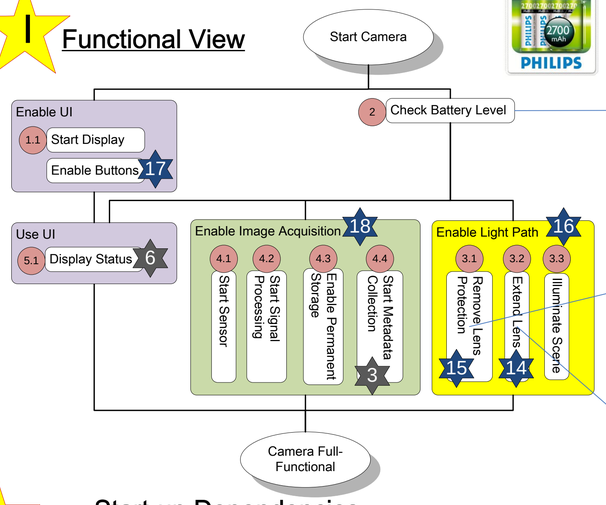
Balancing Start-up and Stand-by Time

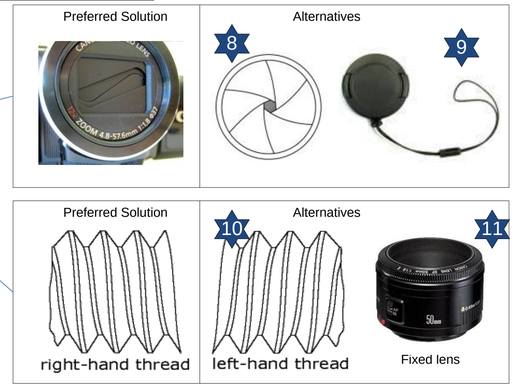
On the readiness for operation of a digital camera

I Functional View



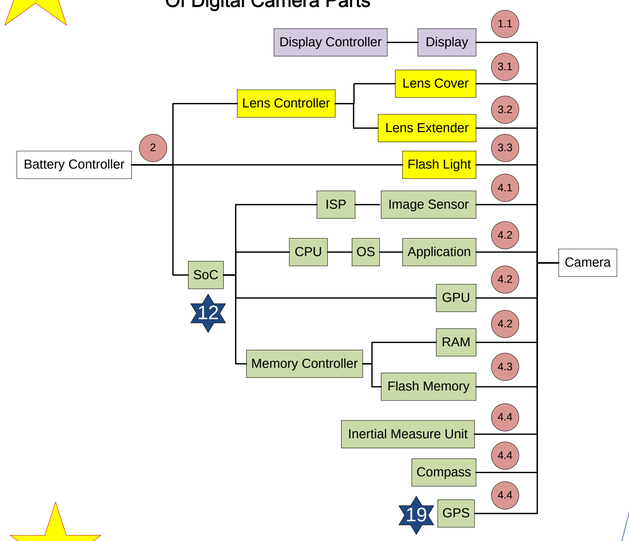
High-end rechargeable AA battery: 1.2 V – 3000 mAh
Assumed stand-by power: 12 mW
Stand-by time / battery runs flat in: 3000 mAh / (12 mW/1.2V) = 300 h = 12.5 day

