MRI Documentation

Final Draft

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Contents

1. Overview

In this document I will outline the requirements and components of an MRI in addition to showing its processes through diagrams. Before that I will also give a brief overview of the system in general and explain its workings.

MRI stands for “Magnetic resonance Imaging” and is used in the medical domain. Its purpose is to get pictures of the anatomy and the physiological processes of the body and is therefore a crucial system in the area of radiology. Parts of the scan-able areas of the body include:

- brain and spinal cord
- bones and joints
- breasts
- heart and blood vessels
- internal organs, such as the liver, womb or prostate gland [99]

Its main elements comprise of the gradient coil, the magnet and a computer, which is the main controlling unit of the system. Tasks like the image processing and the general adjustment of the system are being handled by it. All of these will be further elaborated upon in section 4.

2. Requirements

In this section the requirements for the system will be outlined.

2.1 Hardware Requirements (HR)

HR1: Create magnetic field
Description: System must create a magnetic field in order to scan the subject.
Relation: Magnet, Gradient Coils

HR2: Process images
Description: System must be able to convert received data into viewable data.
Relation: Image Processing

HR3: Display Images
Description: System must visualize viewable data.
Relation: Image Processing

HR4: Power
Description: System must create and maintain enough power for the system to run as designed.
Relation: MRI RF Power Amplifier Module

HR5: Movable bed
Description: System must be able to move bed for the patient.
Relation: MRI subsystem Module

HR6: Receive Data
Description: System must be able to receive data in order to convert them.
Relation: MRI Receive Module

HR7: Input
Description: System must have an input method like a keyboard and mouse.
Relation: Input Device

HR8: Storage
Description: System must storage data on a storage device.
Relation: Storage Device, Server

2.2 Functional Requirements (FR)

FR1: Redundancy
Description: The system must be equipped with two CPUs.
Rational: To ensure redundancy and have the system still be operational during a procedure even if one CPU fails.

FR2: Fail-safe
Description: The system must shut down properly in case of an emergency.
Rational: This has to be ensured due to the magnetic field put onto the patient. Meaning in case of a system failure, the system stop its power delivery to the magnet resulting in the magnetic field disappearing. This in turn results in the entire system to be fail-safe.

FR3: Efficiency

Description: The system must be energy efficient.

Rational: With the system consuming a lot energy it is imperative that the energy being used is managed effectively. This in turn also leads to the components being less in use prolonging their lifespan.

FR5: Reliable

Description: The system must be reliable.

Rational: This is an imperative requirement due to the system being in the medical domain, so reliability is of upmost concern. Otherwise the patient may experience unintended side-effects during the procedure.

2.3 Non-Functional Requirements (NFR)

NFR1: Accessibility

Description: The system shall be accessible for patients with disabilities.

