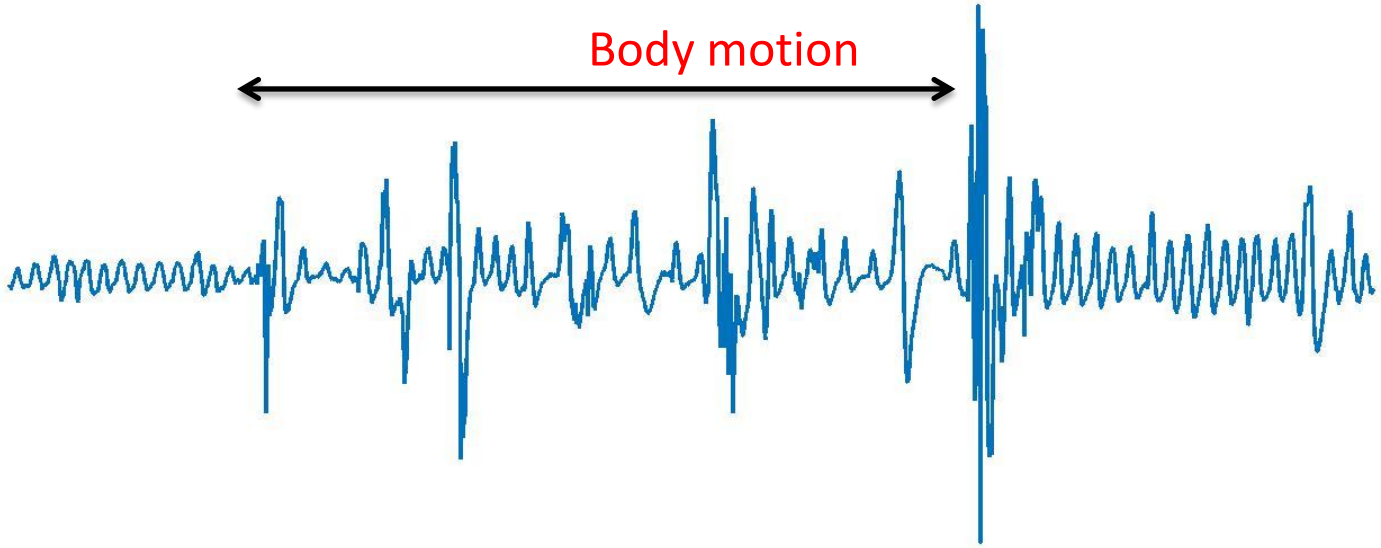
Diagnosing Sleep Apnea from Breathing Signals



$$AHI = \frac{\text{Total \# of apnea events}}{\text{Total sleep time (in hr)}}$$

AHI < 5 : No Apnea
5 <= AHI < 15 : Mild Apnea
15 <= AHI < 30 : Medium Apnea
AHI > 30 : Severe Apnea

We Infer Sleep Time from Body Motion



Sleep time = Total duration – Duration of motion

How well does ApneaApp work?

