Safety & Regulation of Embedded Systems

Blake Babbs

FCC Certification

Radio Emission Testing

Type of device	Equipment authorization required
TV broadcast receiver	Verification
FM broadcast receiver	Verification
CB receiver	Declaration of Conformity or Certification
Super regenerative receiver	Declaration of Conformity or Certification
Scanning receiver	Certification
Radar detectors	Certification

Underwriter Laboratories

Non-profit

Safety and Quality Testing

IoT Specific

- Helps secure data
- Compatibility Testing

CE Certification

Verifies that it complies with EU directives

Do a risk assessment

Done by manufacturer, not independent agency

May need a conformity assessment - performed by independent bodies

Enables it to be sold all over Europe

Directives

Specific guidelines necessary to comply with

Type A - Basic (safety, liability)

Type B - Generic (Voltage directives and Electromagnetic Compatibility)

Type C - Product Specific (Toys, Medical Devices)

CRDH - Medical Device Classification

Class I and II

- less critical devices
- failure will not result in harm
- need to submit 510(k) application saying it's similar to already approved device
- Ex: electronic toothbrush

Class III

- higher risk
- need pre-market approval
- Ex: pacemaker

Bluetooth Certification

Must apply to become a member of Bluetooth SIG

-2 types: Adopter and Associate

-Adopter membership

- Free
- Ability to utilize various tools

-Associate membership

- Costs money
- Discounts on services as well as influencing product specs

Bluetooth Fees

Product Declaration Fee:

- Adopter membership: $8000
- Associate membership: $4000

Innovation Incentive Program

- Reduced fee for startups: $2500

References

https://www.bluetooth.com/develop-with-bluetooth/qualification-listing/qualification-listing-fees

http://www.batteryspace.com/ul-ce-emc-fcc-and-csa.aspx

https://celectronics.com/certification/europe/

https://celectronics.com/pdf/ce_brochure_en.pdf

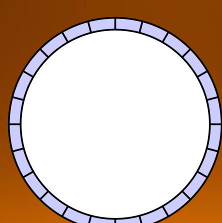
http://industries.ul.com/mobile/internet-of-things-iot

Will Bryant

Ring Buffers

What is a ring buffer?

- AKA a circular buffer
- A data structure which uses a fixed-size array as if it were connected end to end
- Commonly used as a circular FIFO queue



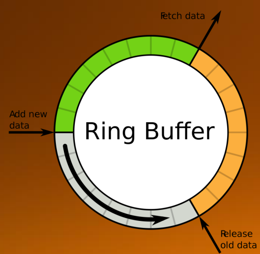
How does a ring buffer work?

- Head and Tail initialized to 0
- (head or tail) mod n_elem = index into the buffer
- Data written at the head index and read at the tail index
- If head and tail are equal:
  - FULL if head-tail = n_elem
  - EMPTY if head-tail = 0

```
struct ring_buffer
{
    size_t s_elem;
    size_t n_elem;
    uint8_t *buf;
    volatile size_t head;
    volatile size_t tail;
};
```

s_elem = size of elements
n_elem = max number of elements
*buf = pointer to the data holding buffer
head = head value (insert elements)
tail = tail value (read elements)

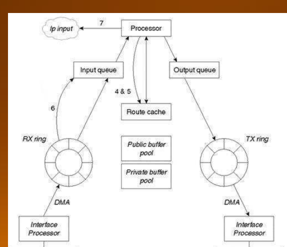
Ring Buffer Visualization



Where (and why) would I use a ring buffer?

Ring Buffer in Serial Data Streams

- Transmit data between asynchronous processes
  - Quick and reliable serialization
- UART example:
  1. Byte in the UART is received
  2. Hardware ISR fires, software moves byte to ring buffer
  3. Periodical checks buffer to process any received packets



Ring Buffer in Message Logging

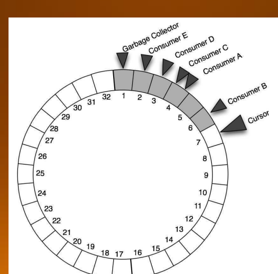
- Message logging because of space & time efficiency
  - Restricted size to overwrite older entries
  - No need to write to disk/database
- Message Log Example:
  1. Application writes log entries while processing requests
  2. Can read processing request logs
  3. Always space for new entries because overwriting of old ones

Log device files

- 4 channels, each have a Ring/Circular Buffer
  - /dev/log/**radio** – radio&phone-related messages (64KB)
  - /dev/log/**events** – system/hardware events (256KB)
  - /dev/log/**system** –framwork or low-level system messages (64KB)
  - /dev/log/**main** – everything else (64KB)
  - The maximum log message size of each channel is specified in kernel driver(logger.c)
- File permission of each(radio/events/system/main) is **0662 (rw-rw-w)**
  - owner/group RW, other Write only
  - owner=root, group=log
  - Anyone can Write logs, root or log group can Read them

Ring Buffers and Multithreading

- Can use ring buffers in multithreaded environments
- Producer Consumer Example:
  1. Producers produce resource
  2. Consumers use these resources while not empty
  3. Producers stop when full



Conclusion

- Ring buffers are an extremely valuable tool in specific situations
- Implementation examples exist online (see references)

```c
typedef struct circular_buffer
{
    void *buffer;     // data buffer
    void *buffer_end; // end of data buffer
    size_t capacity;  // maximum number of items in the buffer
    size_t count;     // number of items in the buffer
    size_t sz;        // size of each item in the buffer
    void *head;       // pointer to head
    void *tail;       // pointer to tail
} circular_buffer;

void cb_init(circular_buffer *cb, size_t capacity, size_t sz)
{
    cb->buffer = malloc(capacity * sz);
    if(cb->buffer == NULL)
        // handle error
    cb->buffer_end = (char *)cb->buffer + capacity * sz;
    cb->capacity = capacity;
    cb->count = 0;
    cb->sz = sz;
    cb->head = cb->buffer;
    cb->tail = cb->buffer;
}
```

References

- http://www.embedded.com/electronics-blogs/embedded-round-table/4419407/The-ring-buffer
- http://www.simplyembedded.org/tutorials/interrupt-free-ring-buffer/
- https://en.wikipedia.org/wiki/Circular_buffer
- http://stackoverflow.com/questions/2553637/what-are-the-uses-of-circular-buffer
- http://stackoverflow.com/questions/827691/how-do-you-implement-a-circular-buffer-in-c

Voltage Regulators

Ashish Nichanametla
EECS 373
March 30, 2017

Introduction

What is a voltage regulator?