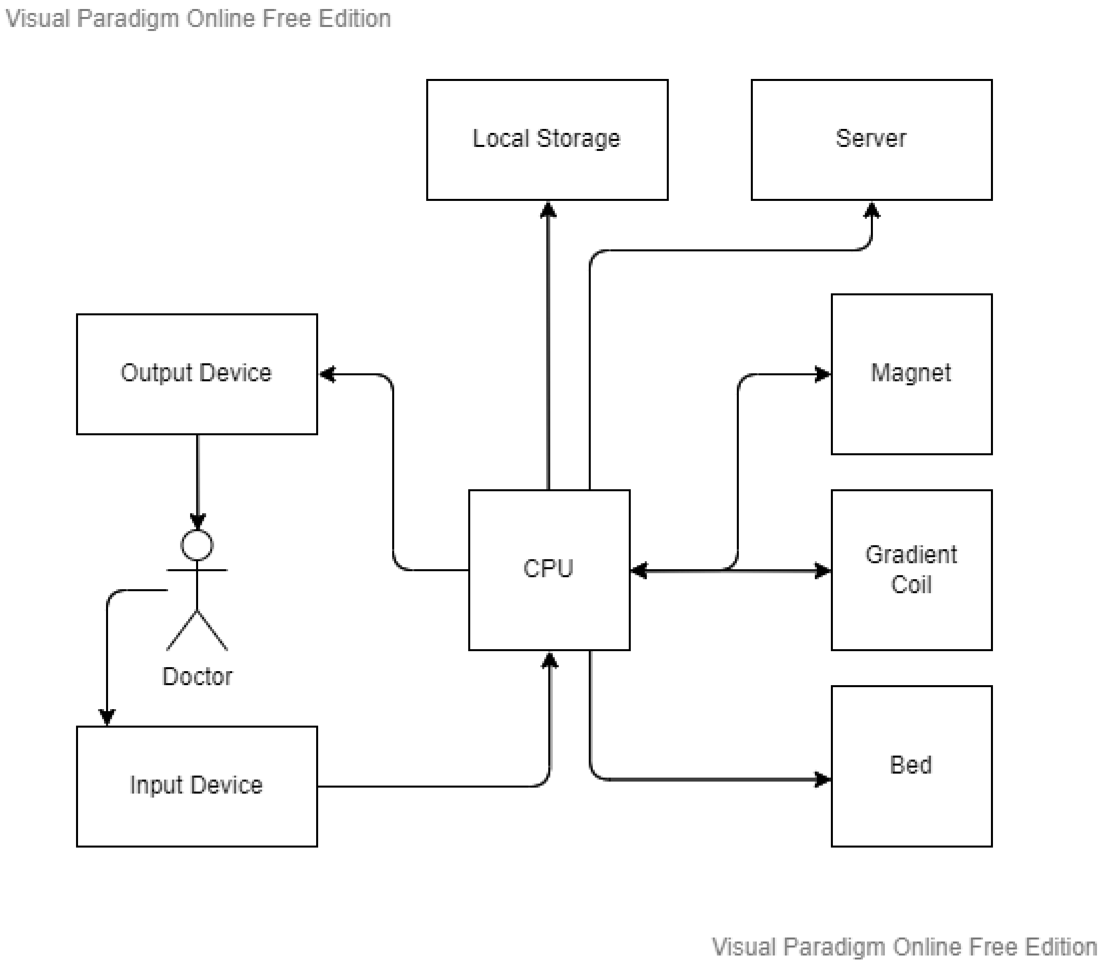
Rational: To ensure even people who are challenged by their mental or physical capabilities are still able to get good treatment.

NFR2: Comfort

Description: The patient should feel comfortable during the procedure.

Rational: This is to get patient comfortable with the machine, due to it being very load. In addition to that it can help with the accuracy of the scan since the patient is not distracted by the machine itself.

3. Architecture



It works in the following steps:

1. System idles
2. Patient lays down on the bed
3. Doctor moves the bed via the computer
4. Patient is moved into position
5. Doctor makes inputs into the system
6. Computer then converts those inputs to the machine
7. Scan begins
8. Data is being processed
9. Processed data is shown to doctor
10. Doctor communicates with patients
11. Scan stops
12. Bed is being moved to a new position
13. Scan resumes
14. Doctor and patient keep communicating
15. Repeats until scanning is complete
16. Doctor moves bed back to initial position
17. System is back to idling
18. Patient is able to get up from the bed
19. Patient leaves

4. Components

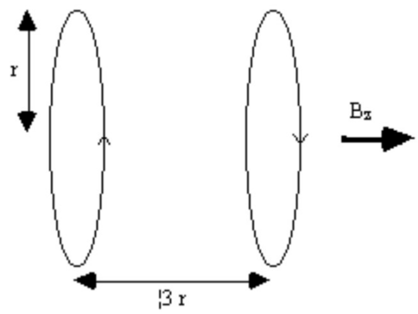
In this section the main components of an MRI system are being outlined and briefly discussed.

4.1 Magnet

The magnet is the most expensive part of the entire system. The current standard for magnets is to use ones which are superconductive. Reason being is that there a lot of applications for such magnets which makes them very desirable. Where before with water cooled resistive magnets the magnetic field was limited to around 0.3T (T = Tesla, the unit to measure magnetic fields), superconductive magnets can achieve up to 4.0T. This in the end allows a full body scan [77].

4.2 Gradient Coil

The gradient coil needs to accomplish two things. Firstly it needs to "produce a linear variation in field along one direction" [77] and secondly to have "high efficiency, low inductance and low resistance" [77]. This has to be done to minimize heat deposition and the requirements regarding currents.
When talking about gradient coil in terms of an MRI, a specific type of coil called "Maxwell coil" is being used. Their characteristics are that they consist of a pair of coils which are being separated by 1.73 times their radius. Current then flows through in the opposite sense in the two coils, which then generates the linear gradient [77].



