Winter Internship-Zhao Zehui

Study on Radar Systems & AI CCTV

Table of Contents

Animal Remote Contactless Vital Sign Detection Radar System

1. Ultra-Wideband (UWB) Radar: suitable for short-range, high-resolution monitoring for dogs and cats about their breathing (respiration rate) and heart rate in real time. Accuracy rate >95%.

• Advantages: high resolutions for heartbeat measurement and imaging, lower power consumption and high penetration to measure objects through materials, can give precise measurements about the shape, size and distance of animals.

• Disadvantages: due to wide bandwidth, wide range of frequency is received, more data shown in frequency spectrum, more complicated to implement and analyze and more restrictions. Most costly.

2. Doppler radar: (continuous wave, 24GHz) for respiration rate and heartbeat rate tracking of small animals, such as cats.

• Advantages: Highly accurate in measuring the velocity of moving targets, simplest radar system among all three to implement and analyze, and less restrictions, most cost-effective.

• Disadvantages: lower resolution, limited penetration, so less detailed information.

3. Frequency-modulated continuous wave (FMCW) radar: Use modulating signal to change the frequency of the transmitted signal in a known rate over a fixed amount of time. Difference between the transmitted and echoed signal is for finding the distance and velocity of an animal, most suitable for horses.

• Advantages: suitable for multi-animal tracking for their cardiac and respiration rate measurement, moderately complex compared to UWB and doppler radar, cost-effective, high-resolution range and velocity measurement, good for real-time monitoring. Penetration ability depends on the frequency range used, versatile and can be adapted to different environmental conditions.

• Disadvantages: sensitive to interference of other radar systems, more complicated to implement and analyse compared to doppler radar.

Overview on the radar systems

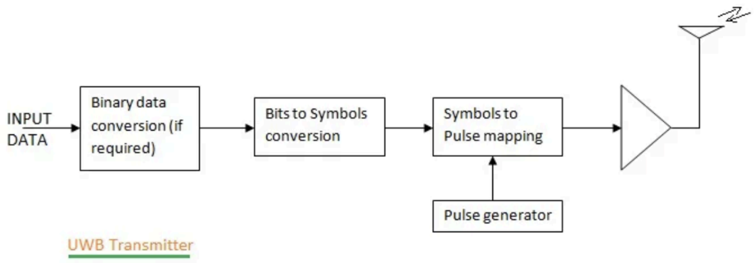
(UWB) Ultra-wideband radar technology

Radar: radio-wave emitted and reflected off the targets and returned to the receiver. The time it takes for echoes to return is used to calculate distance of the object. Bandwidth (BW) of the frequency is at least 500MHz, and the relationship between bandwidth and duration (T) is inversely proportional: $BW \times T \leq \frac{4}{\pi}$.

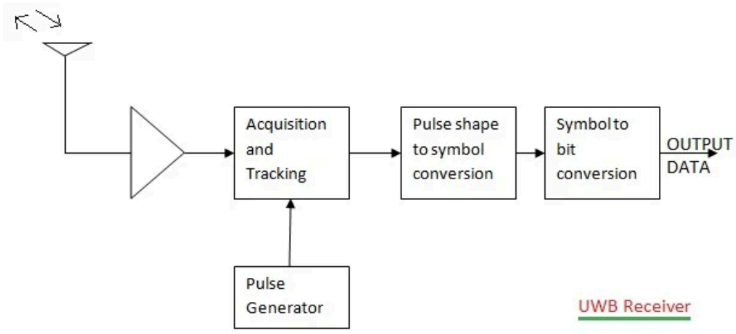
Any radar having a bandwidth > 0.5GHz, or having a fractional bandwidth > 0.2GHz can be classified as UWB. (having low power level which is below noise level more can search IEEE 802.15.4a specifications) It is generated using pulses having very shorter duration (approx. < 1 ns).

