

Feature Tracking on CT & MRI scans

Rohith Krishna

May 23, 2021

1 Pulmonary Ventilation

The physiological process of inspiration and expiration of air in the lungs is called *pulmonary ventilation*, commonly called breathing. In ventilation the air is made available in the lungs for the purpose of exchange of oxygen and carbon dioxide. The multistep metabolic process that involves the exchange of gases is referred to as *respiration*. Thus, respiration and ventilation have a distinct difference.

The physical process facilitating ventilation is pressure differences between the atmosphere outside and the air within the lungs. We know that air, like other gases, moves from a region of high pressure to that of low pressure. Pulmonary ventilation is associated with three air pressures:

- Atmospheric Pressure - in the surroundings outside the body.
- Intraalveolar Pressure - pressure inside the alveoli of the lungs.
- Intrapleural Pressure - pressure within the pleural cavity.

Inspiration is the active phase of ventilation where air is taken into the lungs as a result of muscle contraction. During this process the diaphragm contracts and the volume of the thoracic cavity increases. This leads to a decrease in intraalveolar pressure, which results in air being drawn into the lungs. During expiration, the relaxation of the diaphragm lead to decrease in thoracic volume. This increases intraalveolar pressure which pushes air out of the lungs.

In this study we wish to track velocity of the parts of the lungs during the process of pulmonary ventilation. In order to do so, we consider images of MRI scans of the chest of an individual during full inspiration and full expiration, shown in Figure. Full inspiration is when lungs take in air at maximum capacity and full expiration is at the end of forceful exhalation.

The portion of the lung involved in gas transfer (alveoli, alveolar ducts and respiratory bronchioles) is referred to as *lung parenchyma*. These tissues have physical properties that are distinctly different from that of say brain or liver. ? identifies that for MRI of lungs, the important characteristics are low density and susceptibility differences between tissue and air.

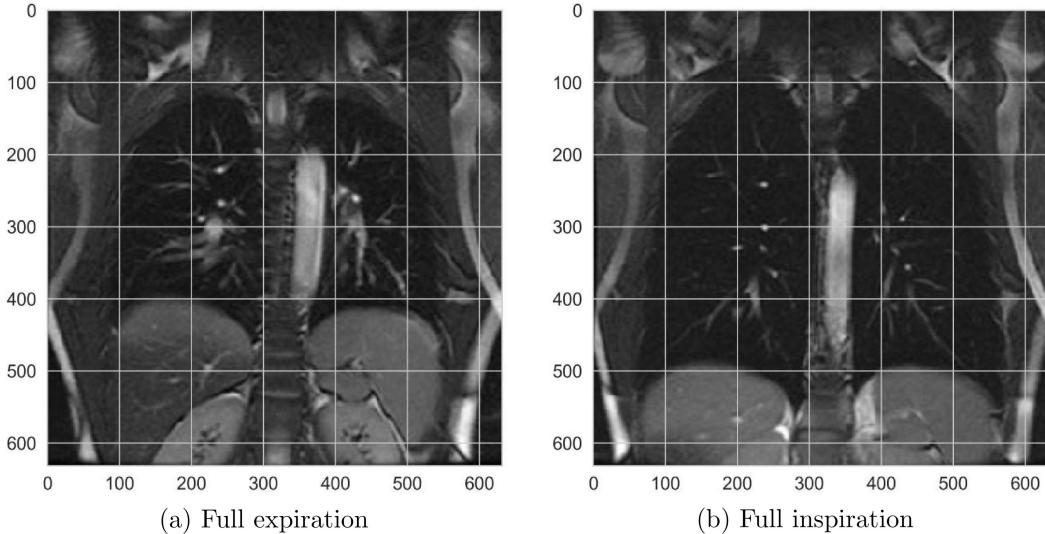


Figure 1: Pulmonary Ventilation components: full expiration and full inspiration at a 20 second duration interval is depicted in the MRI image.

The tissue density of a healthy lung is about $0.1g/cm^3$, which is about 10 times lower than that of other tissues. Since the magnetic resonance signal is directly proportional to the tissue proton density, the MR signal of lungs is 10 times weaker than the neighbouring issues. Further the bulk magnetic susceptibility difference between paramagnetic oxygen and diamagnetic tissues, leads to the creation of small local field gradients which leads to dephasing in gradient echo MRI. Owing to these two reasons the process of signals in a lung MRI are weak and the lungs appear darker than other regions.