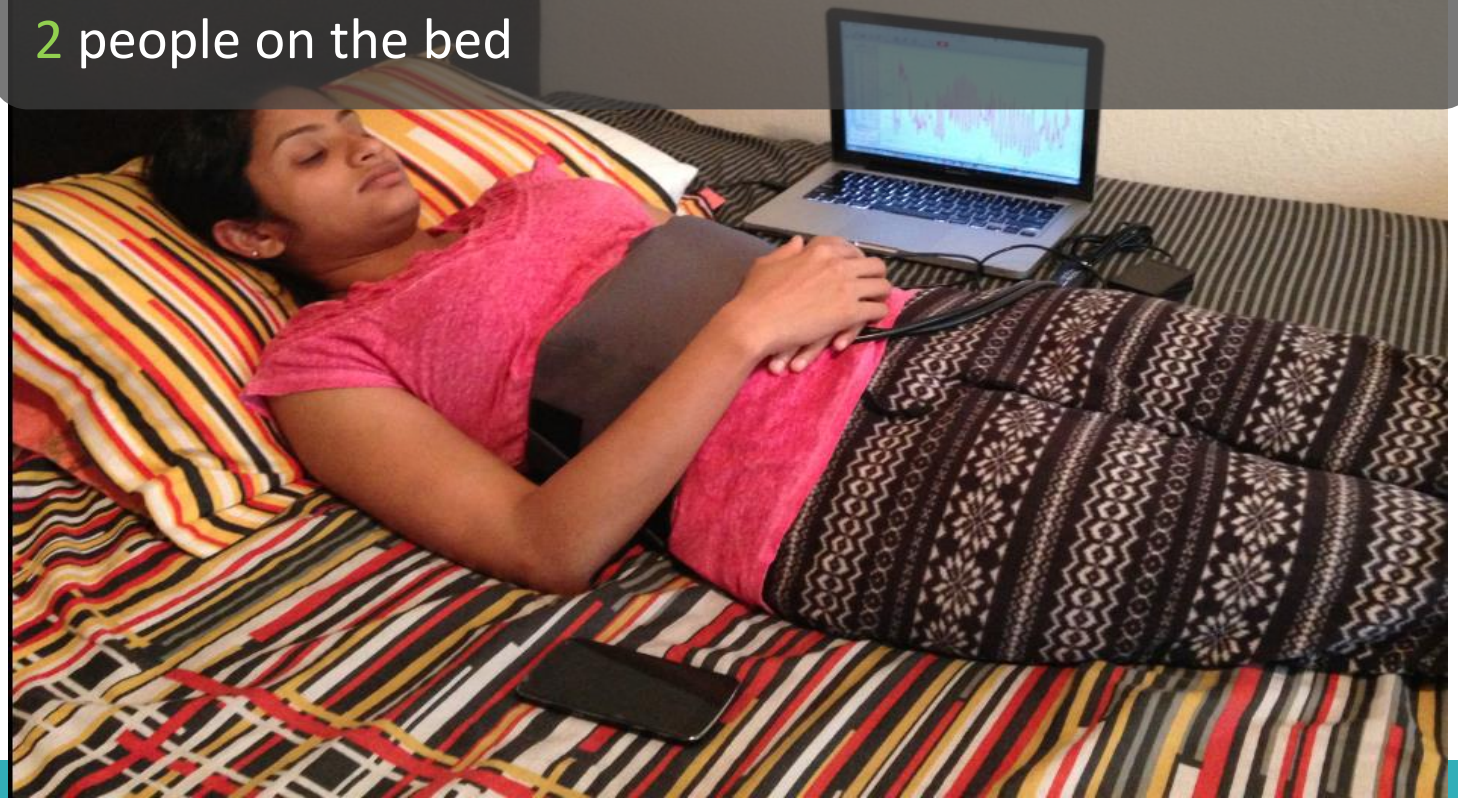
5 Participants over 10 hours

Different distances, phone positions and orientations

All sleeping positions

Different blankets

2 people on the bed



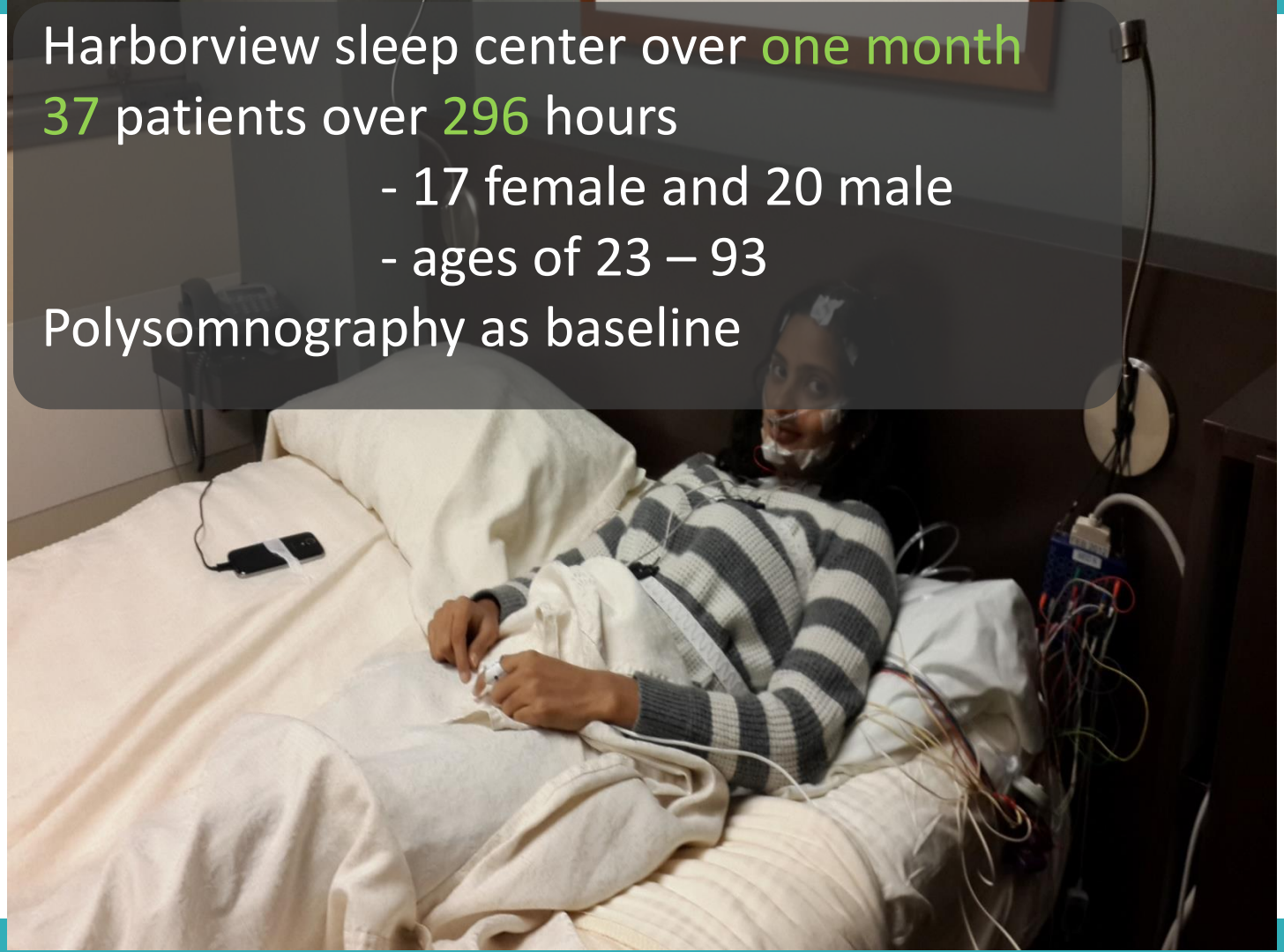
Breathing rate accuracy of 99.2%
at a range of 1 meter