UWB spectrum range: 3.1GHz to 10.6GHz. (for human)

How UWB works:



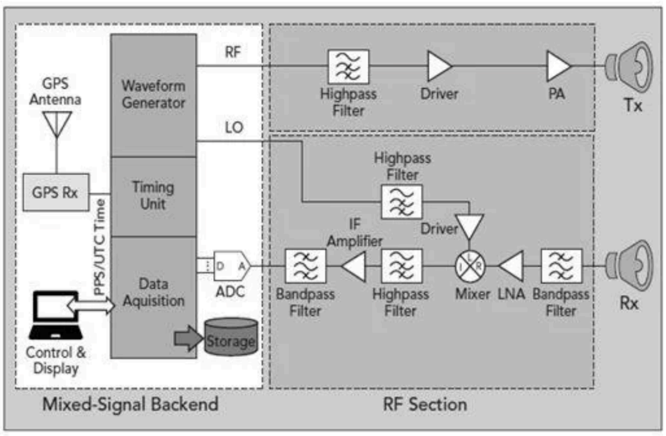
The figure depicts typical UWB transmitter and receiver block diagram. UWB transmitter converts information to be transmitted in the form of pulses before being amplified by amplifier. The amplified signal is transmitted using antenna as shown. At the receiver, zeros and ones are decoded from the pulse train received based on time interval between pulses.



Bits to symbol conversion is done with the help of modulation scheme. The UWB uses time based modulation scheme (i.e. PPM) and pulse shape based modulation schemes (i.e. PAM,OOK, Bi-phase, Orthogonal pulse modulation).

UWB Radar System Block Diagram

The figure depicts typical block diagram of UWB radar system. As shown UWB transmitter part consists of waveform generator, RF filter, driver, power amplifier and transmit antenna. The UWB receiver consists of receiving antenna, RF filter (BPF type), LNA (Low Noise Amplifier), [Down Converter](#) (using mixer and LO circuit), IF amplifier (to amplify down converted IF signal), IF filter (BPF type) and ADC (Analog to Digital Converter). The digital output of ADC is acquired and processed to retrieve desired informations as per applications. Timing unit along with GPS helps in synchronization in order to provide start of frame.



Challenges in UWB Radar:

- Complex radio channel: significant signal degradation due to multipath and fading effects
- Reconciling UWB and high efficiency operation in a compact, low-frequency footprint.

UWB versus millimeterWave(mmWave) and FMCW:

Fractional bandwidth (Fb), is the proportion of signal's bandwidth and central frequency (limit: -10 db emission points);
$BF = \frac{BW}{fC} = \frac{(fH - fL)}{(fH + fL)/2}$.

Bandwidth:

The larger the bandwidth of the frequency is, the higher the range of solution allowed. UWB & mmWave are good for measuring heart rate and respiration rate, while FMCW is good for detecting hand gestures.

Calculation of range resolution (Dres): $Dres = \frac{c}{2 \times BW}$, and c = speed of light.

Radar Type	UWB	mmWave	FMCW
Bandwidth (f)	~0.85GHz	~4GHz	~250MHz
Range of resolution	~10cm	~4cm	~60cm

Radar range Rmax:$Rmax = \frac{(Fs \times c)}{(2 \times BW)}$, Fs is the given sampling rate. That means increasing the bandwidth will reduce the range of radar detection. ∴ High-resolution sensing applications require large bandwidths, long range requires short bandwidths, and the best choice is the UWB radar system.

Moreover, capturing more radar samples/longer observation time can improve radar resolution.

Center frequency:

Center frequency impacts the absorption rate of wireless signals by air molecules and obstacles. A low center frequency typically propagates further, increasing the range of the signals.

UWB: data transmission rate up to 110Mbps within 10 meters, and lower data rate for range up to 100 meters. The relatively low center frequency also allows UWB to penetrate through several materials, making it good for ground-penetrating radar, medical imaging, and through-the-wall observations. Leading companies strive to improve the data to reach 1.66 Gbps.

Modulation Type:

Modulation type of radar affects radar's complexity, energy consumption, and robustness.

WiFi & mmWave: designed for spectral frequency and high-throughput transmission, but required modulation and demodulation processes in the transceiver.

FMCW: does not allow dual use of the radio for both radar and communication purposes.

UWB: Uses pulse-based modulation, precise time-of-flight measurements, supporting high data throughput, inherent resistance to interference enhances its suitability for applications requiring robust performance in crowded electromagnetic environments

Differences in UWB radar system design between human and animals

1. **Frequency and Bandwidth:**

Humans: Operate in the ultra-wideband (UWB) frequency range (3.1-10.6 GHz) or in the 24 GHz ISM band.

Animals: For smaller animals, higher frequencies may be more suitable, while for larger animals, lower frequencies might be used.

2. **Antenna Design:**

Humans: Antennas are designed to optimize signal reflection from the human body, taking into account the typical distances and orientations.

Animals: Antenna design may need to be customized for different animal species to account for variations in body size, shape, and orientation.