It is precisely for this reason that we wish to test the Lucas-Kanade motion flow algorithm on such low signal lung MRI images. The ability to track features in lower intensity images is merit in favour of the tracking algorithm, which makes it applicable to several low-light image applications.

We note that in Figure 1, in the inspiration image, the lungs appear to be much darker than that in the expiration image. This is because, as ? notes, the state of inhalation of lungs play a vital role in determining signal intensity. Signal intensity is higher from the lung parenchyma during expiration. This is because during expiration, the relative density of protons in a voxel (a 3-D analog of pixel) of parenchyma

is increased and the bulk magnetic susceptibility difference between tissue and air is reduced as air is expelled. If one requires a high contrast between pulmonary vessels or alveoli and the background, then the darker image at full inspiration is preferable.

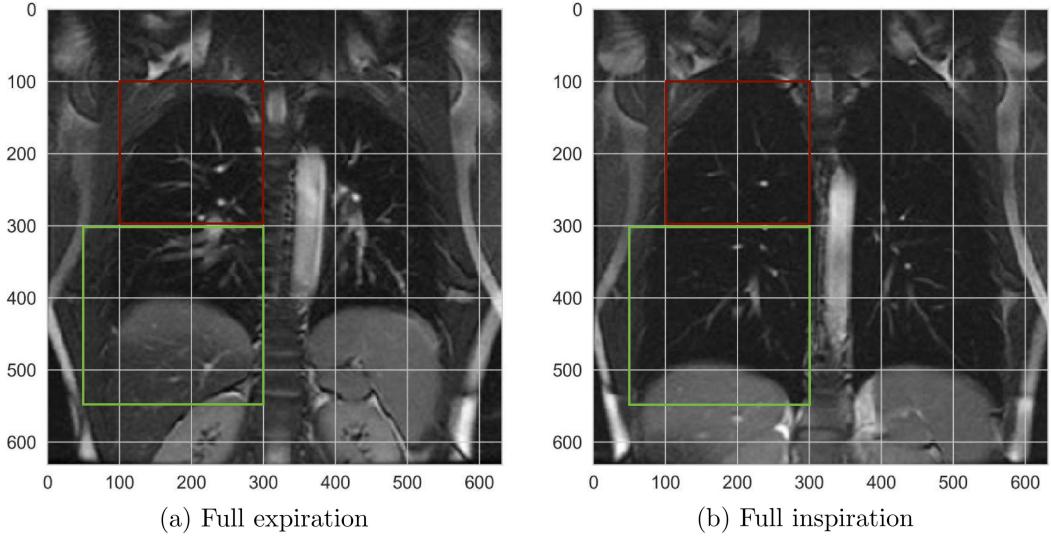


Figure 2: Windows tracked in the two steps of pulmonary ventilation is highlighted. The two windows are marked in red and green colors in both inspiration and expiration panels.

Figure 2 shows the two smaller windows used for tracking velocity. The red window (Window 1) is of dimensions 200×200 and green window (Window 2) is of dimensions 250×250 . In Window 1, bronchioles are visible, and the entire lung expands outwards. This is reflected in the velocity map where the outer wall of the lungs have finite velocities in the direction of expansion. Further the movement in the bronchioles is also tracked in the velocity map. In Window 2, a distinct feature is that the expansion on lungs pushes the liver below it by a certain amount. This motion is of extreme importance in medicine. For instance, in an ultrasound guided biopsy of the liver, the doctor in collecting a sample from the liver is careful against movements in the liver due to the movement of the lungs. Error in this regard could lead to potential puncture of the lungs. Therefore, an automated velocity tracking device could be of immense utility in such situations where the doctor can be made aware of such motions.