$$\text{Stand-by Time} \sim \frac{1}{\text{Stand-by Power}}$$



II Start-up Dependencies

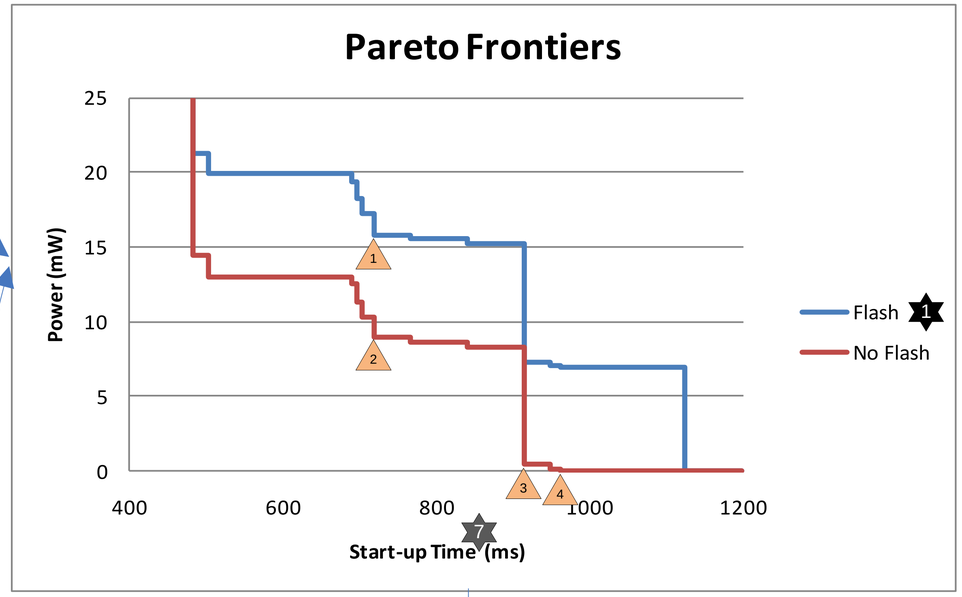
Of Digital Camera Parts

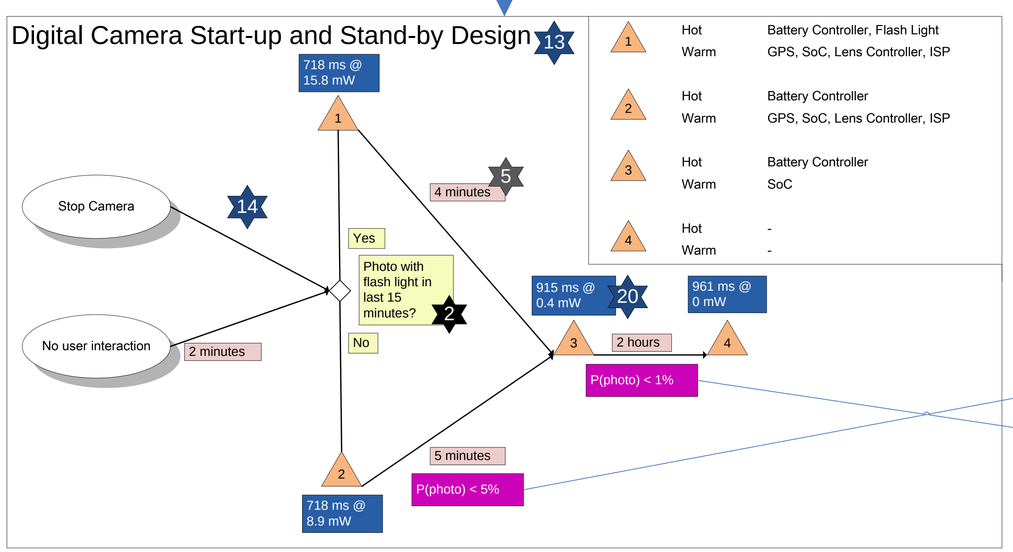


III Quantification of Key Parameters

start-up: max power: 0 mW | start-up: intermediate power: intermediate | start-up: 0 ms power: max

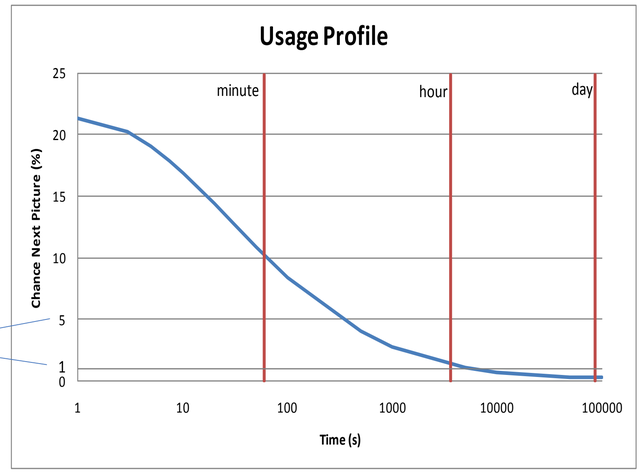
4 Digital Camera Part	Cold start-up (ms)	Warm start-up (ms)	Warm power (mW)	Hot power (mW)
Display Controller	78	15	0.3	2.3
1.1 Display	213	35	3.4	6.2
2 Battery Controller	12			0.1
Lens Controller	69	21	0.3	1.7
3.1 Lens Cover	312	248	1.8	15
3.2 Lens Extender 7	697	482	2.6	14
3.3 Flash Light 5	1123			6.9
System On Chip	123	15	0.3	1.3
4.1 ISP	152	15	0.3	4.3
Image Sensor	674	62	1.5	3.2
CPU OS Application	304	74	0.2	4.3
4.2 GPU	24			2.1
RAM	101	10	1.1	2.6
4.3 Memory Controller	76	2	0.1	1.1
4.4 IMU + Compass	53			1.1
GPS 20	915	351	7.9	46.5