Harborview sleep center over one month

37 patients over 296 hours

- 17 female and 20 male
- ages of 23 – 93

Polysomnography as baseline



How Well Can We Detect Apnea Events?

Interclass Correlation Coefficient (ICC)
between
ApneaApp and Polysomnography

Apnea Event	Correlation
Central Apnea	0.9957
Hypopnea	0.9533
Obstructive Apnea	0.9860

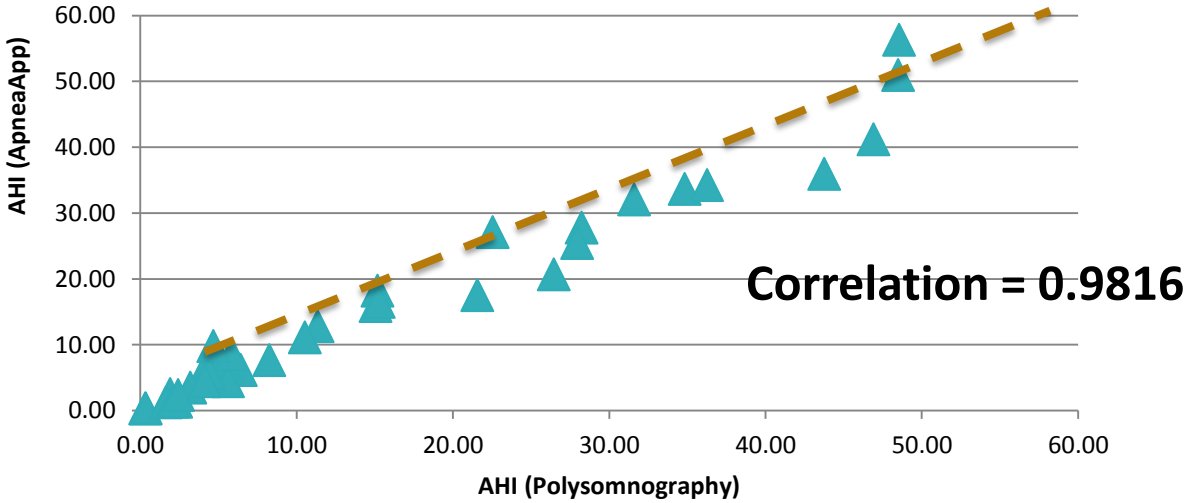
Sleep Time Accuracy of ApneaApp

Motion Detection Accuracy

False Positive	False Negative
59/26070 (0.22%)	43/1281 (3.35%)

Mean sleep time error is 37 minutes

Sleep Apnea Diagnosis Accuracy



32/37 patients were classified correctly between no, mild, medium and severe apnea

Limitations

- Works only on android phones with two microphones.
- High battery drainage. Phone speaker and microphone are switched on for 8 hours.
- Environmental effects not explored. Limited testing shows rapid accuracy reduction beyond 1m radius of phone placement.
- Sleep time error occurs when patients wake up but don’t move.
- Not possible to distinguish between equidistant patients

