Adjusting CT Scans to Account for Respiratory Motion

Benjamin Wilk

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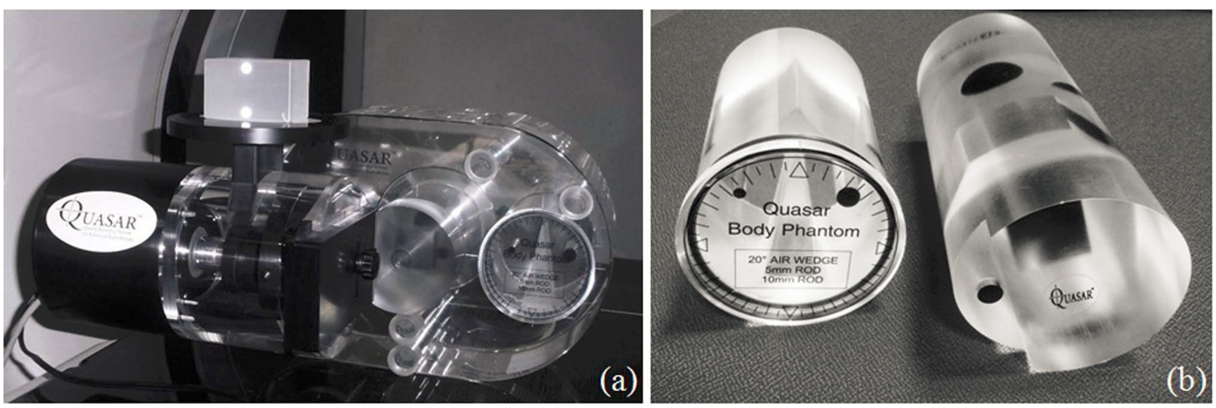

Figure 1: This figure shows the respiratory phantom used in this research.

Summary:
The purpose of this research was to examine and evaluate the impact of breathing motion on CT images

in order to provide a basis for future work in eliminating the image artefacts produced by the patient's breathing motion. To analyse this, both motion synchronised 4DCT and non-synchronised 3DCT were used.

On March seventh, medical physics researchers Ruth Romero-Rodríguez and Pablo Castro-Tejero from Madrid, Spain, published the paper "*The influence of respiratory motion on computed tomography (CT) image volume definition*". Since breathing motion can alter properties such as size, shape and density of a patient's anatomy, it is important to further analyse this motion and its effect on computed tomography. The purpose of the paper was to use breathing synchronised and unsynchronised CT scans to evaluate these alterations. As it stands, there are no ways to adjust the image to account for breathing motion. Of course, the first step to doing this is to figure out how the breathing affects the image and how methods can minimise this effect. In this paper, the effect and synchronisation methods were analysed.

Computed tomography is a type of scan where x-rays are passed through the patient from multiple directions in one plane and detected on the opposite side. This is then repeated for more slices or in a helical pattern. From the detected, a three dimensional image of the patient can be constructed. These CT scans can also be synchronised with the breathing motion using 4DCT which also shows motion over time. In this case, the scan will be taken so that the scan starts with the breathing cycle. On the other hand, 3DCT is not synchronised with the patients breathing motion.

In this research both 3DCT and 4DCT were used to take scans of a respiratory motion phantom with a movable insert. A phantom is a device that designed to evaluate the performance of imaging techniques. The inserts are moved in predetermined sinusoidal patterns to simulate the chest movement. The CT scanner is equipped with a camera which is able to detect infrared markers on the phantom which show the breathing motion. Like this, it is possible to synchronise with the "breathing". When 3DCT was used, since both the motion and geometry of the system are known, coupling between the motion and the scan can still be determined.

To test the techniques mentioned above, they were first used with a static system. A good correlation was found between the manufacturer's data and the results of the CT scan for the maximum and minimum volume. This shows that the techniques are feasible for applications. It was also found that the rotation period of the CT scan did not affect the volume segmentation, meaning that there was little statistical noise. When including breathing motion, using 4DCT the results were expectedly accurate with only small deviation of about 2%.

More problematic is to acquire accurate scans using 3DCT since it is not synchronised with the breathing leading to more artefacts. In this case, the volume discrepancies are larger than in the 4DCT. In fact, the discrepancies are close to 10%. It was also found that the distortion was increased for larger objects. The slowest acquisition speeds have been found to lead to the largest discrepancies, meaning that the period of the CT should be increased to have less distortion. However, most CT scanners have a maximum scanning period.

Lastly, it was found that the acquisition time of the CT scan should be at least twice as long as the breathing cycle. It has been shown previously however, that slow scans with a period of around four seconds lead to severe motion artefacts in the image.

All in all, it has been found that 4DCT takes breathing motion into account quite well while imaging without 4DCT can lead to motion artefacts. Other than that, it was shown that discrepancies arise from longer breathing cycles as well as longer scanning periods. However, the CT scan should be at least twice as long as the breathing motion. These trends and this data can be used in the future to create programs to adjust the image to account for breathing motion.

Interview:

How accurate is a sinusoidal respiratory pattern to the actual one and is there any pattern that could be more accurate?

Typical breath patterns have an asymmetrical wave that differs from a sinusoidal motion, but each patient has his own breath pattern. In our preliminary experience, we have observed different respiratory cycles from sawtooth waves to almost sinusoidal waves. The phantom used can also produce a standard breath pattern and even import actual breath patterns from the patient, but we choose a sinusoidal cycle in order to simplify the mathematical simulation for CT acquisitions without respiratory synchronization. As we point out in the article, further studies based on more realistic breath patterns would be desirable but we think that the results we have presented may be extrapolated to patients. The temporal accuracy of 4DCT acquisitions depends on the motion pattern since it determines the speed of the object, and we have analyzed a speed range comparable to real breath patterns.

Does the 4DCT take into account changes in the patients' breathing pattern during the scan?

In prospective CT acquisitions, the scanner used acquires when the RPM system detects the specified position of reflective markers. If the breathing amplitude varies preventing achieve the predefined position for each cycle, the acquisition will be interrupted waiting to detect the correct position of reflective markers. In retrospective CT acquisitions, the system does not reconstruct slices associated with phases that differ from the initial breath pattern registered. Thus, changes in breathing pattern during a retrospective scan can involve loss of information. So both 4DCT techniques take into account changes in the breath pattern somehow. The prospective mode avoids anomalous acquisitions, whereas the retrospective mode discards anomalous acquisitions.

Is there anything that could be done to increase the accuracy further?

It can be used a slice thickness and spacing lower than 2 mm to improve the spatial resolution of CT images (particularly for small objects). But the temporal accuracy depends on the 4DCT technique implemented by the manufacturer.

Has this method been applied to patients?

Although 4DCT is available in our facility, it is not possible to carry out such CT acquisitions for all patients affected by respiratory motion: either because the patients breathing is not stable enough, or due to incompatibility with diaphragmatic compression technique that hinders respiratory monitoring. In those cases, three fast helical scans are acquired: inhalation and exhalation breath-hold CTs (to estimate roughly the ITV), and a free-breathing CT (for treatment planning purposes). As we emphasize in the article, the slow CT approach is not possible using our CT scanner since it cannot achieve slice acquisition times that double usual breath periods (maximum slice acquisition time of 3 s versus breath periods from 2 to 6 s).