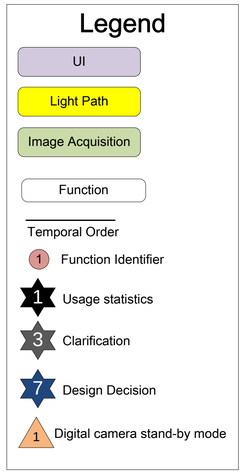




IV Design decisions / constraints

1. Approximately 22% of all photos are taken with flash light.
2. The chance that a photo needs flash light given that a photo with flash light was taken in the last 15 minutes is 95%.
3. Metadata include time, orientation of the camera, GPS location, compass heading, and camera settings.
4. To prevent a state space explosion, we ignored the least relevant parts and combined some other parts.
5. Leakage causes a fully charged flash light to become discharge completely in two minutes. When a flash light is partially charged, its **Start-up Time** is of course shorter than in case of a cold start-up.
6. Status include battery level, start-up progress (using hour-glass animation), available memory (in number of photos), and digital camera settings.
7. Clearly observable start-up activities, like extending the lens and opening the lens cover, reduce the **Subjective Start-up Time**.
8. A shutter-like lens cover was rejected since the **Robustness** of the design was less. In particular, the design is more sensitive to dust and external forces.
9. A manual cover was rejected since the **Start-up Time** of the design is longer. Removing a manual cover requires approximately 0.5 second. Furthermore, it is typically forgotten (approximately 70%): Instead of removing the cover in parallel during digital camera start-up, it is removed after start-up.
10. Left-handed thread was rejected, although there are no difference in relevant system qualities between right-hand and left-hand thread used to extend the lens.
11. A fixed lens was rejected since the design negatively impacts the digital camera's **Ease of Transportation** and requires more **Digital Zoom** than currently possible without compromising the **Image Quality**.
12. To ensure low **Cost**, a generic System On Chip solution has been chosen instead of dedicated, special-purpose hardware.
13. The digital camera's start-up and stand-by design must be simple to implement to ensure low **Cost** not only now but also in the future.
14. **Ease of Transportation** is achieved by folding the lens, resulting in a convenient form factor. The folding of the lens is under control of the user by pressing the on/off button.
15. The lens must be protected against dust and external forces to prevent damage and to ensure the **Image Quality** during the camera's complete **Life Time**.
16. For both **Image Quality** and **Ease of Transportation**, the light path is only enabled when sufficient power is available in the batteries to prevent a partially opened cover [that leaves the lens unprotected], and a partially extended lens [resulting in an inconvenient form factor].
17. The on/off button is always enabled. For **Reliability**, all other buttons are disabled to prevent erroneous input while the camera is stored.
18. For both **Image Quality** and **Reliability**, image acquisition is only enabled when sufficient power is available in the batteries among others to prevent damage to the sensor and permanent storage.
19. Dedicated GPS tracking hardware is chosen to enable a long **Stand-by Time.** A GPS software tracking application consumes too much power in the warm state, since the satellites have to be continuously tracked, requiring all dependent parts, including System on Chip, CPU and OS, to be in the hot state.
20. Currently, after initialization, the GPS hardware returns either "no-signal" or the GPS position. In the next release, the software driver will be changed such that during GPS hardware initialization "no-signal" will be returned. This will reduce the **Start-up Time** from 915 ms to 841 ms. Furthermore, a photo taken when no GPS signal was available will be tagged with a GPS position (and its associated timestamp) when a GPS position was or becomes available within a 1 minute time window around the time the photo was taken.





Balancing Start-up and Stand-by Time

On the readiness for operation of a digital camera

Definitions and Abbreviations

Cold	State in which part performs no activity: it consumes no power and needs maximal time to start-up.
Hot	State in which part is fully active: it consumes maximal power and is ready for operation.
Warm	State in which part has reduced activity: it consumes some power to enable a faster start-up. E.g., processor runs with a reduced clock frequency, or OS is hibernated.

CPU	Central Processing Unit	OS	Operating System
GPS	Global Positioning System	RAM	Random Access Memory
GPU	Graphics Processing Unit	SoC	System on Chip
IMU	Inertial Measure Unit	UI	User Interface
ISP	Image Signal Processor		

1. Introduction

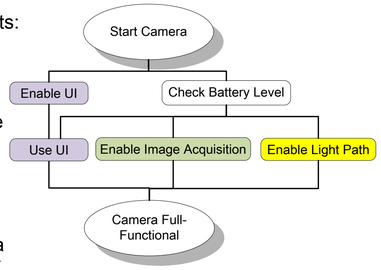
Users of a digital camera want to take high-quality photos of relevant events. The digital camera should thus be ready for operation during those events. This readiness has different aspects.