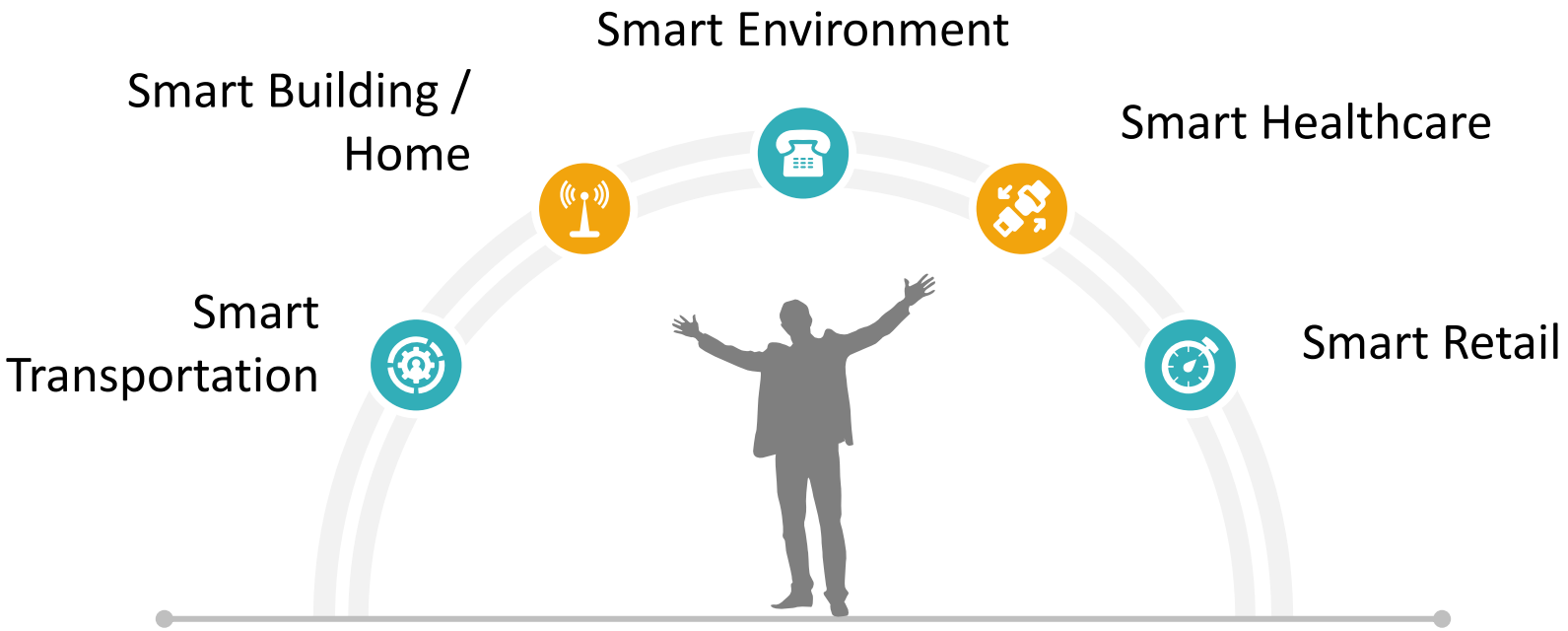
Conclusion

Introduces the first contactless system that measures breathing signals on a smartphone

Detects sleep apnea events (e.g. central apnea, hypopnea, obstructive apnea) from the breathing signals

Evaluated in a clinical study with 37 patients over 296 hours

Typical Industry Applications



5- Retail Industry $1.5T

- “Fast Retail” checkout optimizer
- Shopper analytics
- Supply-chain visibility
- Knowledge worker mobility

5-Smart Retail Leads to Increase in IoT Services

- In 2018, retail technology competition erupts
  - "Front warehouse" and "store-based warehouse" effectively reduce logistics costs
  - Mobile payments improve the checkout experience
  - Breaking through property cost barriers by expanding online orders and convenient offline distribution
  - The application of barcode, RFID and related sensing technology, combined with cloud computing, AI, big data algorithms, efficient and bulk collection of commodity data, supply chain data, user portrait data, forming a true big data assets
- In 2019, "Digital and technology-driven cost control and benefit growth" has become the largest consensus in the retail industry, with a new look of "IoT technology service providers" have a significant opportunity to release volume growth

5-New Species in Retail

- Retail new species can be broadly divided into eleven categories:
  - Technology experience type, community convenience type, living home type, experiential supermarket type, fashion life type, cultural creativity type, retail e-commerce type, preferred department store type, new beverage chain type, leisure experience type, unmanned retail type
- New retail is the active upgrade for the supplier of the market
- The use of technology to empower, improve the efficiency of the fast-cutting industry is a major trend