3. **Signal Processing:**

Humans: Algorithms are tuned to detect and analyze human-specific vital signs, such as heart rate variability and respiration patterns.

Animals: Signal processing algorithms need to be adapted to handle the different physiological characteristics of animals, including faster or slower heart rates and respiration rates.

Choice of UWB radar

X4 module: A Ultra-wideband (UWB) short-range impulse radar transceiver System on Chip (SoC). It is mainly for human vital sign tracking, but it has a version for users to customize it for other uses.

Reference: SoC applied featured a transmitter (TX) that complied with regulations for unlicensed operation, direct-radio frequency (RF) sampling using the swept-threshold (ST) technique, and RF interference rejection.
Source: Non-Contact Vital Signs Monitoring of Dog and Cat Using a UWB Radar - PMC

X4M02 is an industrialized UWB radar module intended for custom application development. We would need to customize the UWB radar to fulfill our demands.
Documents for how to use X4 radar:

- X4M02 datasheet: all information required for using this radar module: X4M02 Datasheet
- XeThru X4 Radar Module user guide: X4 radar User guide

Companies that provides X4 module:

- XeThru/Novelda, Oslo, Norway
- Novelda: X4 Datasheets - NOVELDA

Other companies:
Aria: Hydrogen v1p1 | Aria Sensing (For human vital sign tracking)

Paper: Method for Distinguishing Humans and Animals in Vital Signs Monitoring Using IR-UWB Radar

Guide to customize UWB Radar:

1. A Comprehensive Overview on UWB Radar: Applications, Standards, Signal Processing Techniques, Datasets, Radio Chips, Trends and Future Research Directions

2. Radio propagation modeling methods and tools - ScienceDirect

Radar systems suppliers (China & Overseas)

FMCW radar: Huawei Technologies, Beijing Leishen Intelligence Technology, Texas Instruments (TI), Zhejiang Dahua Technology, DJI Innovation

Doppler radar: Huawei Technologies, Beijing Leishen Intelligence Technology, Zhejiang Dahua Technology

UWB radar: Texas Instruments (TI), Analog Devices (ADI)

Suppliers shown on Alibaba Website:

UWB Radar Suppliers - Alibaba.com

Doppler Radar Suppliers – Alibaba.com

FMCW Radar Suppliers- Alibaba.com

Taiwan website for radar suppliers:

Radar supply - Taiwantrade

References for animal tracking system:

Animal tracking system products - Alibaba.com

Customization of radar system design for animal vital sign tracking:

CATS - Customization

Other ways of remote contactless animals vital sign tracking

1. **Traditional devices such as ECG Sensors**: For heartbeat rate measurements, and spirometers or capnographs for respiration rate measurements.

2. **Thermal Imaging:** Detects infrared radiation to create images based on heat signatures, useful for monitoring body temperature and thermal patterns and detecting fever, inflammation, or thermal stress in animals.

3. **Acoustic Monitoring**: Use microphones and sound analysis algorithms to detect and interpret animal sounds, which monitor vocalizations to understand communication and stress levels, and breathing sounds to detect respiratory distress.

4. **Laser Doppler Vibrometry**: laser beams to measure the velocity and displacement of surfaces which monitor heart rates and respiration rates through chest movements.

5. **Remote Photoplethysmography (rPPG)**: Use light to detect changes in blood volume to measure heart rate and oxygen saturation, monitor respiratory condition and cardiac health.

6. **Ultrasound Imaging**: High-frequency sound waves to create images of internal body structures to monitor blood flow, heart rates and respiration

Reference for ECG sensor application to horse vital sign tracking:

Equimetrics

Comparison on application of radar tracking system on human and animals

Typical radar systems for humans include FMCW radar and doppler radar.

A study shows the accuracy of UWB radar system tracking on respiration rate of dogs and cats is over 95%, suitable for health assessment and sleep monitoring.

(Source: Non-Contact Vital Signs Monitoring of Dog and Cat Using a UWB Radar, Pengfei Wang, https://www.mdpi.com/2076-2615/10/2/205, 25 January 2020)

Countries that apply radar systems into medical application

1. **United States**
- Application: Vital Signs Monitoring
- Make use of continuous-wave (CW) doppler radar & FMCW radar system for non-invasive monitoring of vital signs such as heartbeat rate, respiration rate and blood pressure.
- Related companies: Xandar Kardian: A startup that has developed radar-based sensors for monitoring vital signs, fall detection, and sleep analysis.
- Vayyar Imaging: Provides 4D imaging radar technology for medical applications, including fall detection and vital sign monitoring.