- Since many events happen on the road, a digital camera should be easy to carry around and robust against travelling conditions.
- To capture the moment a digital camera should be able to instantly take photos. Since a digital camera can be turned off, it should have a short start-up time.
- A digital camera might not be used for weeks. Due to consumption of power in stand-by mode, the battery can run flat and the digital camera is no longer ready to take photos. A digital camera should thus not only have a long stand-by time but also clearly communicate the battery level to the user to prevent unexpected flat batteries.

When taking a photo, the user of the digital camera might not want to interfere with the current event. For example, a user might want to take photos of children playing without distracting them from their current activities. For this purpose a high-quality zoom is needed.

2. Top-level Functional View

The digital camera contains four functional parts: battery management, user interface (UI), image acquisition, and light path.



The enabling of both the light path and image acquisition is conditional on the outcome of the battery level check. The elements in the light path and for image acquisition are thus protected against the battery running flat.

The enabling of the UI is executed in parallel with the battery level check. The digital camera thus always tries to start the UI independent of the battery level. The UI also uses the output of the battery level check: When the battery level is too low to start the digital camera an appropriate message, like please replace battery, will be shown on the display.

The reader should consult the Functional View on the other side for additional details.

3. The States of a Digital Camera

A part of a digital camera can be in a cold state, i.e., no activity, or in a hot state, i.e., fully active. Many parts of a digital camera can also be in a warm state, i.e., reduced activity. A digital camera thus seems to have millions of states: the product of the states of all its parts.

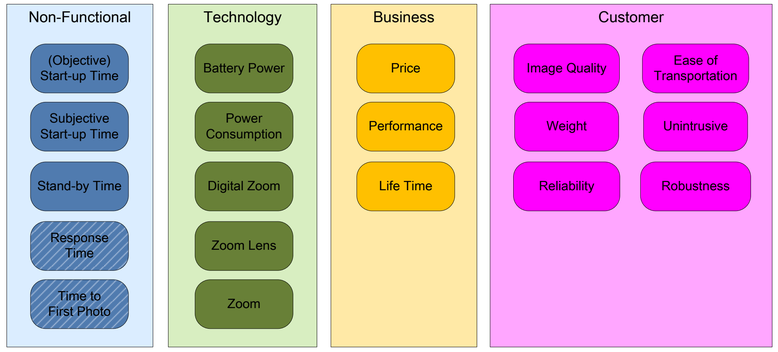
A part can only be in a state, when all parts it (physically) depends on are in the same or higher activity state. To give a few examples: software can not run when the OS is hibernated, and a CPU can not be in reduced clock cycle mode when the enclosing System on Chip is off. The dependencies of a digital camera are shown on the other side. These dependencies reduce the millions of theoretical states of a digital camera to a few hundred thousands valid states.

For the readiness for operation of a digital camera, only approximately ten states turned out to be relevant, since they have unique start-up and stand-by power consumption characteristics: A faster start-up can not be achieved without consuming more power, and less power can not be consumed without increasing the start-up time. These relevant states form a so called Pareto frontier [5] that is shown on the other side. Since illumination of the scene is not always needed and a flash light has both a long start-up time and a high stand-by power consumption, two Pareto frontiers are drawn: with and without flash light.

The digital camera's start-up and stand-by design must be simple to implement and change, since technological advancements will change the quantification of key parameters and thus the Pareto frontier. The final design uses only four states on the Pareto frontiers. The transition between states is based on the usage profile of a digital camera, in particular, on the chance of flash light usage and on the chance that the next picture will be taken, as shown on the other side.

Related System Concerns

When dealing with the readiness for operation of a digital camera, many other system concerns have to be taken into account as well. The relevant system concerns are visualized below. These concerns result in the Key Parameters & Requirements as describe in the next section.



Key Parameters & Requirements

(Objective) Start-up Time: Time needed to enable full-functionality. The user wants to take a photo of the current event even when the digital camera is turned off.

Subjective Start-up Time: Start-up Time as experienced by the user. The user does not want to wait unnecessarily. Progress bars and clearly observable start-up activities, like extending the lens and opening the lens cover, reduce the Subjective Start-up Time.

Stand-by Time: Maximal time after which a digital camera that is left unattended can still take a photo. The digital camera might be laying around for weeks, yet the user expects to pick it up and to take a photo.

Response Time: The time between pressing the shutter button and photo being taken.

Time to First Photo: The time needed to start-up the digital camera and to take one photo. Note that by interweaving start-up and photo taking the Time to First Photo can be less than the sum of the Start-up Time and the Response Time.