A voltage regulator is a device that generates a fixed output voltage of a preset magnitude despite changes to its input voltage or load conditions.

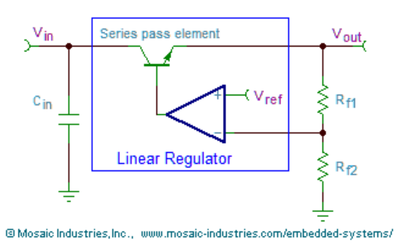
Types of Voltage Regulators

- Linear Regulator
- Switching Regulator
- Zener Diode
- DC-DC Voltage Applications

Linear Regulator

- A linear regulator employs a BJT or MOSFET controlled by a high gain differential amplifier. Compares output voltage to reference voltage and adjusts to maintain constant output.
- Transistor acts like a variable resistor that can be adjusted based on feedback.

Linear Regulator Circuit



Common Linear Regulators and Applications

LM78XX series

- Output voltages of 5, 6, 10, 12, 15 etc.
- LM7805 Input range of [7.5V-30V] – regulated 5V output

Output current up to 1.5A

LDO - Low Dropout Regulator

- A DC voltage regulator that can maintain a constant output voltage even when supply voltage is very close to output voltage.

Ex. Need to generate 3.3V from 5V input

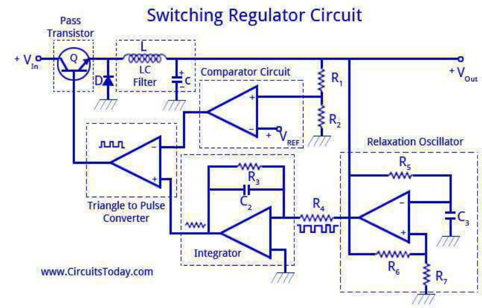
LM3490 input range of [4.5V – 5.5V] – regulated 3.3V output

Switching Regulator

- A switching regulator works by rapidly switching a series device on or off. It is controlled by a feedback mechanism to maintain a regulated voltage.

Types
- Buck – drop a DC voltage to lower DC voltage
- Boost – Provide output greater than input voltage
- Buck/Boost [Inverting] – Output voltage generated opposite in polarity to input

Control
- PWM or PFM(Pulse Frequency Modulation) to control output voltage



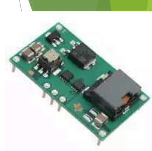
Example Switching Regulators and Applications

TI PTN78020W Buck Converter
- Input Voltage [7V-36V]
- Output voltage [2.5V to 12.6V]

Up to 6A output current

LM27313XMF Boost Converter
- Input Voltage[2.7V – 14V]
- Output Voltage[5V-28V]

Up to 1A output current



Advantages and Disadvantages

	Linear regulator	Switching regulator
Buck	Possible	Possible
Boost	Impossible	Possible
Buck/Boost	Impossible	Possible
Inverting	Impossible	Possible
Efficiency	V_O/V_{IN} Mostly low	Approx. 95% Usually high
Output power	Generally several watts Depending on thermal design	Large power possible
Noise	Low	Switching noise exists
Design	Simple	Complicated
Parts count	Low	High
Cost	○	△

http://micro.rohm.com/en/techweb/knowledge/dcdc/s-dcdc/02-s-dcdc/2642/

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http://www.analog.com/en/education/education-library/technical-articles/how-voltage-regulator-works.html

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https://www.dimensionengineering.com/info/switching-regulators

http://www.futureelectronics.com/en/regulators-references/switching-regulators.aspx

Questions

IoT Security

Kristijan Dokic

Overview

- IoT devices are notorious for poor security
  - Expensive
  - Difficult
- The IoT is growing rapidly and must address security concerns or pay the price

Default Usernames and Passwords

- Many IoT devices rely on users to change default credentials

USER:	PASS:	USER:	PASS:
-----	-----	-----	-----
root	xc3511	admin1	password
root	vizxv	administrator	1234
root	admin	666666	666666
admin	admin	888888	888888
root	888888	ubnt	ubnt
root	xmhdipc	root	klv1234
root	default	root	Zte521
root	juantech	root	hi3518
root	123456	root	jvbzd
root	54321	root	anko
support	support	root	zlxx.
root	(none)	root	7ujMko0vizxv
admin	password	root	7ujMko0admin
root	root	root	system
root	12345	root	ikwb
user	user	root	dreambox
admin	(none)	root	user
root	pass	root	realtek
admin	admin1234	root	00000000
root	1111	admin	1111111
admin	smcadmin	admin	1234
admin	1111	admin	12345
root	666666	admin	54321
root	password	admin	123456
root	1234	admin	7ujMko0admin
root	klv123	admin	1234
Administrator	admin	admin	pass
service	service	admin	meinsm
supervisor	supervisor	tech	tech
guest	guest	mother	fucker
guest	12345		
guest	12345		

A list of the most commonly used default password and username pairs

Universal Plug and Play (UPnP)

- A set of networking protocols intended to make setting up a network easy
  - Similar idea to Plug and Play
  - Allows devices to easily discover and communicate to each other
  - Xbox live, home appliances, etc.
- FBI recommended disabling UPnP on routers

Universal Plug and Play (UPnP)

- Makes your network vulnerable
  - Allows any device to open a port (discoverable by any public network)
  - Does not require authentication (infected devices can open ports on your network).

Consequences

- Critical IoT devices such as medical devices and security cameras can be easily hacked
- IoT devices can be used to create a botnet
  - Infected devices that can perform various tasks for the owner

Distributed Denial of Service

- Overwhelming an online service with more traffic than it can handle, effectively making it unavailable
  - MasterCard was attacked in 2010 because they cut off services to WikiLeaks

Takeaways

- Be aware of UPnP vulnerabilities when designing an IoT device (ease of use vs. lack of security)
- Require users to set their own passwords when configuring a device
- Consider the potential impact of poor security

References

- http://www.upnp-hacks.org/sane2006-paper.pdf
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- http://www.computerworld.com/article/2514804/cybercrime-hacking/update--mastercard--visa-others-hit-by-ddos-attacks-over-wikileaks.html

Any Questions?

