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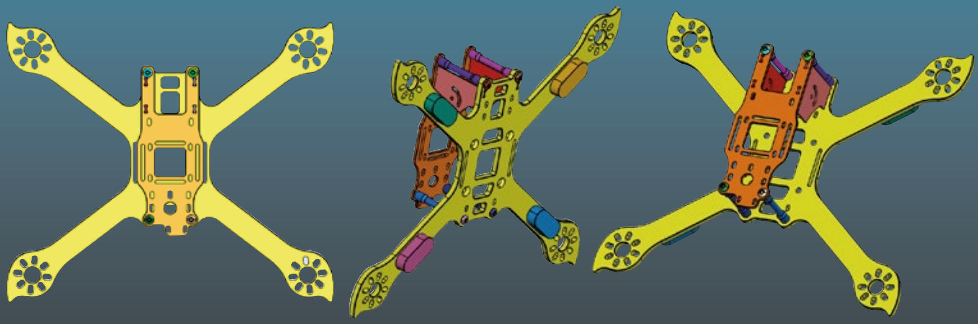

Industrial System Engineering for Drones

A Guide with Best Practices for Designing

Neeraj Kumar Singh
Porselvan Muthukrishnan
Satyanarayana Sanpini

Apress®

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Neeraj Kumar Singh
Bangalore, India

Porselvan Muthukrishnan
Bangalore, India

Satyanarayana Sanpini
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Printed on acid-free paper

Dedicated to my sons, Anant and Atulya,
for filling my life with joy and inspiration

—Neeraj

Dedicated to my teachers and mentors

—Satya

Dedicated to my teachers and mentors

—Porselvan

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About the Authors

Neeraj Kumar Singh has been a Platform Architect for Intel Client platforms for more than 12 years. His areas of expertise are hardware/software co-design, SoC system/platform architecture, and system software design and development. Neeraj is the author of *System on Chip Interfaces for Low Power Design* and *The Impact of Loop Unrolling on Controller Delay in High Level Synthesis*.

Porselvan Muthukrishnan has been a Hardware/System Design Engineer for Intel IOT platforms for over 10 years. His area of expertise is hardware/system design. Porselvan is currently working on system designs for connected home, connected cars, and other IoT devices.

Satyanarayana Sanpini has been working in the fields of low-power embedded systems architecture, SoC definition, architecture, and design for the past 17+ years. He has contributed in various technical positions at start-ups Ittiam, Beceem Communications, and MNCs Broadcom, and also Qualcomm and Intel. He is currently based out of Bangalore, India and works at Intel India Center. Satya obtained his M.Tech degree in Electronics Design from Indian Institute of Science (IISc), Bangalore, India. Apart from a passion for technology, Satya likes to spend time with his young kids and explore nature's grandeur through travel and trek.

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It's impossible to not risk missing someone, but we will attempt anyway.

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CHAPTER 1

Introduction

System design is a discipline of creating a system/product, starting from requirements to the final deployment in the field. It is a very vast subject and encompasses multiple cross-functional domains such as market research, planning, product definition, hardware design, software design, industrial design, validation, certification, etc. It is very difficult to cover all of these aspects in detail in a single book. This may be why few references cover the system design in detail. This book is an attempt to provide a brief introduction to the system design discipline.

As anyone can understand, a vast variety of systems are possible in the real world. The focus of this book is a typical electromechanical system design, with emphasis on electrical hardware system design concepts. You will be taken through the processes and methodologies comprehensively using the fairly complex electromechanical system of a drone as an example. While this book primarily focuses on the electrical part of the system design, other critical disciplines like mechanicals and software are covered at a high level to give a complete perspective of the system design. To give you a feel of designing a system from scratch yourself, at many places the content is presented from a first-person perspective. By end of the book, you will get a glimpse of how multiple subsystems are developed or chosen carefully (components are either "make" or "buy") to get a flawless system (through the drone example). The focus areas vary dynamically, but "make" components are emphasized more than "buy" components. Hardware is always a make item for most of the system design, so that's why it's covered in so much detail.

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The organization of the book is as follows. In Chapter 1, we start with brief description of the drone system and its critical components. In Chapter 2, the typical system design flow details are presented. Chapter 3 delves into the drone system's key ingredients and selection procedure. In Chapter 4, the electronic hardware development process is covered in detail. Chapter 5 covers typical procedures and checks followed as part of a system bring-up. In Chapter 6, the software processes and real-time software that go into drone-like systems are discussed. Chapter 7 concludes the book with coverage of the final certification processes a system needs to go through before deployment. Two appendixes provide additional basics and references.