Maxwell coils used to produce a linear field gradient in B_z along the z-axis [77]

4.3 Control and Processing

The control of the whole system is handled by a central computer, as well as the processing. It is able to specify the shape of the RF-waveform and the timings that are meant to be used during the scanning process. A possible part of the computer can be the

- AM2732 Dual-core Arm® Cortex-R5F based MCU with C66x DSP, ethernet and security up to 400 MHz [4][5]

by Texas instruments. It would be a viable choice due to its two integrated CPUs and rating for security applications [77].

4.4 Image Processing

Image Processing is one of the most elementary parts of the whole MRI-System, since without it a medical analysis is impossible. To do this effectively a number of components is required to make this possible. These are in no particular order:

- 12-Bit, 1.5Gsps High-Dynamic Performance DAC [6]
- High-Dynamic-Range, 16-Bit, 100Msps ADC with -82dBFS Noise Floor [7]
- Ultra-Low-Power, 8-Channel, 12-Bit, 64Msps ADC [8]
- Ultra-Low-Power, Octal, 12-Bit, 50Msps, 1.8V ADC with Serial LVDS Outputs [9]
- Ultra-Low-Power, 8-Channel, 12-Bit, 40Msps ADC [10]

4.5 Integrated Circuits

Integrated circuits also play a role in the design of an MRI-System. They are able to accomplish specific tasks which lead to better results in the scanning process. The three modules listed below combined accomplish optimized coil and gradient performance, which leads to enhanced diagnostic capabilities.
In addition to that, MRI-System often require “precise control of the magnetic and radio frequency field in the system”, “reduced scan time and improved form factor to enhance patient comfort” as well as “optimized power consumption and cloud connectivity” [1][2][3].
It also makes sense to choose those modules do to their shared technologies. They are each powered by their own power supply and possess input protection. Both things helping with the security of the entire system. Tasks like line protection, clocking or gradient control is covered by multiple modules, enabling redundancy. Below is a simplified list of the components of each module, with previously mentioned components not listed.

4.5.1 MRI RF Power Amplifier Module [1]

- Transmit signal chain
- Digital processing

4.5.2 MRI Receive Module [2]

- Receive signal chain
- Digital processing
- Receive line input

4.5.3 MRI subsystem Module [3]

- Diagnostics
- Gas sensor front-end
- Digital processing
- Transmit and receive signal chain
- Motor drive
- Drive MCU
- Current Sensing
- Analog or digital position sensing for motor
- Input user interface
- Wired interface
- Memory
- Clocking
- Output user interface

4.6 Storage Device

Storage plays a minor factor in the entire system, but is nonetheless important. This is because it serves as a place for the doctor to access the processed pictures from, but also a medium to save them on. In addition to that it plays a factor in building a permanent back-up that can be stored on the hospitals server. Lastly it is common practice to give the patient a CD with all the pictures included so it makes sense that a storage device of at least 20GB. It also makes sense to use an NVMe SSD or SSD over an HDD due to the speed difference. A possible solution could be:

- 850 EVO SATA III 2.5zoll SSD [11]

4.7 Server

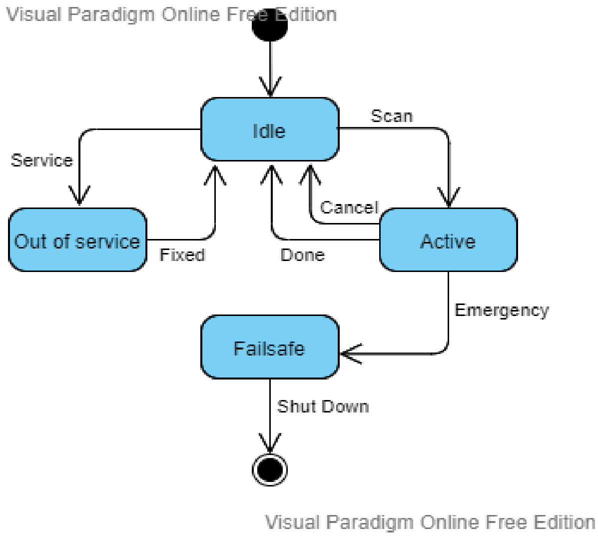
To back up and save data in the long term it makes sense that system is connected to a server. This way it can be ensured that data of multiple patients can be saved for multiple years and it is not required for the patient to bring their physical copy to each appointment after the scan.
It would therefore make sense to use a local server directly at the hospital. The main benefits being that it can be connected from the MRI-System through an intranet connection, which adds another layer of security, but also to the internet so medical personal can access it when they are not directly in the hospital themselves.
Alternatively the server space could be bought from service providers like AWS S3, but that might not be cost efficient in the long term. Pricing for an AWS S3 solution would look something like this:

- **Storage cost**: charged per GB / month. ~ $0.03 / GB / month, charged hourly
- **API cost for operation of files**: ~$0.005 / 10000 read requests, write requests are 10 times more expensive
- **Data transfer outside of AWS region**: ~$0.02 / GB to different AWS region, ~$0.06 / GB to the internet [12]

Overall a server adds another point of redundancy since the desired data is now available at two points.

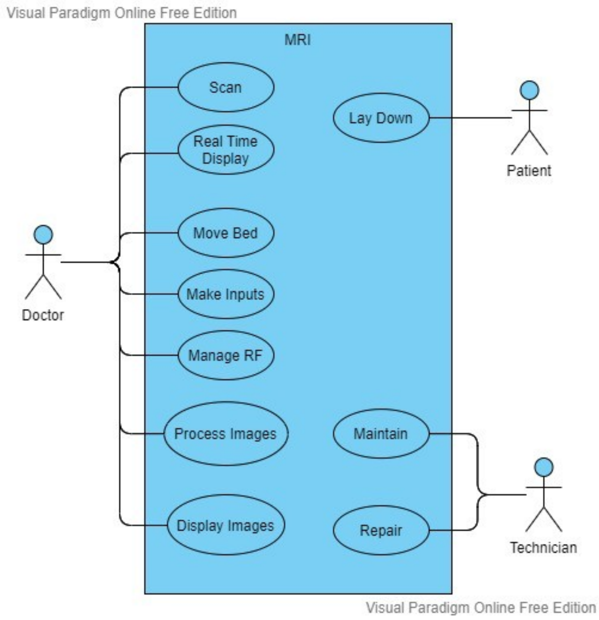
5. Models

5.1 State Machine Diagram



This diagram describes the different states the system can be in. Initially it is in the idle state and awaits inputs from the person operating the system. It then remain idle unless a scan is being performed, in which case it switches to the active state. This one can either be canceled or completed. Should an emergency occur, the system then moves into the fail-safe state and eventually shuts down. Both outcomes lead to the system resuming the idle state. The system can also be serviced in which case it moves to the out of service state and back to idle once it is fixed.

5.2 Use Case Diagram



For the Use-Case-Diagram we have 3 actors and 10 possible use-cases. The actors are the doctor, patient and technician.

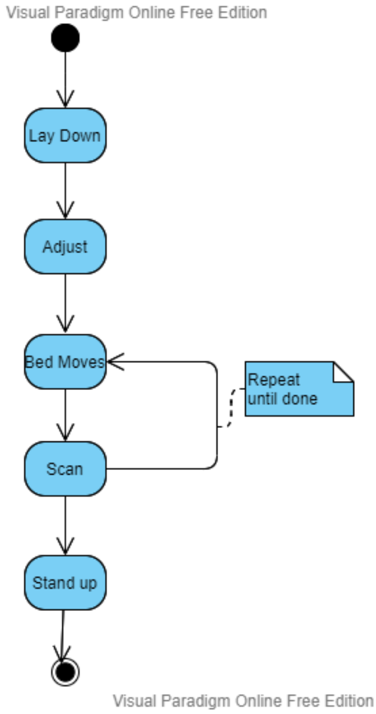
The patient only has to lay down as the more detailed procedure for them is described in the Activity-Diagram in 5.3.

The technicians use-cases describe the general maintenance and repair of the system. This is crucial to keep the system running flawlessly and ensure that in case of a failure that it is brought back to a state of operability.

The Doctor plays the most important part as they are the ones operating the system. Therefore they are able to control the system as a whole, which is represented in their ability to scan the patient or move the bed. Additionally they can view the scanned images in real time and control the images that are being displayed. Lastly they have control over the radio frequencies (RF) and can make other minor inputs. Another minor adjustment they can make is the way images may be processed.