5-Unmanned Retail

- In December 2016, Amazon opened a revolutionary offline convenience store in Seattle, Amazon Go.
  - Amazon Go ditches the checkout process in traditional supermarkets
  - Amazon Go integrates a number of sensors to identify people's movements, and product locations to complete the entire process of uncollected cash
  - The complexity of its system makes it difficult to be used in general stores and is currently only available to Amazon employees
- Due to technical limitations, more of the options are now available for closed or semi-closed unmanned retail
- 3 questions need to address
  - Cashier Efficiency: Scanning Process, Payment Process, Identification Rate
  - Customer Experience: Entering the store, selecting items, storing items, checking goods, paying, checking bills
  - Operational efficiency: guide purchase, consulting, promotion, anti-theft, cash register, replenishment, research and development, marketing, promotion

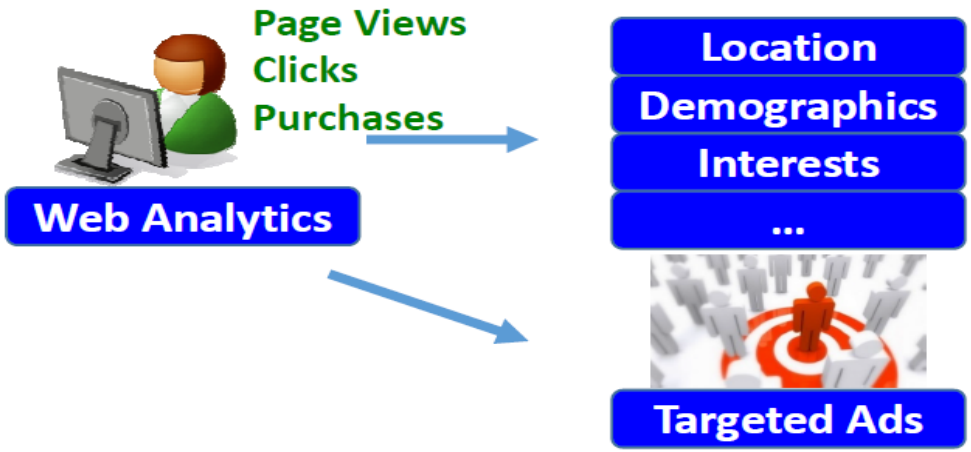
5-The Solution by Amazon Go

- Identify movements, goods, and people, and associate them by position or posture
- The intention of identifying the action is to identify whether you want to buy this thing, pick up and put it back means whether you buy
  - The first is visual recognition
  - The second is sensors, such as gravity sensors and infrared sensors
- When identifying a person, can use GPS or WI-FI tracking technology after entering the store. Can also base on the image recognition to track position
  - Currently, Amazon Go has no way of deciding who is taking the item by location, so it requires multi-dimensional posture detection

Enabling Physical Analytics in Retail Stores

Online sales in U.S. in 2013 only 11%

---- Using Smart Glasses



3x growth in 5 years from 2009 - 2013

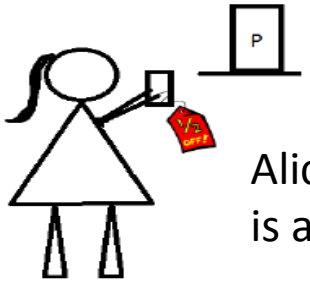
Important to capture shopper behavior not only in the online world but also in the physical world

S. Rallapalli, A. Ganesan, K. Chintalapudi, V. Padmanabhan, L. Qiu, ACM Mobicom 2014.

Physical Analytics

Understanding the intent of the shoppers in the physical world

Benefit



Alice sees a coupon as she is about to walk away!

Enable contextual recommendations

Shopping list reminders

Guides to product locations

Contributions

- Fuse Wi-Fi, inertial sensor and video data from smart glasses
- AutoLayout: Map the store without any user or store input
- Use these inferences to track glass/non-glass users in online phase
- Characterize walk, dwell, gaze and reaching-out activities of s hoppers
- Attention identification within the captured frame

Technology

Localization, Product layouts, User analytics

Incentives

- **Stores:** increased sales
- **Physical analytics provider:** share of profits by p artnering with stores
- **Users:** discounts, shopping