What Is a Drone?

An unmanned aerial vehicle (UAV), commonly known as a drone, is an aircraft without a human pilot onboard. UAVs are a component of an unmanned aircraft system, which includes a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy, either under remote control by a human operator or autonomously by onboard computers.

Drones are classified into different categories based on the applications. Applications are broad, and from the design perspective, generally fall under three major groups: military, industrial (`enterprise`), and commercial.

Military

Drones in military applications are used for anti-aircraft target practice, intelligence gathering and, more controversially, as weapons platforms.

Industrial

The integration of drones and IoT (Internet of Things) technology has created numerous industrial and enterprise use cases: drones working with on-ground IOT sensor networks can help agricultural companies monitor land and crops, energy companies survey power lines and operational equipment, and insurance companies monitor properties for claims and/or policies.

Commercial

The commercial field is a growing development, where the largest, strongest, fastest, and most capable drones on the market are targeted toward the professional community. They are the types of machines that the movie industry puts to work and that commercial agencies use to inspect infrastructure. Some impressive self-piloted drones survey individual farmer's fields. Commercial drones are the smaller consumer products that make up just a tiny portion of the overall drone market. Figure 1-1 shows the form factor of a commercial drone.

Figure 1-1. *Commercial drone*

Parts of a Drone System

From an engineer's view, the key parts of a drone system are the hardware, software, and mechanical elements; and a perfect balance between the three provides a flawless system design.

Hardware

Hardware is the electrical part of the drone system, which is eventually a PCBA (`printed circuit board assembly`). Hardware is a multilayer PCB that accommodates the SOC (`system on a chip`) and different components of the subsystems interconnected through copper traces (part of the PCB) or physical wires. Figure 1-2 shows the PCBA assembled with SOC and subsystems on the top side (`primary side`).

Figure 1-2. *PCBA mounted with SOC and subsystems*

The SOC

The SOC is a miniature computer on a chip of a present generation systems, especially a drone system. It's a semiconductor device and an integrated circuit that usually integrates digital, analog, mixed signal, and radio frequency devices on a single chip. SOCs are most commonly used in mobile computing and embedded systems.

In general, there are three distinguishable types of SOCs: SOCs built around a microcontroller, SOCs built around a microprocessor, and specialized SOCs designed for specific applications that do not fit into the above two categories.

SOC usually consume less power and have a lower cost than the multichip systems they replace.

Note Intel Core, Atom, and Quark processors are SOCs on a single package.

Figure 1-3 shows a typical SOC that integrate digital, analog, and mixed signal devices on a single chip. The device at the center of the SOC is the silicon, and some capacitors are distributed on the top side of the SOC. The bottom side of the SOC shows pins (called as balls in a ball grid array), which are soldered on to a PCB to establish the connection with the subsystems through PCB traces. You'll see more details on this in later sections.

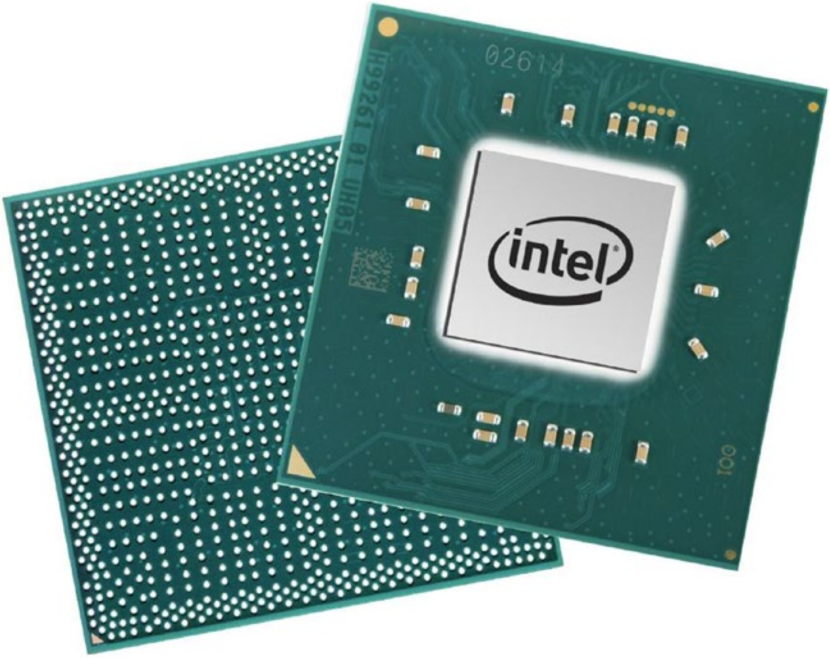

Figure 1-3. *Top and bottom views of the SOC*

Subsystems

Subsystems or electrical subsystems are technologies required in a system to fulfill the intended usage of the system.