Battery Power: The more power a battery contains, the longer before the battery runs flat.

Power Consumption: The more power is consumed, the quicker the battery runs flat.

Digital Zoom: Changing the area shown in the photo by changing the reading out of the sensor and the processing of the sensor data.

Zoom Lens: Changing the area shown in the photo by changing the light path.

Zoom: Changing the area shown in the photo.

Cost: Expenses needed to realize the digital camera, including Bill-of-Material and development and manufacturing costs.

Performance: Behavior of the digital camera, ranging from Start-up Time to Ease of Transportation, and from Stand-by Time to Response Time.

Life Time: Period of time during which the digital camera can be used.

Image Quality: The lens and sensor are key to achieve high-quality photos. Therefore, when the digital camera is not used, the lens is always protected to prevent damage and thus to ensure high quality photos throughout the digital camera's Life Time. Furthermore, the sensor is only operated when sufficient power is available in the battery to prevent any possible damage due to usage outside specifications.

Ease of Transportation: The digital camera should be easy to carry and store, among others in a pocket or bag.

Weight: The digital camera should not be too light (to reduce vibrations and improve Image Quality) and not be too heavy (for Ease of Transportation). The battery's weight constitutes approximately 40% of the digital camera's weight.

Unintrusive: The user wants to take a photo without interfering and intruding in the scene. For this reason a high-quality zoom of at least 15x is needed. Currently, this can only be realized using an extendable zoom lens.

Reliability: Photos stored in the permanent storage can only be removed explicitly by the user. Photos should never get lost or damaged. Therefore, buttons are disabled when the digital camera is stored and the permanent storage is only accessed when sufficient power is available in the battery to prevent any possible damage due to usage outside specifications.

Robustness: The digital camera should be able to withstand travelling conditions, including dust, external forces, and extremes of weather conditions.

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Model Status: APPROVED (v4 Nov 2010)

Model ID: ESI 2.20.4.3.1

Reviewers: Pierre America, David Watts, Teade Punter

Commentators: Daniel Borches, Gerrit Muller, ESI Research Fellows

Design Strategies

- The digital camera gets power from a battery. The battery can run flat. A flat battery should not leave the digital camera in an inappropriate state, such as a partially covered lens that is sensitive to damage or a partially extended lens that makes the digital camera difficult to handle and store. Therefore, the battery is checked during start-up before initiating changes in state to ensure completion of those changes.
- When photos are taken in the dark illumination of the scene is needed. The digital camera is equipped with a flash light for this purpose. However, charging a flash light takes quite a lot of time, and a charged flash light leaks quite some power. In fact, without power, a flash light complete discharges in approximately two minutes. Since a flash light is not always needed, we have considered both cases: with and without flash light. This resulted in a stand-by strategy of the digital camera that depends on the usage of flash light in the last 15 minutes.

Roadmap

- Present:

A digital camera has multiple modes to ensure the desired overall readiness for operation. These modes handle the balance between start-up and stand-by time differently based on the current usage.

- Past:

Image acquisition using film barely used power. Power was only consumed to open the shutter to illuminate the film, to charge the flash light, and to display information in the viewer. As a consequence, customers are used to cameras with long stand-by time.

- Future:

Improvements in LEDs will make them suitable to illuminate the scene. Whether LEDs will replace or complement the flash light is not yet clear. Since flash light is dominant in the balance between start-up and stand-by time, a change in illuminating the scene will certainly cause changes in this architectural overview.

Improvements in image sensor and digital zoom will make high-quality digital zooming possible. These improvements enable a digital camera with a fixed instead of an extendable zoom lens. Without the extension of the lens, the start-up becomes less observable by the user. This change will thus negatively influence the subjective start-up time, making start-up time even more critical.

References

- Experts: Daniel Borches (P.D.Borches@ctw.utwente.nl),
Gerrit Muller (Gerrit.Muller@ESI.nl)

- Documents:

[1] A3 Architecture Overview Cookbook – Daniel Borches

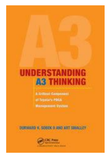
[2] ESI 2.20 System Architecting Course

- Other documents:

[3] Understanding A3 Thinking – A Critical Component of Toyota's PDCA Management System – D.K. Sobek II and A. Smalley

[4] http://a3thinking.com/

[5] Pareto efficiency, http://en.wikipedia.org/wiki/Pareto_efficiency



- Relation with other design principles:

Power from the battery is also consumed during normal operations.

- Relation with other models:

The model uses the parts as described in the "Realization of digital camera" model.

- Model hierarchy:

Child of "Times & Digital Cameras"