Privacy

January 17, 2012, 9:00am EST

Shoppers Willing to Tell A

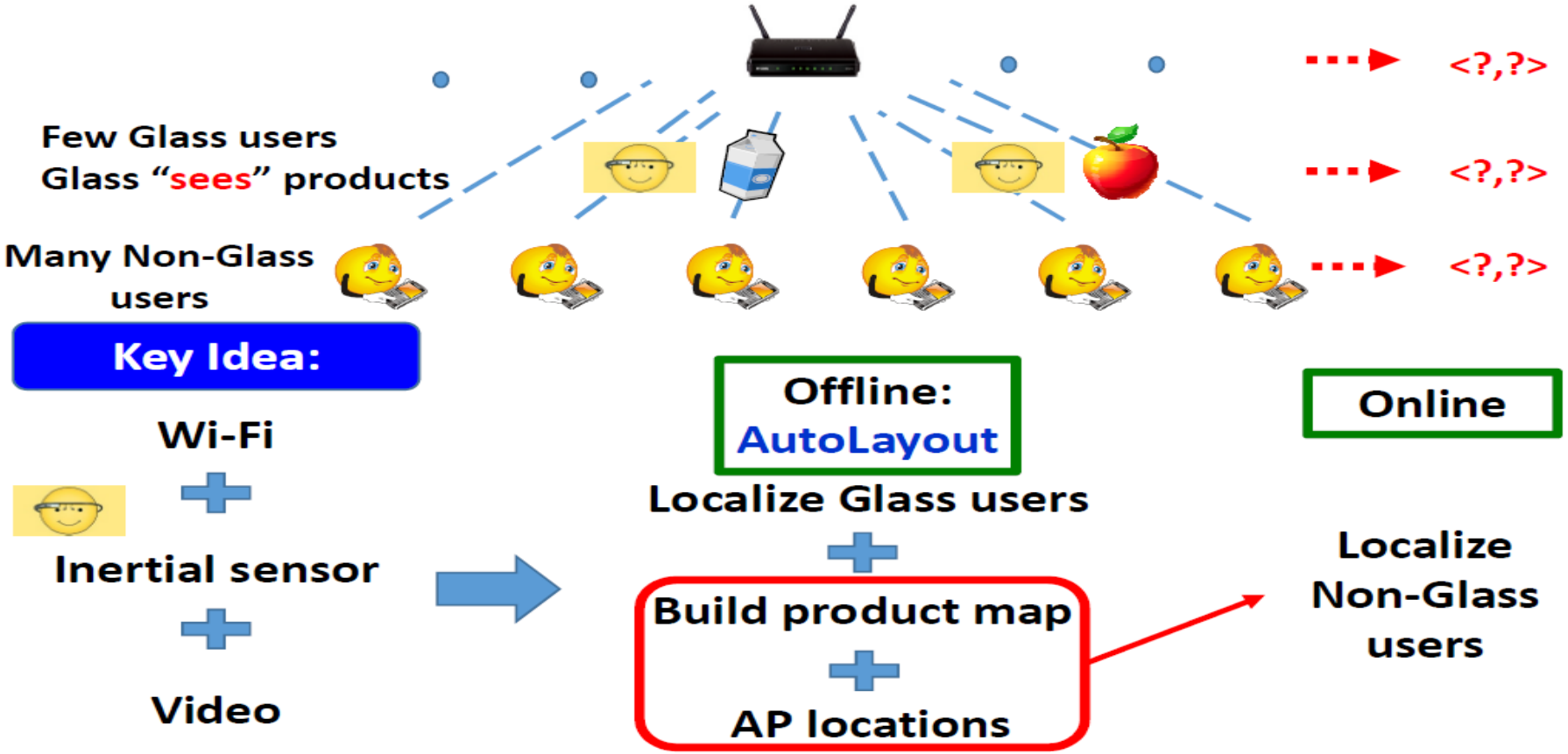
Teresa Novellino
Upstart Business Journal Entrepreneurs & Enterprises Editor
Email | Twitter

It might surprise retailers, but a new IBM study reveals that consumers are much more willing to give up information about themselves.

AutoLayout

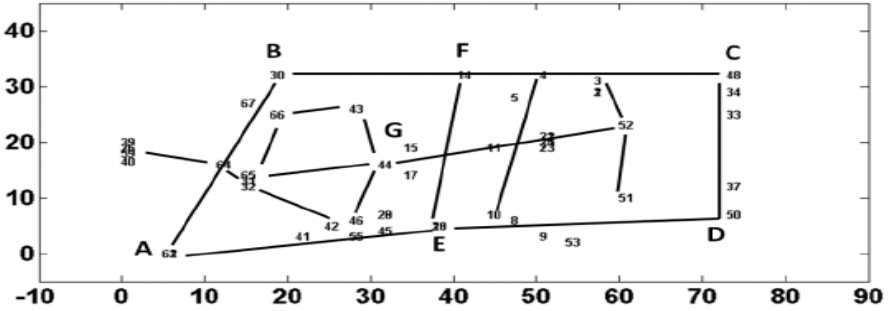
Behavior Classification

Overview: ThirdEye - AutoLayout

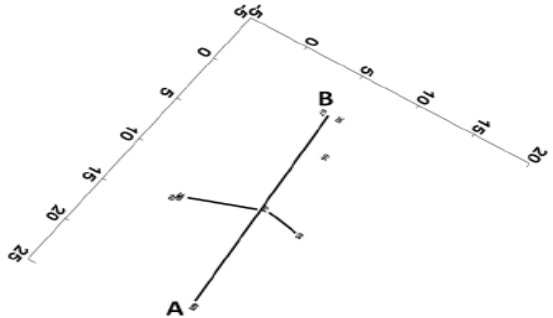


Inferred Layout for H-E-B:

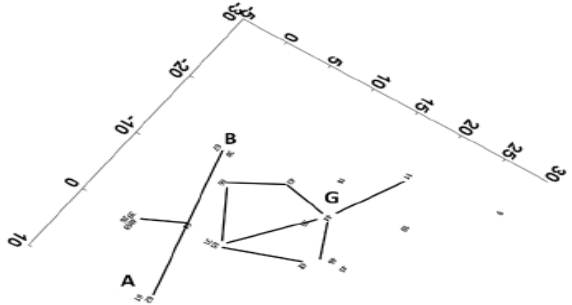
Improves with more shoppers



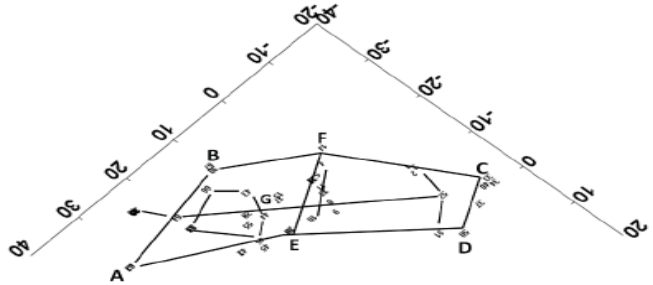
Actual Layout



2 Shoppers



4 shoppers



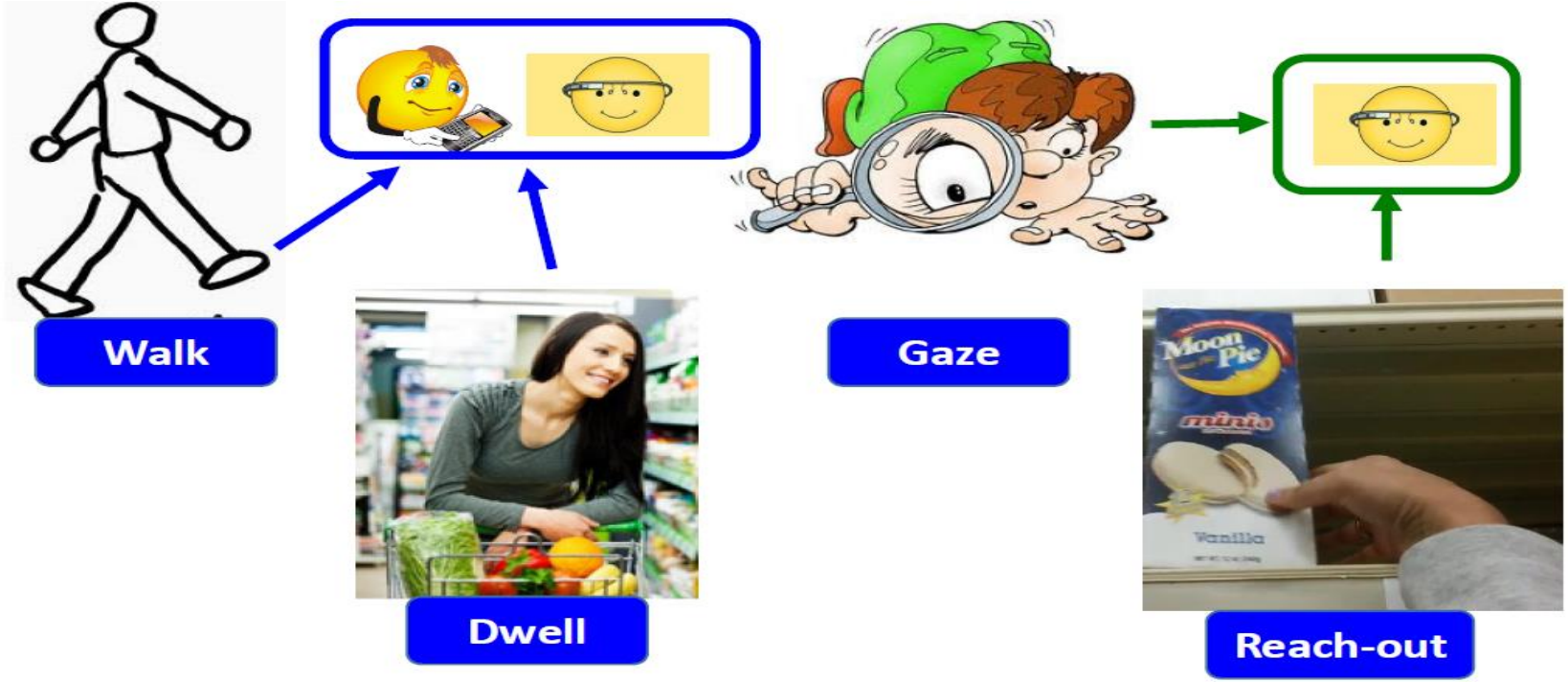