2 Brain Midline Shift

The Midline Shift is the shift of the brain past its centre line. Such a shift occurs due to intracranial pressure, which is the pressure exerted by fluids such as the

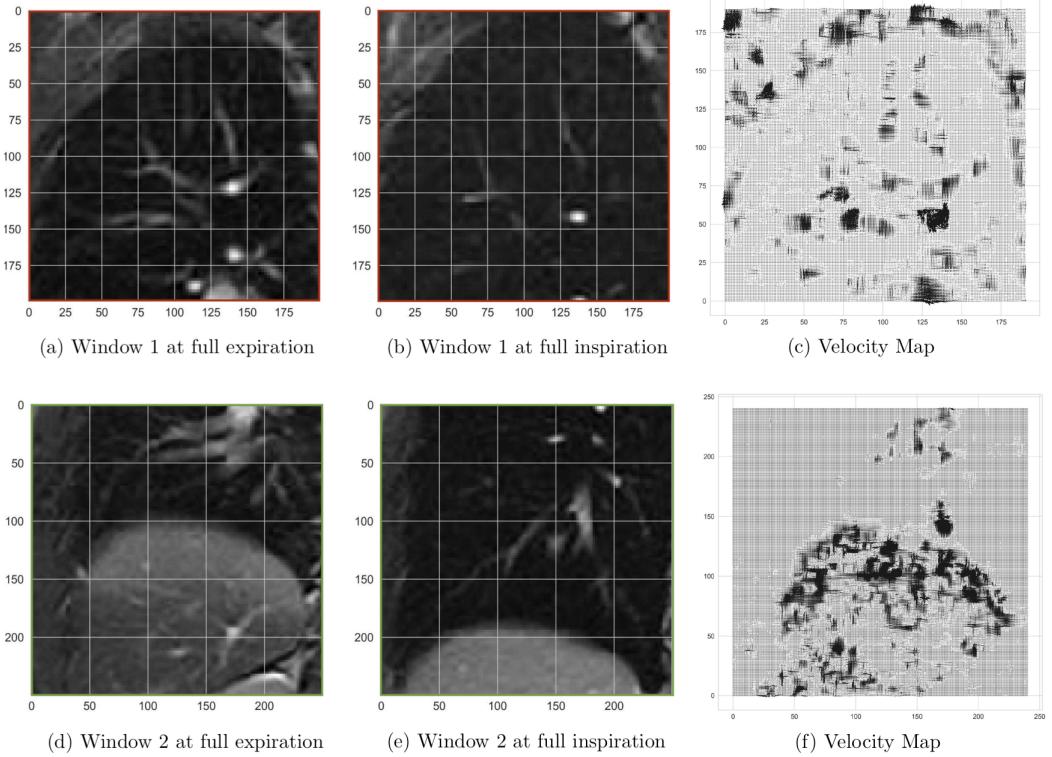


Figure 3: Velocity tracking using Lucas-Kanade optical flow method. The red window (1) and the green window (2) capture different parts of the lungs.

cerebrospinal fluid inside the skull on the brain tissues. Intracranial pressure is caused by conditions such as traumatic brain injury, stroke or subdural/epidural hematoma. Midline shift of more than 5mm requires immediate surgery and neglect can be fatal to the patient. Midline Shift is detected using Computed Tomography (CT) scan.

In this analysis we track the displacement and velocity of the midline shift in a patient using CT images taken at admission (less than 3 hours after traumatic brain injury) and 20 hours after admission (Figure 4). The images are sourced from the study by ? on lateral ventricle volume asymmetry during a midline shift. Lateral ventricles are the largest ventricles in the brain that contain the cerebrospinal fluid. In the images, we see that the right ventricle (shown in the left side) has been compressed and there is a midline shift towards the rightward direction of the image. The paper asserts that detection of midline shift often comes too late for patient, and suggests that detection of lateral ventricle volume asymmetry would be an early sign for developing intracranial pathology. Note that the right ventricle and left ventricle are located on the left and the right sides of the images respectively.

We apply both the Lucas-Kanade displacement and velocity tracking algorithms.