Digital Signal Processor

SHIHAO FENG
EECS 373

A digital signal processor (DSP) is a specialized microprocessor, with its architecture (both hardware and software) optimized for the operational needs of digital signal processing.

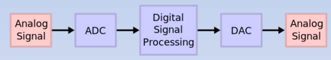
The goal of DSPs is usually to measure, filter or compress continuous real-world analog signals.

Widely used in communication fields, such as mobile phones.

TMS5100

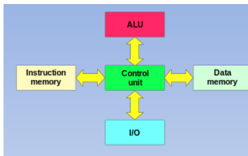
1. the industry's first digital signal processor, built in 1978
2. used in TI Speak & Spell toy
3. originally advertised as a tool for helping children whose ages are between 7 and 12 to learn to spell and pronounce over 200 commonly misspelled words

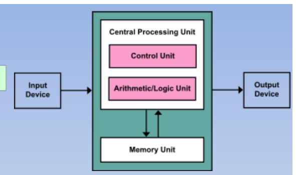
Typical DSP Architecture



Hardware Architecture

DSPs are usually optimized for streaming data and use special memory architectures that are able to fetch multiple data or instructions at the same time, such as the Harvard architecture or Modified von Neumann architecture.





Harvard Architecture

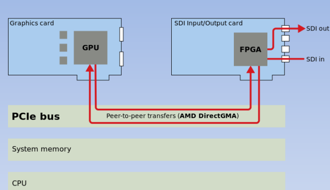
Von Neumann Architecture

pure von Neumann architecture: the CPU can be either reading an instruction or reading/writing data from/to the memory. Both cannot occur at the same time since the instructions and data use the same bus system.

Harvard architecture: the CPU can both read an instruction and perform a data memory access at the same time.

A Harvard architecture computer can thus be faster for a given circuit complexity.

DMA



Direct memory access (**DMA**) is a feature of computer systems that allows certain hardware subsystems to access main system memory (RAM), independent of the central processing unit (CPU).

Software architecture

Instruction set

By the standards of general-purpose processors, DSP instruction sets are often highly irregular.

Traditional instruction sets: more general instructions that allow them to perform a wider variety of operations

DSP instruction sets: contain instructions for common mathematical operations that occur frequently in DSP calculations.

For many mathematical operation, it might require multiple ARM or x86 instructions to compute while require only one instruction in a DSP optimized instruction set.

MAC

$$a \leftarrow a + (b \times c)$$

multiply–accumulate operation is a common step that computes the product of two numbers and adds that product to an accumulator

1. used extensively in all kinds of matrix operations
   - convolution for filtering
   - dot product
   - polynomial evaluation

2. Fundamental DSP algorithms depend heavily on multiply–accumulate performance
   - FIR filters
   - Fast Fourier transform (FFT)

Parallelism
- Single instruction, multiple data (SIMD)
- Very long instruction word (VLIW)
- Superscalar processor

Data structure
- Fixed-point arithmetic is often used to speed up arithmetic processing

Reference
- https://en.wikipedia.org/wiki/Digital_signal_processor

Deep Learning and FPGA

EECS373 Presentation
Jiyong Yu

Deep Learning Overview

Definition of Deep Learning

- A subfield of machine learning concerned with algorithms inspired by the structure and function of the brain[1].

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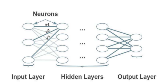
- Modeling abstractions using multiple processing layers.

Definition of Deep Learning

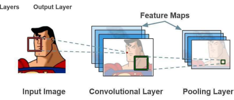
- A subfield of machine learning concerned with algorithms inspired by the structure and function of the brain[1].
- Modeling abstractions using multiple processing layers.
- Using supervised and/or unsupervised strategies to automatically learn hierarchical representations in deep architectures[2].

Category of Neural Networks

- Deep Neural Network



- Convolutional Neural Network



- Recurrent Neural Network
- ……

Applications

- Computer Vision
- Automatic Speech Recognition
- Natural Language Processing
- Audio Recognition
- Bioinformatics
- ……

Why Deep Learning on FPGA

FPGA: An Alternative Solution

- CPU is slowwww

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- CPU is slowwww
- GPU is fast, but expensive, and unpopular in SoC (NVidia Jetson TK1)

FPGA: An Alternative Solution

- CPU is slowwww
- GPU is fast, but expensive, and unpopular in SoC (NVidia Jetson TK1)
- FPGA, on the other hand:
  - Is flexible
  - Has high performance per watt of power consumption
  - Recently adopted software-level programming models like OpenCL, Caffe[4]

Can We Map Deep Neural Network to Embedded Systems

Challenges and Opportunities

- Neural networks are compute-intensive, resulting in high power consumption[5]

Challenges and Opportunities

- Neural networks are compute-intensive, resulting in high power consumption[5]
- FPGA outperforms CPU in terms of speed, and outperforms GPU in terms of performance per watt[6]

Challenges and Opportunities

- Neural networks carry a large memory footprint[5]

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- Neural networks carry a large memory footprint[5]

- Researchers are aggressively creating accelerators to maximize data reuse (Microsoft Catapult)

Challenges and Opportunities

- Neural networks are not well understood by embedded architects[5]

Challenges and Opportunities

- Neural networks are not well understood by embedded architects[5]

- Frameworks like DnnWeaver provide a high level of abstraction to the programmers[6]

```
layer {
  name: "conv1"
  type: CONVOLUTION
  bottom: "data"
  top: "conv1"
  convolution_param {
    num_output: 20 stride: 1 kernel_size:
5
  }
}
```

```
layer {
  name: "pool1"
  type: POOLING
  bottom: "conv1"
  top: "pool1"
  pooling_param {
    pool: MAX stride: 2 kernel_size: 2
  }
}
```


Let’s Create Deep Learning Projects with FPGA

Reference

[1] http://machinelearningmastery.com/what-is-deep-learning/

[2] Xue-Wen Chen and Xiaotong Lin. Big data deep learning: Challenges and perspectives. Access, IEEE, 2:514–525, 2014

[3] Hauswald, Johann, et al. "DjiNN and Tonic: DNN as a service and its implications for future warehouse scale computers." Computer Architecture (ISCA), 2015 ACM/IEEE 42nd Annual International Symposium on. IEEE, 2015.

