(Slide 1)

(Slide 2)

In this project, we focused on three main points. We first created an ideal MRI simulator so that we have an environment to investigate MRI related phenomena. After we ensured that our simulator is working, we added some non-ideal cases to the simulation so that we are able to understand some roadblocks in MRI in real life. We also consciously created artifacts to emphasize the properties related to image quality.

(Slide 3)

For data, we have used the Brain Web dataset for imaging subject, which is 3D array representing the human brain. The dataset has T1, T2, T2star, and PD values of each tissue. We also found a realistic inhomogeneous b0 field from the same dataset, and we used it while simulating an inhomogeneous magnetic field.

(Slide 4)

To simulate MRI, as it is done in real life, we started with selecting a slice of the brain by using RF pulses. The RF pulse which we have used is a rectangular pulse, which is impossible to recreate in real life. After selecting the target slice, we acquired the k-space data by using an algorithm similar to gradient echo. This step is essential allows us to compute the 2D Fourier transform of the effective spin density. Then we took the inverse 2D Fourier transform of the k-space to reconstruct MRI image.

(Slide 5)

To show the results of the simulation, we began by showing results for different contrasts. On the left the k-space of the effective spin density is shown and on the right the T1 contrast image of the effective spin density is shown. In this image, CSF is dark and white matter is brighter than the grey matter.

(Slide 6)

In this image, T2 contrast is used. In this one, CSF is bright and white matter is darker than the grey matter.

(Slide 7)

In this image, PD contrast is used. In this one CSF is bright and white matter is darker than the grey matter. Also we included proton densities in all of images which is also a non-ideality. The differences between these three pictures is that TE and TR scanning parameters are different.

(Slide 8)

In real life MRI experiments, due to the inhomogeneities in the magnetic field, theoretical T2 values do not fully represent the occurring transversal decay. It is modelled by T2star values. The difference between these two decays can be seen in this graph. In real life, the MRI signal decays faster.

(Slide 9)

The change in the contrast can be seen in this image. This is a T2 scan and the loss in contrast can be seen easily. With gradient echo sequence, it is not possible to eliminate this effect, however, it is possible to eliminate additional phases in spin echo sequences.

(Slide 10)

Using the realistic inhomogeneous magnetic fields that we found from the Brain Web dataset, we also simulated this non-ideality. As it can be seen from the image, same tissue types with different spatial locations look different in terms of brightness. We used PD contrast in this image.

(Slide 11)

Another important non-ideality in MRI is noise. In all electronic circuits there is an intrinsic noise called thermal noise. In MRI, the noise can appear both from receiver coils and the electrolytes in the human body. The variance of the noise affects the signal-to-noise ratio. During our simulations we modeled the noise with the additive white Gaussian noise model. On the left, T1 contrasted effective spin density can be seen without any noise. On the right, effective spin density with added noise is shown.

(Slide 12)

After acquiring the k-space and reconstructing the image, naturally the noise remains. The resolution of the image is not affected; however, its SNR is decreased.

(Slide 13)

To remove noise and increase SNR, we applied a low-pass filter to the k-space. As it can be seen on the right, the SNR is increased; however, the resulting resolution is inferior compared to the initial image. Simulating noise is a good way to demonstrate how resolution works in MRI.

(Slide 14)

To demonstrate the importance of acquiring k-space correctly without any major errors, we simulated the spike noise artifact. As it can be seen on the left, there is a bright little spot on the k-space, however, the reconstructed image is immensely affected by it. We used T2 contrast in this example.

(Slide 15)

To show the effects of FOV parameter, we implemented the wrap around artifact to our simulation. Whenever a FOV smaller than the subject’s size is selected without updating other parameters, this artifact occurs. The exceeding parts of the subject are encoded to the wrong location as a result of this. Exceeding parts on the left are encoded to the right-side of the image, and vice versa. We also used T2 contrast in this example.

(Slide 16)

For completeness of the simulation, we have also implemented viewing different slice locations other than the center, with varying slice thicknesses.

On the left, eye-level slice of the brain can be seen. On the right, a slice closer to the top of the skull can be seen. We used T1 contrast in this example.

(Slide 17)

On the left, slice with a thickness of 3mm can be seen, and on the right, slice with a thickness of 5mm can be seen. As slices get thicker, resolution worsens, however, thicker slices allow us to see more of the object in a single scan. We used T2 contrast in this example.