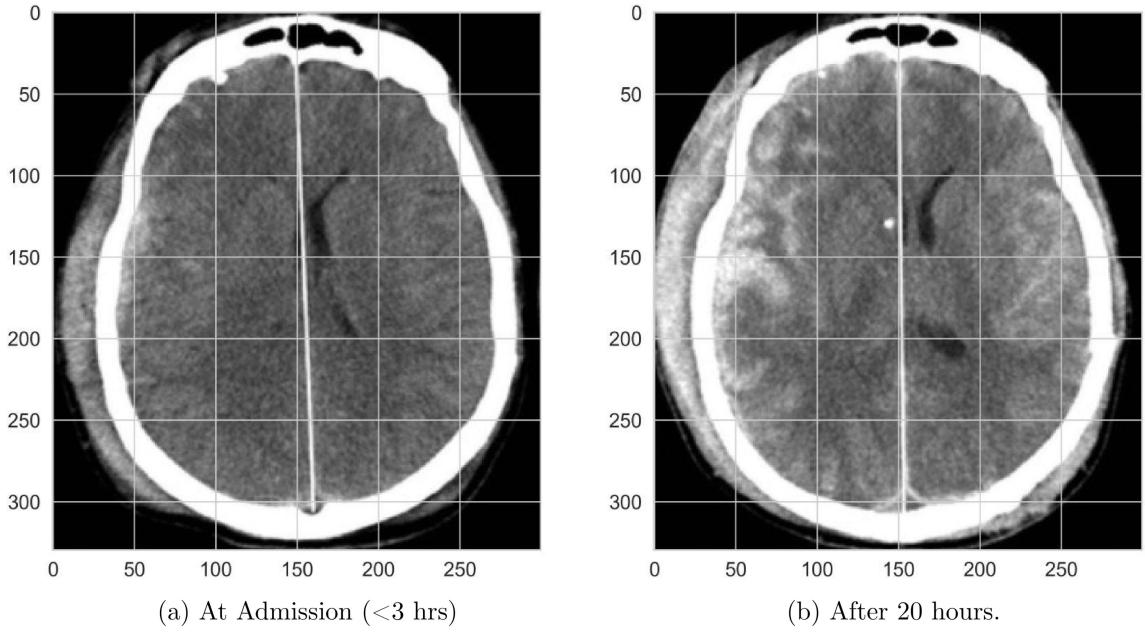


Figure 4: CT scan of a patient with Midline Shift due to traumatic brain injury taken at admission and after 20 hours.

We select 3 windows shown in Figure 5. An optimal window size of 10 is used both in the iterative bilinear interpolation step of the displacement tracking algorithm as well as in the formation of the Hessian matrix in the motion flow algorithm. The optimization to compute velocity and displacement are carried out and the results are shown in Figures 6, 7 and 8.

In Figure 6 the displacements of the left ventricle (on the right) is tracked. It shows a curved movement of regions in the ventricle with a small rightward drift. In contrast hardly any displacement is seen in the right ventricle that has been compressed by the bleed. In Figure 7 the velocities show motion activity on the left ventricle and in Figure 8 the gradual curvilinear motions of the bleed (depicted by white regions) is also tracked.

For the purpose of testing the algorithms, we also perform Lucas-Kande tracking on a set of 2 brain CT images - one of a normal brain and the other of a brain with a hemorrhage, causing a deformed midline shift, and is shown in Figure 9. The image is taken from the study by ? where a new method for tracing a deformed midline shift is developed. In Figure 10 the results of tracking is displayed in the form of displacement and velocity maps.