[4] Lacey, Griffin, Graham W. Taylor, and Shawki Areibi. "Deep learning on fpgas: Past, present, and future." arXiv preprint arXiv:1602.04283 (2016).

[5]https://community.cadence.com/cadence_blogs_8/b/design-chronicles/archive/2016/05/02/the-road-ahead-for-neural-networks-in-embedded-systems

[6]Sharma, Hardik, et al. "Dnnweaver: From high-level deep network models to fpga acceleration." the Workshop on Cognitive Architectures. 2016.

Q & A

FPGA’s in High-Frequency Trading (HFT)

Charles Kowalec

What is HFT?

High speed, large volume trading of equities

Utilizes various algorithms to analyze the market

Very short-term investments

Competitive Advantages in HFT

Ten years ago:

- Trading strategies/algorithms

Today:

- Latency in processing and executing trades

When Latency Matters

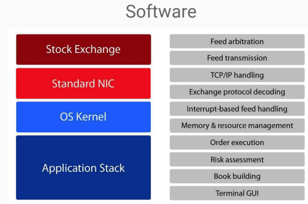
Receiving market data

Processing market data

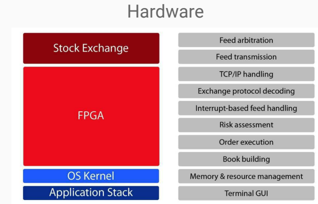
Executing trades

Software model vs FPGA model

Software



Hardware



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http://www.eetimes.com/author.asp?section_id=36&doc_id=1323278

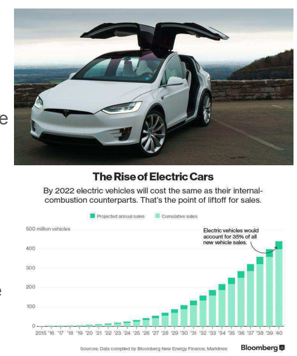
Questions?

Embedded Systems In Electric Vehicles

Swagat Tripathy
Brian Klein

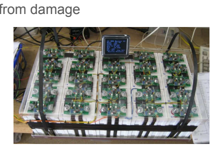
Electric Vehicles

- Rapid growth of Electric Vehicles
- 2010 to 2016 - 80% drop in battery price
- 50-75% of the value in Electric vehicles are embedded systems
- US is lagging behind other countries with only ~.7% EV market share
- Norway leader with ~33% market share

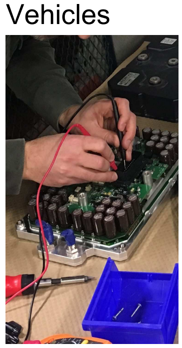


Major Embedded Systems in Electric Vehicles

- Battery Management System
  - Protects battery cells from damage by monitoring vitals



- Motor Controller
  - Determines necessary power draw from battery pack to achieve desired motor output

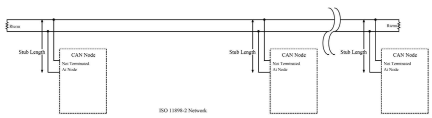


Battery Management System

- Contains a number of components to achieve each of the following actions
  - Monitoring & Shut-Off
    - Cell, Module, and Pack Voltage
    - Cell, Module, and Pack Current Draw
    - Cell, Module, and Pack Temperature
    - Pack State of Charge
  - Cell Balancing
    - Active
    - Passive
- Capable of communication on many different serial busses
  - CAN - most common in automotive industry
  - I2C
  - SPI

Serial Bus: Controller Area Network (CAN)

- Multi master bus designed for onboard vehicle communication between Electronic Control Units, or nodes
- Requires 2 or more nodes to transmit/receive data
- All nodes connected through a 2 wire bus
  - Transmission wire and Receiver wire
- Data transmission
  - CAN Messages
    - Message ID
    - Data
    - Acknowledge
  - Any node may read or write

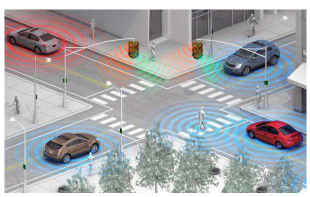


Autonomous Vehicles

- The end-goal for human transportation in the future
- Decades away from perfection but driving force of massive investments
- Will require many engineers and will become an even larger industry in the extremely near future
- Encompassing computer vision, massive amounts of code, and many other key embedded systems

Vehicle to Vehicle Communication

- Rolling out in very near future to almost all new cars on market
- Wirelessly sending information on position, direction, speed and other variables to all surrounding cars
- Step beyond current sensors and warning systems
- Much simpler than autonomous driving and will have huge impact on driving safety
- Legislation introduced now to make V2V communication mandatory



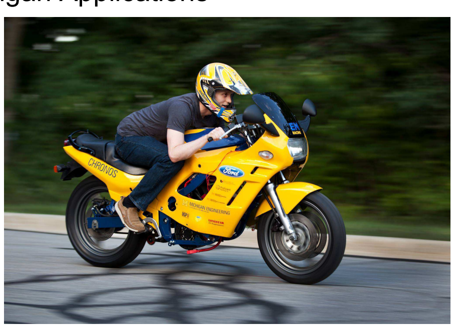
Vehicle to Vehicle Communication

Embedded Systems Involved:

- Wireless Protocol for sending/receiving information
- Accelerometers
- Roadside Units that communicate with passing cars
- Precision timing for all communication
- CAN Serial Bus Interfacing with all nodes in automobile
- Many more

University of Michigan Applications

SPARK Electric Racing

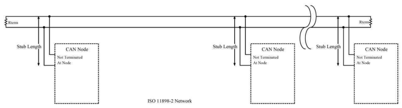


Controller Area Networks (CAN)

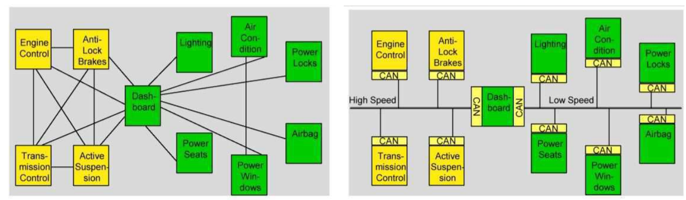
Melinda Kothbauer

CAN History

- Developed by Bosch in 1985
- Became international standard in 1993
- Needed in order to introduce more electronics into cars with fewer wires
- Bosch is still extending CAN licenses today!