Broadly speaking, subsystems fall into any one of the following computer architecture parts: input, output, storage, and communication devices.

Input

A touch panel, keyboard, mouse, microphone, camera, sensors, and remote control are some examples of input devices of a system.

Output

Displays, speakers, motors, fans, and LEDs are some examples of output devices of a system.

Storage

Memory, flash, hard disk drive, optical drive, secure digital, and solid state drive are some examples of the storage devices of a system.

Communication Devices

Wired LAN (local area network), wireless LAN, mobile networks (3G, 4G, and LTE), GPS (Global Positioning System), and USB are some examples of the communication devices of a systems.

All of the subsystems listed above may or may not be a part of a particular drone design. The target application picks the right subsystems to be part of the drone system design.

For example, if the intended application of a drone is surveillance, it should be equipped with a high resolution camera and the SOC used in the system should be capable of accepting and processing the high speed data from that camera. The PCBA should be designed in such a way as to interconnect the high speed data between SOC and the camera module and then be capable of transmitting the live or recorded data via the wireless communication modules.

Besides SOC, the camera module, wireless module (`WiFi/3G/4G modules`), memory, internal storage, sensors, and flight controllers are the basic required subsystems for a surveillance drone. Figure 1-4 is the transparent view of the internal parts of the drone, highlighting a few high-level subsystems, which are visible.

Figure 1-4. *Parts of a drone*

Subsystems play an important role in defining the specifications of the product. ("Product" is the right term for a system when in production stage and available in the market). An end user will see these subsystems as a feature list when selecting a product. A typical drone will have the features listed in Table 1-1.

Table 1-1. *Basic Features of a Drone*

Features	Specifications
Camera pixels	2MP, 720PHD
Controller	2.4GHz
Channels	4 channels
Gyroscope	6-axis control
Distance	Control by phone about 164ft/ Control by controller about 262ft
Battery for quadcopter	3.7V 900mAh li-po battery

Table 1-2 lists the specifications covering additional internal features of the drone system. It must again be noted that the specification here is for an example drone and will vary from one drone system to another. As seen earlier, some subsystems from the list may or may not be required for the target application of the system.

Table 1-2. *Detailed Features of a Drone System*

Subsystems	Features	Specifications
NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE
PROCESSING	CPU	Quad-core 2.34 GHz
	GPU	6-core graphics
MEMORY	Card slot	No
	Internal	32/128/256 GB, 2 GB RAM
CAMERA	Primary	12 MP (f/1.8, 28mm, 1/3"), phase detection autofocus, OIS, quad-LED dual-tone flash, check quality
	Features	Geo-tagging, simultaneous 4K video and 8MP image recording, touch focus, face/smile detection, HDR (photo/panorama)
	Video	2160p@30fps, 1080p@30/60/120fps, 720p@240fps, check quality
	Secondary	7 MP (f/2.2, 32mm), 1080p@30fps, 720p@240fps, face detection, HDR, panorama
AUDIO	Alert types	Vibration
	Loudspeaker	Yes, with stereo speakers
	3.5mm jack	No

(*continued*)

Table 1-2. (*continued*)

Subsystems	Features	Specifications
COMMS	WLAN	Wi-Fi 802.11 a/b/g/n/ac, dual-band, hotspot
	Bluetooth	4.2, A2DP, LE
	GPS	Yes, with A-GPS, GLONASS, GALILEO, QZSS
	NFC	Yes
	USB	2.0, proprietary reversible connector
SENSORS	Sensors	Fingerprint, accelerometer, gyro, proximity, compass, barometer

Software

There are three or maybe four categories of software that we'd use on the drone system:

1. *Firmware components*: Many of the HW components (devices) that we put on a system today are not just passive hardware components; they have associated firmware that can help offload certain activities without requiring the CPU's attention.

2. *OS and drivers*: Typically, in an OS-based environment, to maintain the coherency of device usage and establish a level of security, the SW is divided into system and application domains. Different OSes use different terminologies for the same: system and application domains. This separation typically uses the protection and separation mechanism provided by hardware. And different SOC architectures implement and/or

provide different ways for protection and separation. Broadly speaking, there are two parts to the system part of the software:

a. The controllers' and devices' drivers, which provide access to the hardware and serialize the access requests from different SW components.

b. The other part is the overall management of resources (devices/controllers, processor, and memory), and scheduling, etc. It also provides infrastructure for communication across various beings (hardware and software) on the system. This part is commonly referred as the operating system (OS). Given the nature of the usages, drones need to use a real-time operating system (RTOS). RTOS is a category of operating systems that provide a mechanism to guarantee higher bound to a process completion.