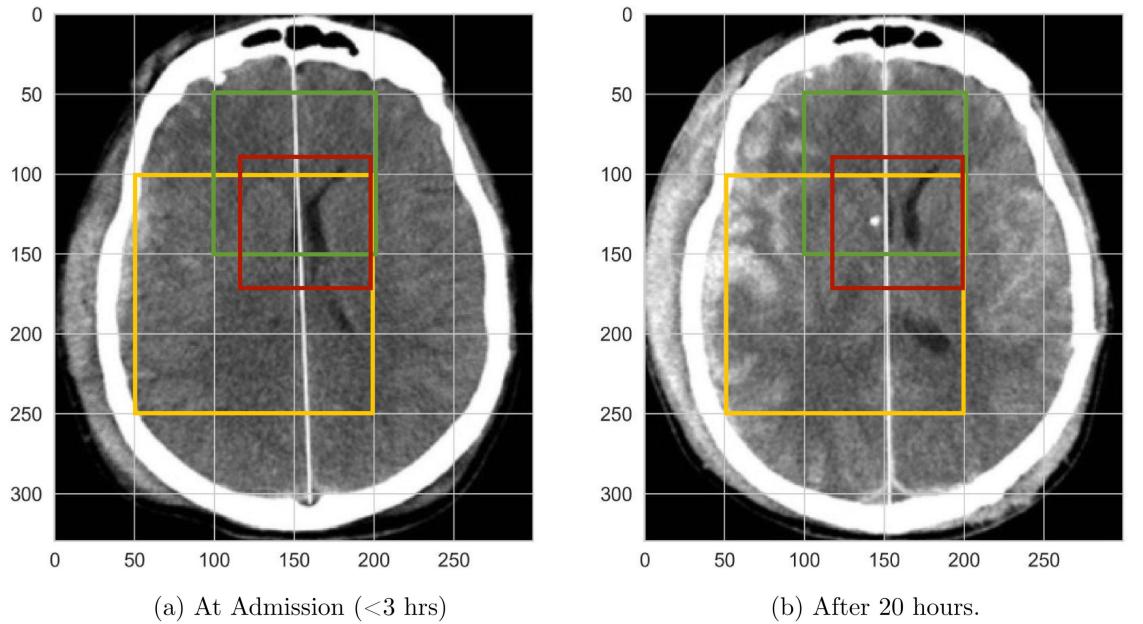


Figure 5: CT scan of a patient with Midline Shift due to traumatic brain injury taken at admission and after 20 hours. 3 windows are analyzed and are marked in red, green and yellow in corresponding images. The white line marked in the centre is midline. In tracking methods vectors due to shift in this line could be ignored.

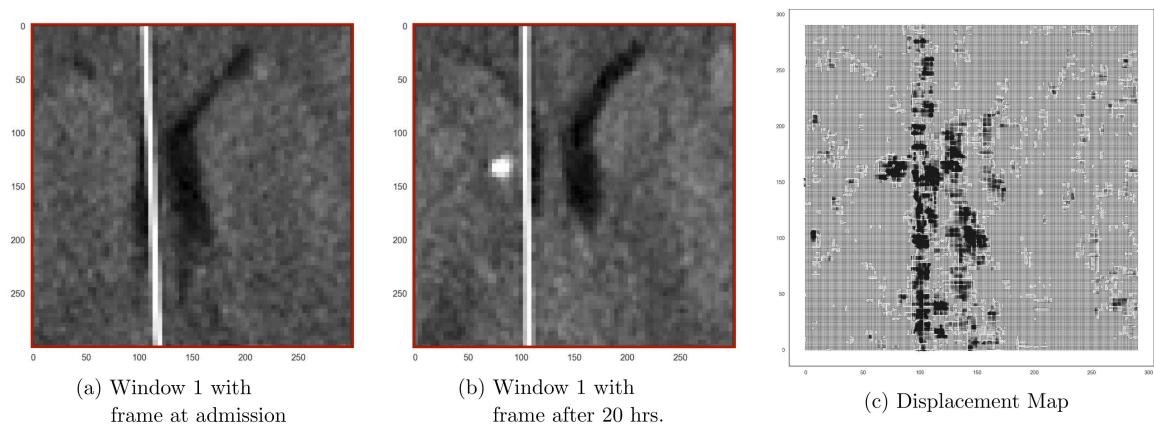


Figure 6: Lucas-Kanade Displacement tracking of the Midline Shift. The vertical line of represents the midline and its tracking may be ignored in the results.