Before CAN .... After CAN



Seminar on CAN Bus Protocol By Abhinaw Tiwari CSE-12010330

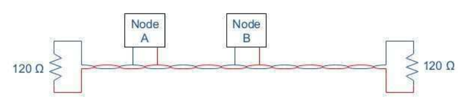
What is CAN used in?

- Cars
- Airplanes
- Railway systems
- Operating rooms
- Lab equipment
- Telescopes
- Automatic doors
- Coffee machines

CAN Capabilities

- High speed CAN
- Low speed (fault tolerant) CAN
- Single wire CAN
- Software selectable CAN

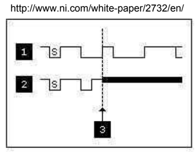
http://www.ni.com/white-paper/2732/en/



Seminar on CAN Bus Protocol By Abhinaw Tiwari CSE-12010330

How Does CAN work?

http://www.ni.com/white-paper/2732/en/



1 Device A: ID = 11001000111 (647 hex)
2 Device B: ID = 11011111111 (6FF hex)
3 Device B Loses Arbitration; Device A Wins Arbitration and Proceeds
S = Start Frame Bit

- Peer-to-peer network
- (no master/slave)
    - Data Frame
    - Remote Frame
    - Error Frame
    - Overload Frame
- No addresses, only message IDs
- Priority - wired AND system (priority encoded into ID)

Should *you* use CAN in *your* system?

Pros

- Low cost & lightweight
- Reliability
- Multiple speeds available
- Peer-to-peer network
- Low message size, but system wide

Cons

- Wires
- Pre-set speeds, can't control precise speed
- Peer-to-peer network
- Limited message length

References

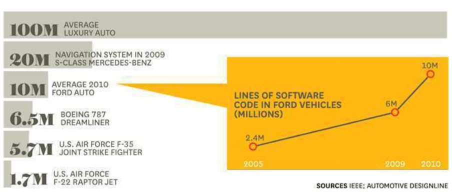
- http://www.ni.com/white-paper/2732/en/
- https://www.slideshare.net/abhinawambitious/can-controller-area-network-bus-protocol
- http://inst.cs.berkeley.edu/~ee249/fa08/Lectures/handout_canbus2.pdf

Over The Air updates

Bahaa Aldeeb

Introduction

The typical car contains about 2,000 components, 30,000 parts, and 10 million lines of software code.



Problem?

Code issues:
- Outdated
- Buggy
- Insecure

Results
- Customer dissatisfaction
- Security issues

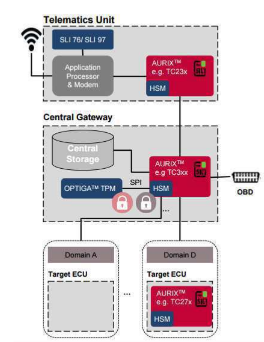
Outcome
- Recall
  - Costly
  - Timely
  - Very costly!

Solution - OTA

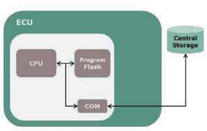
- Main motivation:
  - Save money
- Currently intended implementation:
  - Integrate in the vehicle network with little change as possible
- Issues:
  - Hack threats

How is it done - OTA

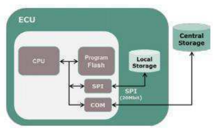
- Decrypt, verify, unpack and bundle
- Update ECU units
- Reboot



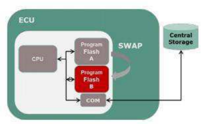
Update ECU?



- No cost
- High downtime



- Medium cost
- Low downtime



- High cost
- No downtime
- Under development

Question?

References:

- https://hbr.org/2010/06/why-dinosaurs-will-keep-ruling-the-auto-industry
- http://www.infineon.com/cms/en/applications/automotive/car-security/sotware-update-over-the-air/
- https://vector.com/portal/medien/cmc/events/commercial_events/vses16/lectures/vSES16_09_Freiwald.pdf

Caraoke: an E-Toll Transponder Network for Smart Cities

Yulong Cao, March 28th 2017

Electronic Toll Collection (ETC)

- 70% - 89% coverage in the US
- Some states are making it mandatory
- Advantages:
  - No deployment compared to other smart cities solutions
  - Low cost ($40 for the readers)

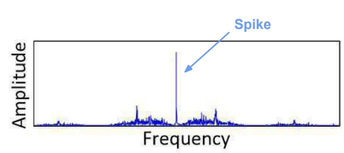
Software-Hardware Solutions: Caraoke

- Count cars (smart traffic-light timing)
- Localize cars (red-runner detector)
- Decode transponders (smart street-parking)

Count Cars: Counting Despite Interference

Problem: No MAC protocol to prevent collision

Solution: Carrier frequency offset (CFO) exploitation



Calculations:
Range of 1.2MHz
Resolution of 1.95KHz
1.2MHz/1.95KHz = 615 FFT bins

Count Cars: Counting Despite Interference

Problem: Spike collision

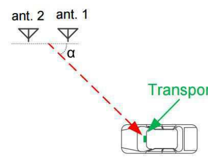
Solution: Second measurement with time shift

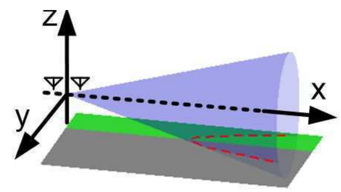
$$\mathbf{R(f) = R(f) \cdot e^{j\,2\pi f \tau}}$$

$$\mathbf{R(f) + R(f') \neq R(f) \cdot e^{j\,2\pi f \tau} + R(f) \cdot e^{j\,2\pi f' \tau}}$$

Localize Cars

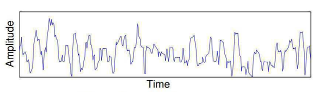
Multiple readers with Network Time Protocal (NTP)