2. **China**
- Application: Health Monitoring in Smart Homes
- Make use of UWB radar and FMCW radar systems for continuous monitoring of vital signs and fall detection
- Companies: Huawei: Develops radar sensors for healthcare applications, including vital sign monitoring and fall detection.

- Xiaomi: Involved in integrating radar-based health monitoring systems into smart home devices.

3. Japan

- Application: Make use of UWB radar and FMCW radar system to monitor elderly’s health and safety, especially vital sign monitoring and fall detection
- Companies: Murata Manufacturing: Develops radar sensors for various applications, including healthcare monitoring.
- Panasonic: Involved in developing radar-based systems for fall detection and vital sign monitoring.

4. Germany

- Application: Use UWB radar and FMCW radar system for diagnosis such as sleep apnea, cardiac arrhythmias, and respiratory disorders.
- Companies: Infineon Technologies: Provides radar sensors and modules for medical applications, including vital sign monitoring and fall detection.
- Rohde & Schwarz: Offers advanced radar systems for medical diagnostics and research.

5. South Korea

- Use UWB radar and FMCW radar system for remote monitoring of patients, particularly for chronic conditions and post-operative care.
- Companies: Samsung: Develops radar sensors for healthcare applications, including vital sign monitoring and fall detection.
- LG Electronics: Involved in developing radar-based systems for remote patient monitoring and healthcare applications.

6. United Kingdom

- Application: Use UWB radar and FMCW radar systems for non-invasive monitoring of respiratory and cardiac functions, particularly for patients with chronic conditions.
- Companies: Cambridge Consultants: Develops radar sensors for healthcare applications, including vital sign monitoring and fall detection.
- Blighter Surveillance Systems: Provides advanced radar systems for medical diagnostics and research.

AI assistant and platform with embedded CCTV content analysis function that use cloud-based methods

Goal: A cctv product with embedded functions for enhancing security, operational efficiency, and data analytics, such as human tracking, object and colour recognition

Current existing system that provides AI platform for developers to build a model/function for

1. Google Coral

- A hardware and software platform for building intelligent devices with fast neural network inferencing of local AI.
- Features: Edge TPU for accelerated machine learning inference,
- Integration with Google Cloud for advanced analytics,
- Custom model deployment,
- Real-time video processing

Google Coral

2. NVIDIA Jetson

- Create AI products across all industries
- Features: High-performance GPU for real-time video processing
- Integration with NVIDIA DeepStream for advanced analytics
- Custom model deployment
- Support for multiple AI frameworks

NVIDIA Developer

3. Microsoft Azure Percept

- AI powered assistant that provides product solutions, including embedded cctv content analysis
- Features: Edge hardware and software for real-time analytics
- Integration with Azure AI services for advanced analysis
- Custom model deployment
- Secure and scalable cloud integration

Azure

4. Amazon Web Services (AWS) Panorama

- A machine learning appliance and software development kit (SDK) that brings computer vision to on-premises cameras for high-accuracy, low latency prediction.
- Features: Real-time video analytics
- Object detection and tracking
- Integration with AWS Recognition for advanced analysis
- Custom model deployment

[AWS Panorama]

Include AI model into hardware cameras

1. Model training
- Collect data then label them. This involves recording videos and annotating them with relevant labels (e.g., behaviours, and types of animals)
- Model selection: Choose an appropriate model architecture. For animal detection and classification, models like YOLO (You Only Look Once), SSD (Single Shot MultiBox Detector), or Faster R-CNN can be used.
- Training: Train the model using the collected and labeled data. This typically involves using frameworks like TensorFlow, PyTorch, or Keras.
2. Model Optimization
- Optimize the model for deployment on hardware cameras, which often have limited computational resources.
- Quantization: Reduce the precision of the model weights to lower bit-widths (e.g., from 32-bit floating point to 8-bit integers).
- Pruning: Remove less important weights or neurons from the model.
- Knowledge Distillation: Train a smaller model to mimic the behavior of a larger, more accurate model.
3. Hardware Selection
- Choose appropriate hardware cameras that support AI model deployment.
- Edge Devices: Devices like NVIDIA Jetson, Google Coral, or Intel Movidius can run AI models locally.