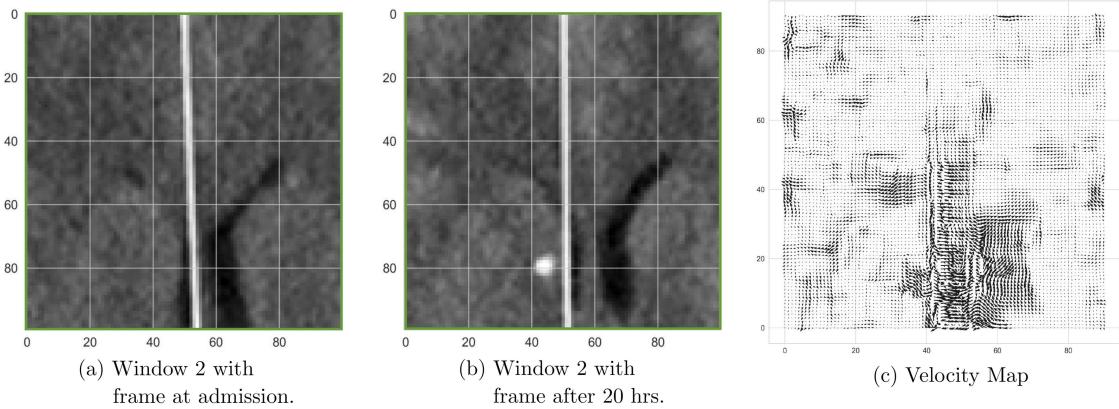


Figure 7: Lucas-Kanade Optical Flow results in velocity of the Midline Shift. Curvilinear motion within the left ventricle is observed, with slight rightward drifts.

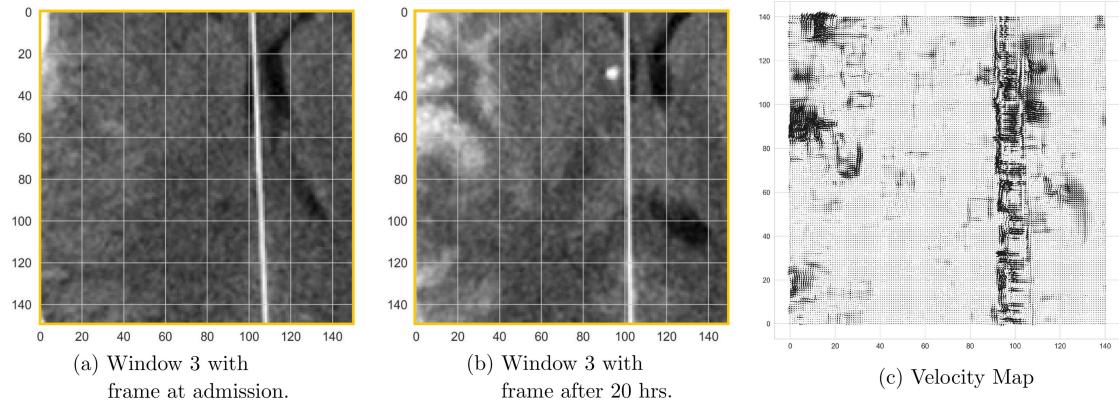


Figure 8: Lucas-Kanade Optical Flow results in velocity of the Midline Shift. The motion of bleed in the top right corner is also tracked.

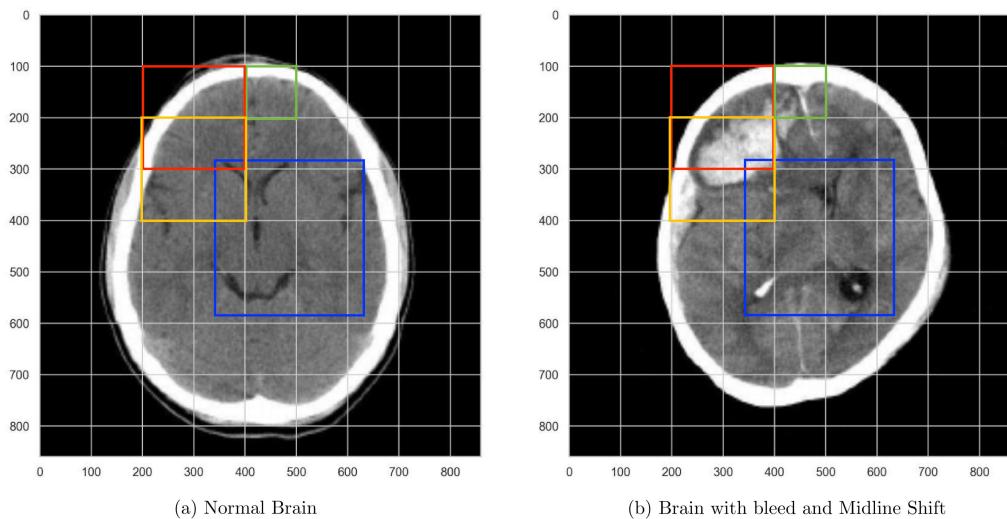


Figure 9: Normal Brain and a brain with Midline Shift (MDS) due to hemorrhage. Windows representing areas of interest for tracking is also shown.