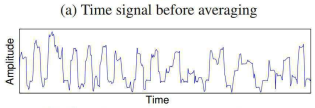


Decode Transponders

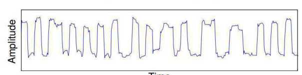
Averaging with multiple query responses



(a) Time signal before averaging



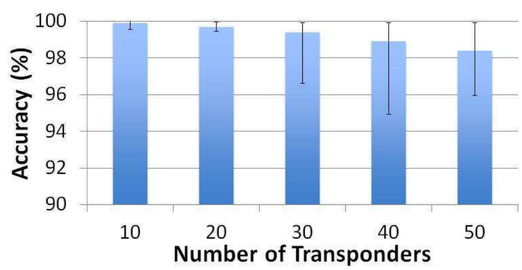
(b) Time signal after averaging 8 times



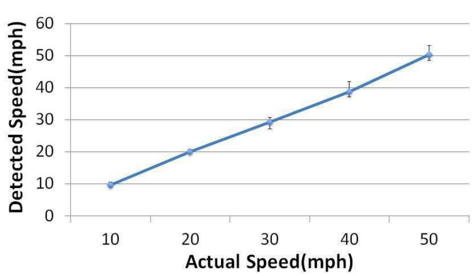
(c) Time signal after averaging 16 times

$$\tilde{s}_1(t) = N \cdot s_1(t) + \sum_i \left(\sum_j \frac{h_{ij}}{h_{1j}} \right) s_i(t) \cdot e^{j2\pi(\Delta f_i - \Delta f_1)t}$$

Evaluation



Evaluation



Q&A

Reference

Abari O, Vasisht D, Katabi D, et al. Caraoke: An e-toll transponder network for smart cities[C]//ACM SIGCOMM Computer Communication Review. ACM, 2015, 45(4): 297-310.

Drones

Sensor → Processor → Actuator

Yetong Zhang - Team Rofcopter

Drones Overview

Most popular drone:
Phantom 4 by dji

https://www.idrone.com.tw/photo2011/prod_2016/3/G3030127-A.jpg

Smallest drone:
Aerius by Aerix drones (3cm x 3cm x 2cm)

https://i.ytimg.com/vi/Wt0WSi56-UQ/maxresdefault.jpg

Drones Overview

Most popular Drone
Phantom 4 by dji

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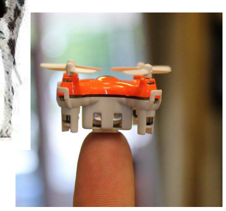
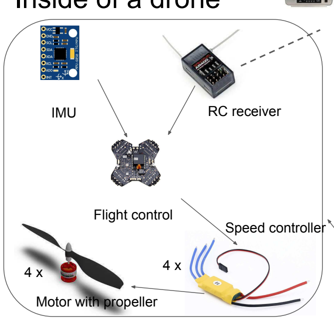


https://www.idrone.com.tw/photo2011/prod_2016/3/G3030127-A.jpg

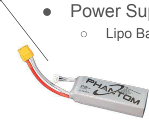
https://i.ytimg.com/vi/Wt0WSi56-UQ/maxresdefault.jpg

Inside of a drone

RC transmitter



- Sensor / Input
  - IMU (inertial measurement unit)
  - RC Receiver/ Transmitter
- Processor
  - Flight Controller
- Actuator
  - Motor
  - Speed Controller
  - Propeller
- Power Supply
  - Lipo Battery



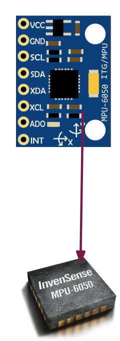
battery

Inside of a drone —— IMU

What is measured through IMU?

- Angular velocity (gyroscope)
  - Self spinning, rotation
- Linear acceleration (accelerometer)
  - acceleration/ tilt (direction of gravity)
- Advanced: 10 axis IMU
  - 3-axis accelerometer
  - 3-axis gyroscope
  - 3-axis compass
  - 1-axis barometer

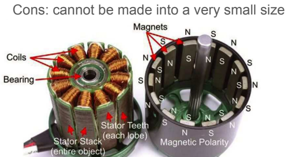
http://www.flightofthephantom.com/what-is-an-imu



Inside of a drone —— Motor

Brushless motor

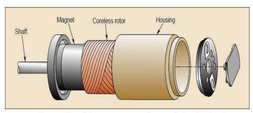
- AC power supply
- Used for large sized drone
- Pros: stator no rotation, high efficiency, high torque
- Cons: cannot be made into a very small size



http://www.dronetrest.com/uploads/db5290/607/daeb6b781f95bf13.png

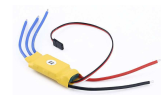
Coreless motor

- Typically DC
- Used for smaller sized drone
- Pros: no metal core, thus less inertia, accelerate and deccelerate faster
- Cons: cannot withstand large current, thus power limited

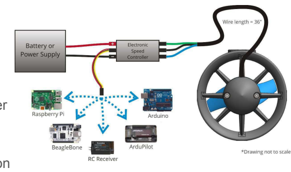


http://machinedesign.com/site-files/machinedesign.com/files/archive/motionsystemdesign.com/images/miniature-motors-coreless.jpg

Inside of a drone —— Speed Controller

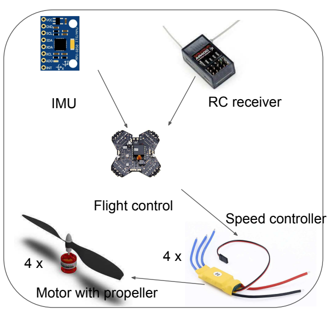


- Why using speed controller? Input & Output signal
  - DC power supply → AC voltage to control brushless motor
  - Input:
    - DC power supply
    - Pwm signal
    - 1~2ms pulse width, 20ms period
    - Similar to servo
    - Can directly connect to rc receiver
  - Output:
    - AC output
    - Switch two wires: reverse direction
  - Also speed controller for DC motors



http://cdn.wellnessarticles.net/2016/11/11/brushless-motor-speed-controller-l-9f779ca53ebba244.png

Inside of a drone —— What's More



- Sensor (Input)
  - IMU (internal measurement unit)
  - RC Receiver/ Transmitter
  - GPS
  - Camera / Infrared Sensor
- Processor
  - Flight Controller (self balance)
  - Obstacle avoidance
  - Motion Planning
  - Computer Vision
- Actuator
  - Motor, Speed Controller, Propeller
- Power Supply
  - Lipo Battery