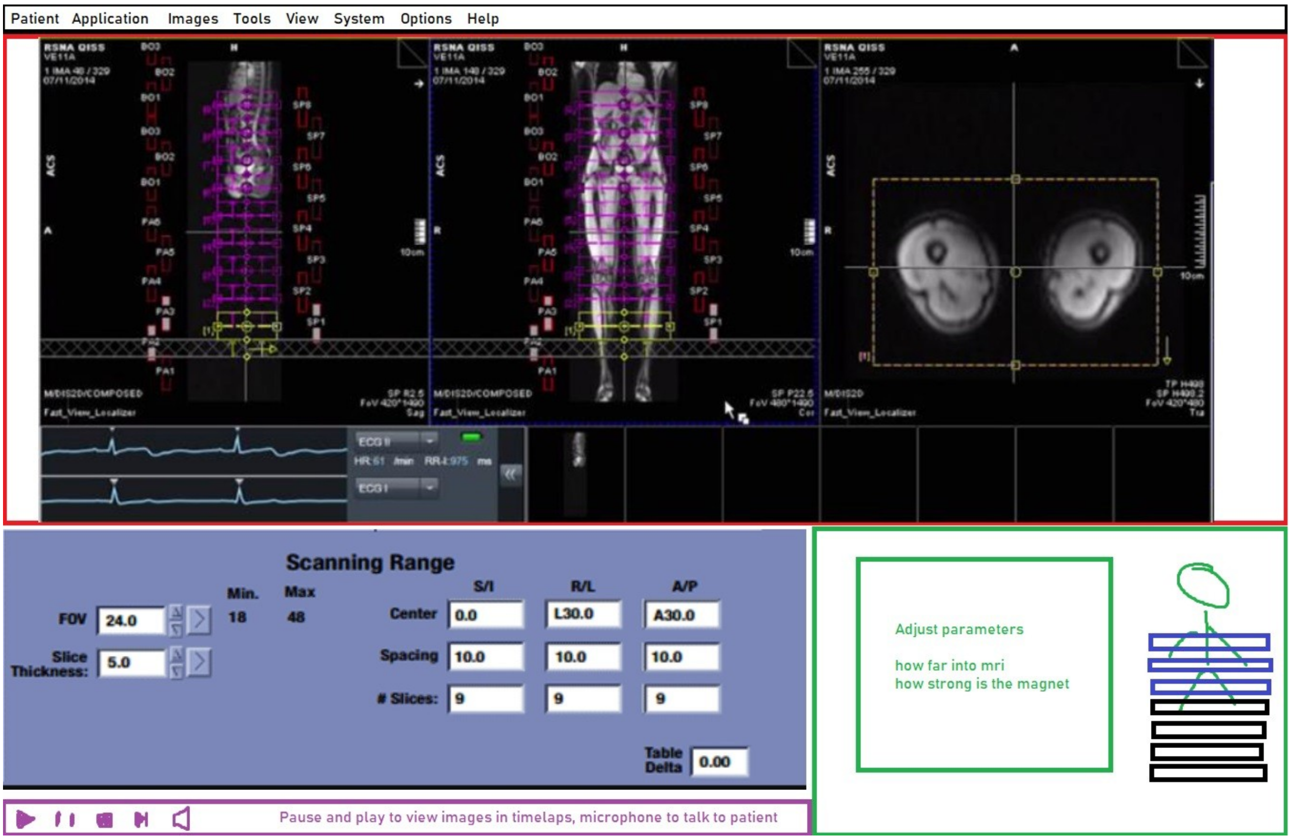
5.3 Activity Diagram Patient

Initially the patient lays down on the bed of the MRI and gets comfortable to begin the procedure. They can adjust themselves and have to keep their arms on their body. After that the bed begins to move and is brought into position for the scanning procedure to begin. A scan is then started and completed and a decision has to be made to either continue scanning or if the scanning is complete. Should more scans be necessary the bed moves to a new position and the scanning continues. If it is then decided that the scanning has finished the bed is moved back to its initial position and the patient is able to stand up and leave.



6. User Interface

A possible user interface could look something like this:



7. References

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