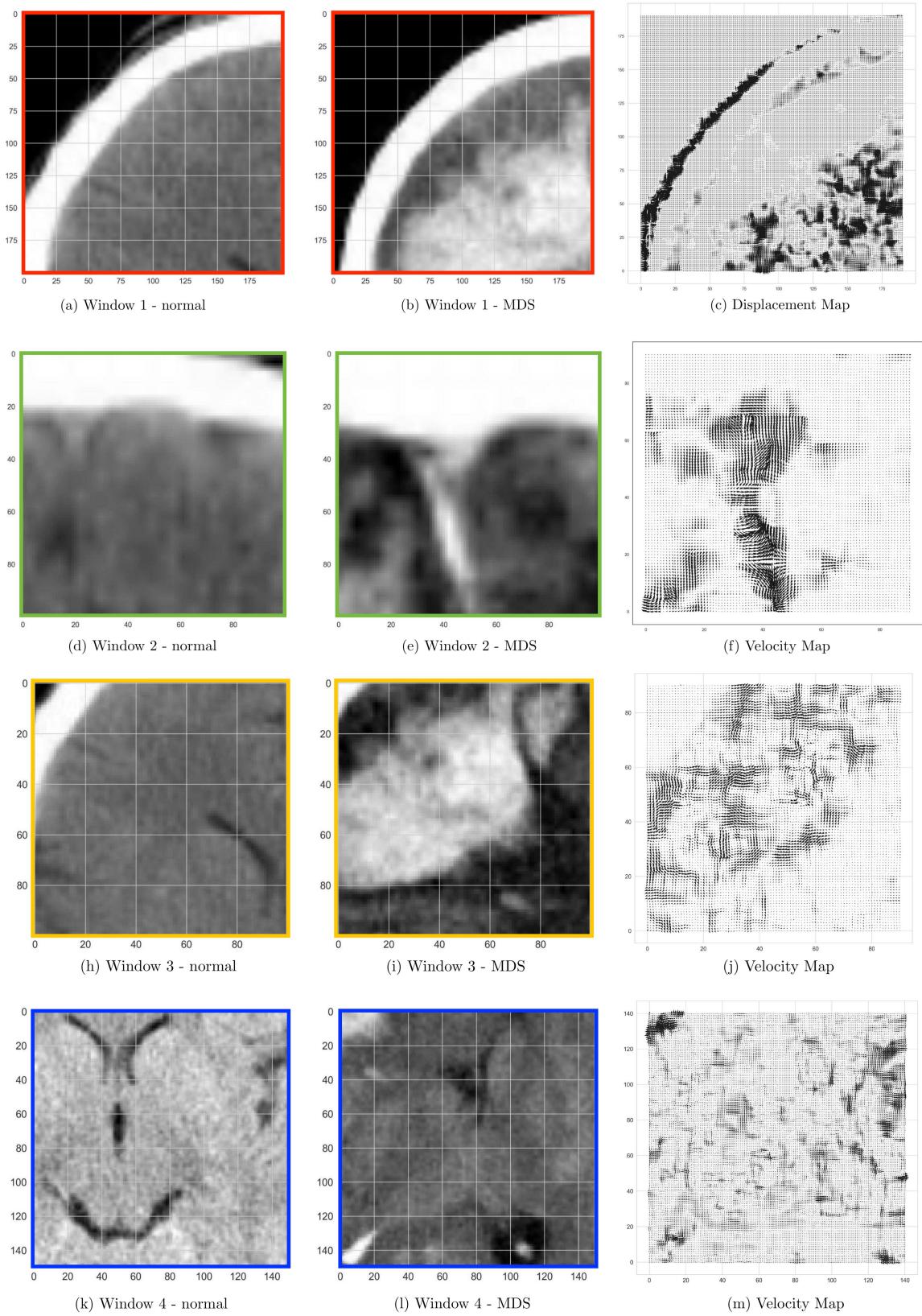


Figure 10: Lucas-Kanade Displacement and Velocity tracking method for different regions.