Inside of a drone —— What's More

http://www.dji.com/inspire-2

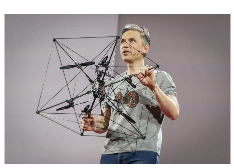
- ...put)
  - ...ernal measurement unit)
  - ...eiver/ Transmitter
  - ... / Infrared Sensor
  - ...ontroller (self balance)
  - ...e avoidance
  - ...Planning
  - ...rocessing
- Actuator
  - Motor, Speed Controller, Propeller
- Power Supply
  - Lipo Battery

Irregular Drones

Amazon Prime Air

https://www.amazon.com/Amazon-Prime-Air/b?node=8037720011

Omnicopter
(By Raffaello D'Andrea at ETH Zurich)



https://www.youtube.com/watch?v=RCXGpEmFbOw

Reference

- Phantom image: https://www.idrone.com.tw/photo2011/prod_2016/3/G3030127-A.jpg
- Aerius image: https://i.ytimg.com/vi/Wt0WSi56-UQ/maxresdefault.jpg
- IMU usage: http://www.flightofthephantom.com/what-is-an-imu
- Brushless motor image: http://www.dronetrest.com/uploads/db5290/607/daeb6b781f95bf13.png
- Coreless motor image: http://machinedesign.com/site-files/machinedesign.com/files/archive/motionsystemdesign.com/images/miniature-motors-coreless.jpg
- Electronic speed controller wiring diagram: http://cdn.wellnessarticles.net/2016/11/11/brushless-motor-speed-controller-l-9f779ca53ebba244.png
- What's more of drones: http://www.dji.com/inspire-2
- Amazon air prime: https://www.amazon.com/Amazon-Prime-Air/b?node=8037720011
- Omnicopter: https://www.youtube.com/watch?v=RCXGpEmFbOw

Power Consumption in Embedded Systems for Drones

Sean McLoughlin - Team Roflcopter

Why power is important...

- Main peripherals
  - Accelerometer + Gyroscope
    - Minor corrections in stability for drone
    - On practically all the time, need to be low-powered
    - Tend to consume small amounts of power
  - 4 (or more) Motors
    - Very high torque needed to generate enough lift
    - On only while drone is flying
    - Consumes the most power
  - Camera
    - High quality cameras are heavy and power consuming
    - Ex. Phantom 4 Pro - Large size and high quality camera
- In this presentation, I will cover:
  - Type of Battery
  - Type of Motor
  - Ways Commercial Drones tackle power usage

LiPo Batteries - Advantages and Disadvantages

Lightweight, high capacity, and fast discharge

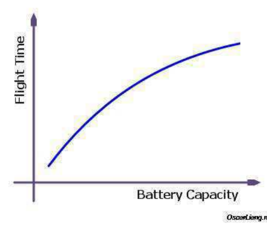
- Allows drone to generate lift
- Can power motors

Short lifespan

- Drone cannot fly for very long

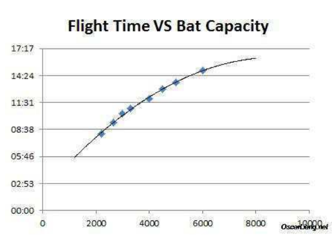
The Tradeoff between Weight and Flight Time

- Flight time is not linearly proportional to battery capacity
- Large enough batteries will actually *lower* flight time
- This is due to larger batteries weighing more, thus needing more power for lift
- Current draw also increases with battery size, leading to shorter flight times



Analysis for Optimal LiPo Capacity

- Flight time ~ Effective Capacity / (mAh/s)
  - Effective Capacity is ~86% of total capacity because voltage drops as battery drains
- Plot Flight Time VS Battery Capacity
- Find maximum of plot

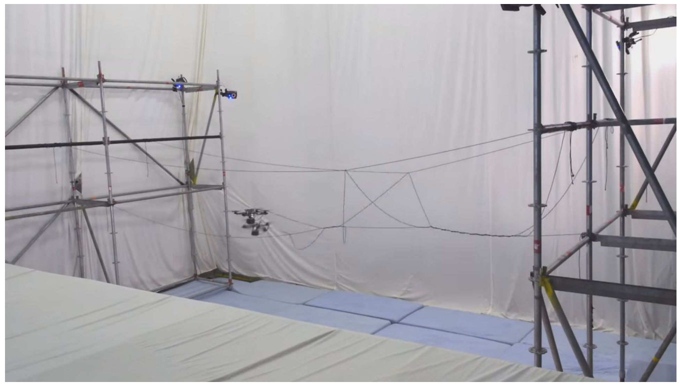


Brushless Motors

- Advantages
  - Faster than DC
  - Lower Power than DC
- Disadvantages
  - Much more expensive
  - Requires Electronic Speed Controller (ESC), which is also expensive
- Practically required for any decent flight time

How Commercial Drones Tackle Power Issues

- Amazon Prime Air
  - Drone the size of a Go Kart to deliver a package as big as a laptop (Amazon Fire TV)
  - Presumably a large amount of the drone is battery
  - Very large Brushless Motors
- DJI
  - Newer models with better cameras → Larger drone frame
  - DJI Mavic (low quality camera, drone that follows you) is much smaller than Phantom series
- Overall, if the drone needs to carry something, manufacturers just make them bigger.
- However, with better battery technologies, more elaborate drones will emerge
  - There are many applications
  - Example: Amazon would love smaller delivery drones for large cities...



Key Points

- Motors and external weight consume the most power on a drone
- A larger battery is not always better
- Battery technologies will continue to improve, leading to more elaborate drones available for lots of different applications

Questions?