3. *Sensing, navigation, and control*: With drones being UAVs, sensing, navigation, and control are of the utmost importance. The first piece of this crucial part is the sensing infrastructure, which feeds the navigation system, which triggers control decisions.

4. *Application-specific components*: In addition to the first three fundamental components, there are likely to be some application-specific components (both software and hardware). For illustration, taking the example of the surveillance drone, there will be image capture, processing, and transmit-related components on the system. The application-specific components make use of the "OS and driver" piece in order to accomplish the goal.

Figure 1-5 shows the logical view of the software components of a typical drone system, as just discussed.

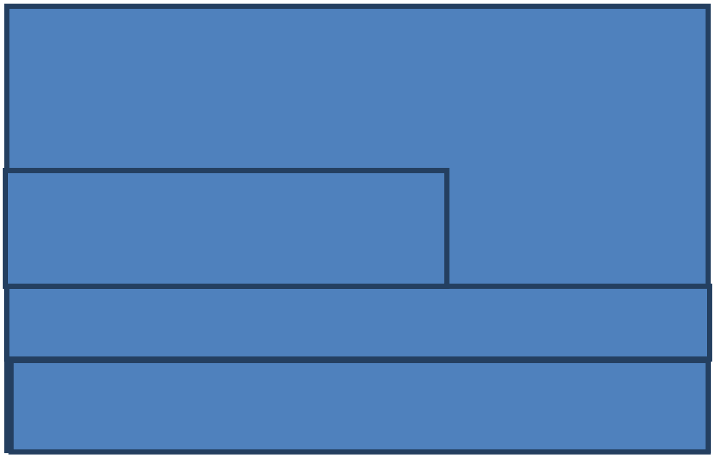

Figure 1-5. *Logical view of the drone software stack*

Mechanical

The mechanical system is basically the enclosures, form factor, or simple ID (`industrial design`) of the drone. The ID determines the exterior and appearance of the drone. The ID of the drone will usually have numerous mechanical parts in a complicated assembly with electrical parts interconnected through mechanical or thermal interconnects.

The most popular drone, seen in Figure 1-1, has a quadcopter built from an X-frame or H-frame with four servo motor/propeller units on each end with numerous other mechanical parts along with the PCBA enclosed in plastic.

A drone with frame as a base includes propellers, motors, landing gear, body (`usually PCBA, flight controllers, and motor drivers`), and a battery.

Note Heavier drones are powered using alternate fuels other than batteries, such as solar power or gasoline. Drones operating with these fuels are not only heavy but they use different technology and are designed for different purposes.

The PCBA is usually considered a single mechanical part of a system. The PCBA is the energy consuming part of the system and dissipates heat while doing the operation, so it needs a cooling system.

A typical electronics hardware setup will have a heatsink to spread the heat generated by the integrated circuits, which is often accompanied by a fan on the head to blow out the excess heat. The fan needs separate, additional power on top of the system power and this kind of cooling is termed as “active cooling,” whereas heatsink-based cooling without a fan is called as “passive cooling.” Passive cooling doesn’t need any extra power.

For a very low-power system, the ground layers of the PCBA spread the heat and become self-sustaining without any extra cooling system/mechanism. Figure 1-6 shows the discrete mechanical parts of an ID excluding enclosures. Most mechanical parts are customized for the design, which can be designed in-house or can be created using third-party mechanical expertise designers. Some mechanical parts like motors, screws, and cables will be available off the shelf and can be purchased directly from third-party vendors.

Figure 1-6. *Mechanical parts of a drone*

Ground-Based Controllers and Accessories

Ground-based controllers and accessories are essential items required for a drone to operate, just like any other electronic gadget available on the market.

The most important accessory is the RF-based remote controller for the drone, which helps to control the UAV from a remote location. Alternatively, the drones can also be controlled through a smartphone, thanks to the latest advancement in the technologies, but only if the drones are capable of connecting to the 3G/LTE mobile network.

Other functions like video streaming and capture can be done through a smartphone application or GUI (`graphics user interface`) from a host controller.

The majority of the drones today are battery operated; a charger/power adapter is the other most important accessory of the system.