7 shoppers

AutoLayout

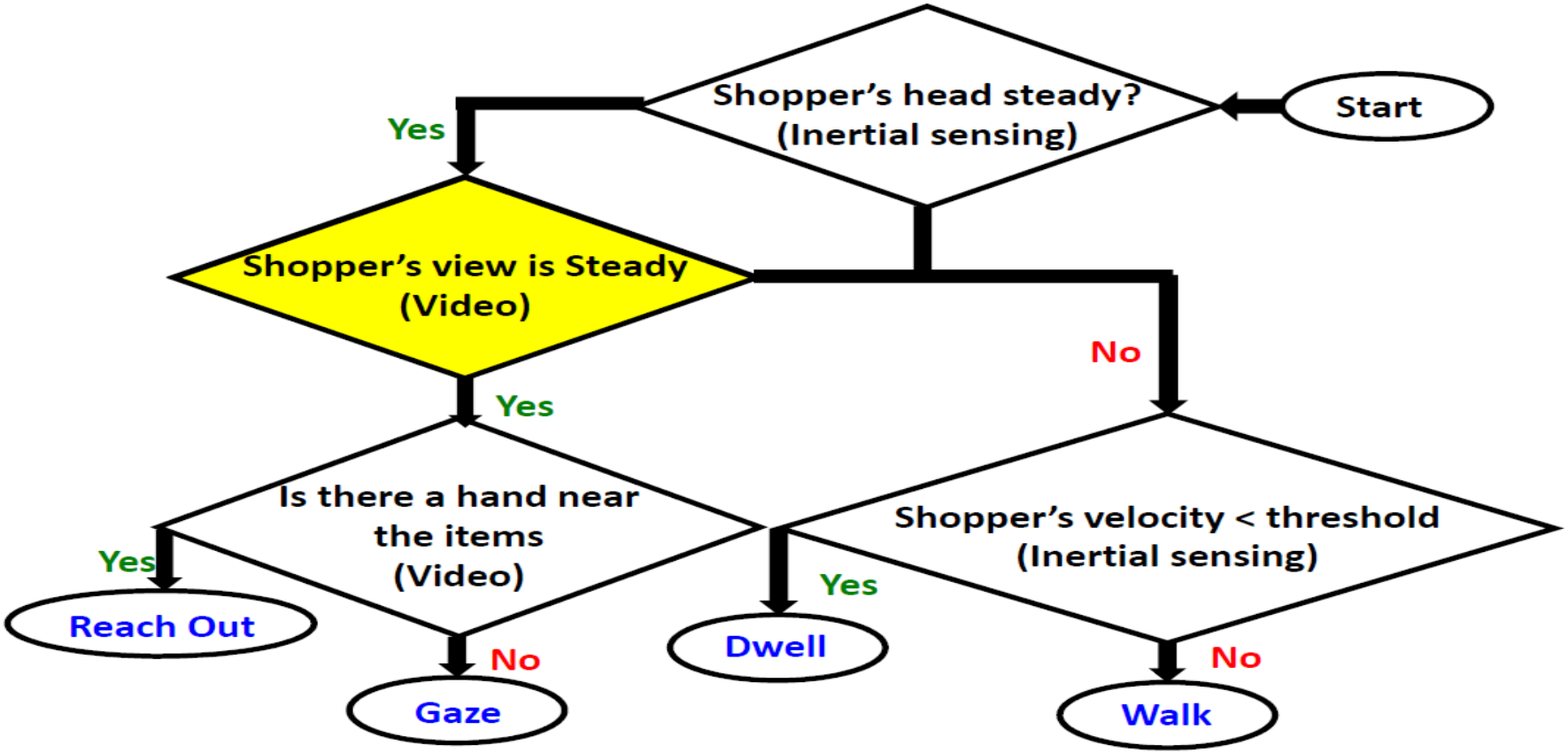
Behavior Classification

Overview: ThirdEye - User analytics

In a retail setting



Behavior Classification Algorithm



End of This Chapter