- Smart Cameras: Some cameras come with built-in AI capabilities, such as the Hikvision DeepinMind series or Dahua IPC-HFW4831E-SE-LED
4. Model Deployment
- Use NVIDIA Jetson
1. Install JetPack: Set up the JetPack SDK on the Jetson device.
2. Convert Model: Use TensorRT to optimize and convert the model for deployment on Jetson.
3. Deploy Model: Load the model onto the Jetson device and integrate it with the camera feed

5. Integration and Testing

- Integrate the AI model with the camera feed and test the system.
- Camera Feed: Capture the video feed from the camera.
- Model Inference: Run the AI model on the captured frames to perform the desired analysis (e.g., animal detection, gait analysis).
- Post-Processing: Process the model outputs to extract meaningful information (e.g., animal types, gait parameters).
- Testing: Test the system in real-world scenarios to ensure accuracy and performance.

6. Monitoring and Maintenance

Monitor the system for any issues and perform regular maintenance.

- Monitoring: Use logging and monitoring tools to track the performance and accuracy of the AI model.
- Updates: Regularly update the model and software to improve performance and fix any issues.

Example code for deploying model on Jetson:

```
import jetson.inference
import jetson.utils

# Load the model
net = jetson.inference.detectNet("ssd-mobilenet-v2", threshold=0.5)

# Open the camera
camera = jetson.utils.videoSource("csi://0")
```

```
# Capture and process frames
while True:
    img = camera.Capture()
    detections = net.Detect(img)
    for detection in detections:
        print(detection)
    jetson.utils.cudaDeviceSynchronize()
    camera.Render(img)
    camera.SetStatus("Object Detection | Network {:.0f}
FPS".format(net.GetNetworkFPS()))
```

Hardware Option: Jetson Nano VS Raspberry Pi

Reference list

Taiwan Vital Sign Measurements Resources

Website for these research: National Digital Library of Theses and Dissertations in Taiwan

Excel form conclusion for this website: Radar systems for vital sign measurement .xlsx

翁國精教授 - 野生動物長期監測系統之優化與資料整合計畫(1/4)：uses IR camera for animal detection

https://ieeexplore.ieee.org/document/9594688

https://www.infineon.com/dgdl/Infineon-Contactless_Measurement_of_Vital_Signs_with_Radar_Sensors-Article-v01_00-EN.pdf?fileId=8ac78c8c8caa022e018ce79f05e3046d

https://pmc.ncbi.nlm.nih.gov/articles/PMC6888617/

https://www.mdpi.com/2076-2615/10/2/205

https://www.semanticscholar.org/paper/Non-Contact-Vital-Signs-Monitoring-of-Dog-and-Cat-a-Wang-Ma/d1c3e3cbe3ed81ac110ede69023226be79ecd54f#:~:text=An%20ultra-wideband%20radar-based%2C%20non-contact%20animal%20vital%20sign%20monitoring,such%20as%20pet%20sleep%20monitoring%20and%20health%20assessment.

https://www.verifiedmarketresearch.com/blog/top-radar-manufacturers/#:~:text=Top%207%20radar%20manufacturers%20are%20Raytheon%20Technologies%2C%20Lockheed,Group%2C%20Leonardo%2C%20Saab%2C%20Northrop%20Grumman%2C%20and%20BAE%20Systems.

https://www.sciencedirect.com/science/article/abs/pii/S1746809416302208

https://www.equimetrics.ie/

https://ieeexplore.ieee.org/document/8038323

https://www.everythingrf.com/community/what-is-a-fmcw-radar https://www.geeksforgeeks.org/fmcwr-radar/#what-is-continuous-wave-r

adar

https://www.semanticscholar.org/paper/Non-Contact-Vital-Sign-Monitoring-of-Cat-Using-Lai-Lu/b02d039082b6b57e1047e52970341fbbd23fc3d5

https://ieeexplore.ieee.org/document/7890438

https://www.researchgate.net/publication/338849475_Non-Contact_Vital_Signs_Monitoring_of_Dog_and_Cat_Using_a_UWB_Radar

https://www.safetyshieldglobal.com/insights/ai-cctv

https://www.avigilon.com/blog/ai-security-cameras

https://www.forest.gov.tw/research/0003951

Taiwan website

Paper: A Comprehensive Overview on UWB Radar: Applications, Standards, Signal Processing Techniques, Datasets, Radio Chips, Trends and Future Research Directions