References

LiPo Batteries and Analysis: https://rogershobbycenter.com/lipoguide/

Optimal Battery Choice: https://oscarliang.com/how-to-choose-battery-for-quadcopter-multicopter/

Overview of Quadcopters: http://www.socialledge.com/sjsu/index.php?title=S14:_Quadcopter#Abstract

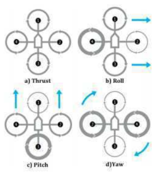
TED Talk: Meet the dazzling flying machines of the future - Raffaelo D'Andrea: https://www.youtube.com/watch?v=RCXGpEmFbOw

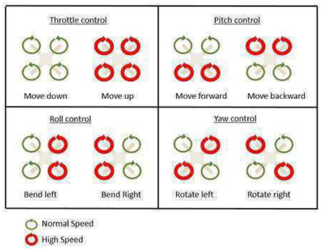
Control and Stabilization of Drones with Embedded Systems

Gordon Dwyer

Basics of Quadcopter Flight

- 2 configurations of quadcopters
- 3 types of motion in quadcopter flight
  - Thrust or Throttle
  - Roll and P
  - Yaw





What is a Flight Controller

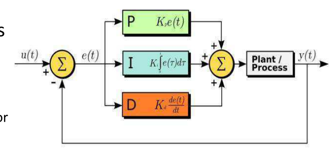
- Onboard microcontroller
  - Incoming controls
  - Sensor data processing
  - Stabilization
- Inertial Measurement Unit (IMU)
  - Consists of a gyroscope and an accelerometer
- Other components
  - GPS
  - Ultrasonic sensors
  - Barometers

The Microcontroller

- Common processors
  - STM32 Variants F1, F3, F4
    - Widespread use in the recreational market
    - Different processing speeds and serial bus support
    - Based on Cortex-M7,M3,M0
  - Intel Processors used on higher tech drones
- DIY quadcopter builds
  - Arduino kits such as the UNO
  - Arduino libraries for ease of use

Intro to Stabilization

- 3 axes measured to stabilize quadcopter
  - Pitch, Roll, and Yaw
- PID controllers are used on each axis
  - Proportional – Integral – Derivative
  - 3 algorithms in a PID controller
    - P represents current error
    - I represents the accumulation of past error
    - D represents a prediction of future error

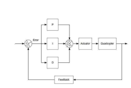


Adjusting PID Parameters for Tuning

- Each of the three algorithms has a coefficient
  - Coefficients are essentially the sensitivity of the PID
  - P coefficient determines the ratio of control between the user and the stabilization
  - I coefficient sets the precision of accumulation
  - D coefficient is a damping coefficient for overshooting caused by a P term
- Using these the quadcopter can be tuned for different purposes

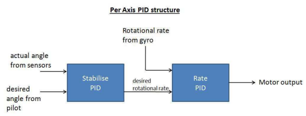
PID for Quadcopters

- PID is a feedback system
  - It compares the user input values with sensor values
  - Coefficients determine strength of algorithms
- PID works by assessing the change in error
  - Weather
  - Operator overshoot
  - Collisions



Stabilization (PID) Improvements

- Dynamically changing PID coefficients
  - Adapting to different conditions such as weather and user preference
- Feeding forward
  - Combine feedback knowledge with knowledge about the system
    - Reduces dependence on changing error by adding desired terms
- Cascading PIDs
  - Increase performance by assigned PIDs to different tasks



Questions?

References

- https://oscarliang.com/quadcopter-pid-explained-tuning/
- http://dspace.ucuenca.edu.ec/bitstream/123456789/21401/1/IEE_17_Romero%20et%20al.pdf
- http://www.socialledge.com/sjsu/index.php?title=S14:_Quadcopter#Abstract
- https://github.com/br3ttb/Arduino-PID-Library/blob/master/PID_v1.cpp
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- https://en.wikipedia.org/wiki/PID_controller

Drone Image Transmission Quality Using Different Method

Zihan Li

Outline

- Frequency to be compared:
  - 5.8GHz
  - 2.4GHz
- Protocols to be compared (all on 2.4GHz):
  - WIFI TCP
  - WIFI UDP
  - DJI Lightbridge

Objectives:

Important:

- Clear.
- Real-time.
- No distortion.

Not important:

- Getting every single pieces of data.

5.8GHz

Pros:

- Fast.
- Less noizes.
- More channels. (30+)

Cons:

- Less penetration ability.
- Limited max power. (Power larger than 2W is rare)

2.4GHz

Pros:

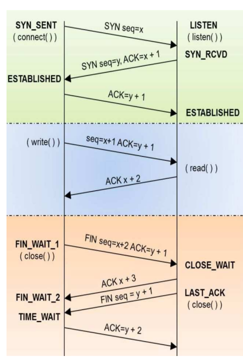
- Acceptable speed.
- Widely used.
- Large max power. (Easy to get a 15W one.)

Cons:

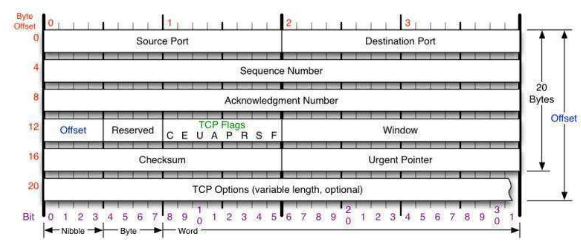
- Lots of noises.

TCP Protocol

- Full duplex
- Three handshakes before transmitting.
- Four handshakes before closing.
- Data package lost:
  - Retransmit the data.



TCP Protocol Head



TCP Protocol

Pros:

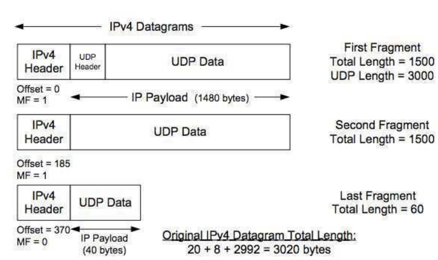
- Reliable data delivery

Cons:

- High delay
- Resend if data package lost.
- High power consumption.

UDP Protocol

- Full duplex
- No error checking
- No error correction
- No acknowledgment
- Provides speed



UDP Protocol

Pros:

- Low delay
- Low power consumption.
- No resend if data package lost.

Cons:

- Unreliable data delivery

DJI Lightbridge

Pros:

- Low delay.
- Single direction broadcasting.
- No resend if data package lost.
- Insensitive to data lost.

Conclusion

- Avoid using TCP when UDP is available.
- Special designed protocol is even better.
- 5.8GHz and 2.4GHz are subject to choose.
    - In open space 5.8GHz is usually better.
    - In space full of obstacles 2.4GHZ is better.