ContinuousLy Adaptive Windowing Strategy (CLAWS) for Real Time Reduction of Motion Artefacts

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Aim

Navigator acceptance imaging methods are invariably compromised when the breathing pattern of a subject changes during the scan. Techniques such as Phase ordering with Automatic Window Selection (PAWS) (Jhooti et al, MRM 2000) have attempted to overcome such problems by the use of automatic sampling strategies which make no assumptions as to the final acceptance window. As all possible windows are treated with equal importance the techniques was shown to be effective in situations of changes of respiration whilst also allowing scans to terminate in an optimal time. However, as this technique is focussing on its final optimal image, no image is available until this has been acquired. The Diminishing Variance Algorithm DVA (Sachs et al. 1995) attempted to provide an image as soon as possible and then to continually improve this image until a particular range of motion was achieved or the scan quality was deemed to be satisfactory. However, as this technique made a decision as to which range of motion would be accepted and further acquisitions were made accordingly, the technique was unsuitable in situations of respiratory change. A technique is therefore required which takes the benefits of automatic techniques, which seek to keep open options regarding the final acceptance window, allows images to be reconstructed as early as possible so no scan must be terminated without resulting in an image, and, most importantly has the element of “human thinking” in their decision making. That is, whatever the algorithm may automatically choose to do based on its sampling strategy, decisions will be made exactly as the operator would choose to do given the data acquired so far. The proposed technique, ContinuousLy Adaptive Windowing Strategy, attempts to draw on the experience gained from techniques such as PAWS and DVA whilst incorporating adaptive decision making as the scan progresses which is more appropriate for each acquisition.

Method

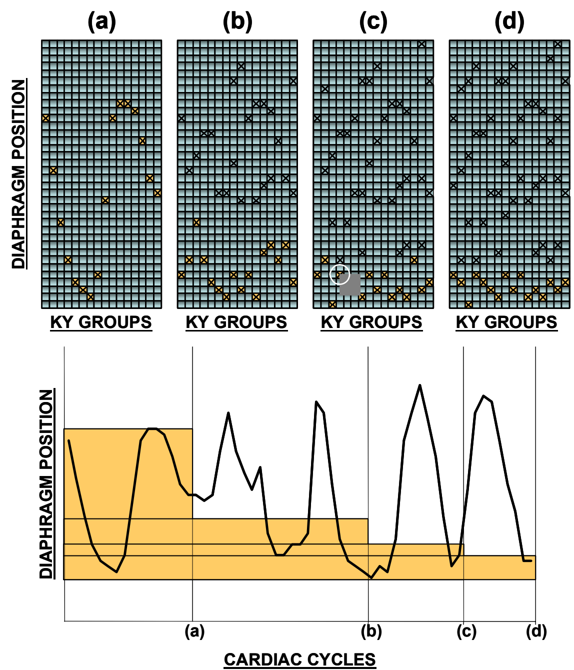
The ContinuousLy Adaptive Windowing Strategy (CLAWS) attempts to mimic the same question/answer strategy that an operator would go through during a scan when it makes a decision on what is to be acquired next. Data acquisition is visualised as a grid depicting each ky group to be acquired along with all the possible diaphragm positions (dpos) it may be acquired at (Fig. 1a). The decision process is as follows:

[1] If there is a ky group which is yet to be acquired, acquire it as, in the first instance, we would like to ensure the most rapid coverage of k-space. In our example we have simply acquired the first free ky group although this may be altered.

[2] Find the ky group whose closet dpos is furthest away from the current dpos. If the distance is less than the desired acceptance window we move to step 3. Otherwise, this is the next ky group to be acquired. If more than one such ky group exists then the following must be taken into consideration: the number of acquisitions already made of this ky group and the average distance of each acquisition from the current dpos.

[3] If the closest dpos for each ky group is less than the size of the acceptance window several other factors must be taken into consideration as it is in this situation that incorrect decisions may be made. Two acquisitions which are made by the same ky group in a region which may ultimately be the final acceptance window will lead to a less than optimal scan time. Therefore, the following factors need to be taken into consideration at this stage: How many acquisitions have been made already by each ky group?; What is the average distance from these previous acquisitions to the current dpos?; Has an acquisition already been made in what is currently the most frequent window?; What is the distance from the most frequent window to the closest acquisition for each ky group? As the scan progresses, therefore, the most important factors change depending on the current situation. It may be that a ky group is acquired which has already been acquired next to the current dpos but, whilst all the other ky groups have been acquired further away, they have all been acquired in the most frequent window whilst this one has not.

Four stages of acquisition are shown in Figure 1: (a) After all the ky groups have been acquired once; (b) Mid acquisition; (c) At a stage where the current dpos is within the acceptance range of all other acquisition for each ky group. (d) Termination of scan once all ky groups have been acquired in the required range of positions. The crosses depict ky group/dpos pairings which have been acquired whilst the orange crosses illustrate the ky group acquisitions which can be used to reconstruct what is deemed to be the best image so far.



A situation where the ky group with the dpos furthest away from the current dpos is not the most appropriate ky group to acquire is demonstrated in (c). In this situation the ky group with the dpos furthest from the current dpos is no. 3 but as all the dpos are within the acceptance range the other factors must be taken into consideration. Ky groups no 2 and 4 are the only ky groups which have not been acquired within the most frequent window and, as ky group no. 2 has been acquired more times than no. 4, ky group no. 4 is acquired in this instance (shown by a circle).

The priorities associated to these different factors may be changed and the decision made above is one example of how decisions may be made in such a situation.

Results/Discussion

The final CLAWS image had an average percentage difference of less than 0.5% and a standard deviation less than 1.75 for all window sizes (3mm, 5mm, 7mm) when comparing the final scan time to the optimal scan time possible. The comparable result for PAWS was 0.6% (stdev 0.76), 5.8% (stdev 6.5) and 9.7% (stdev 8.1) for the corresponding window sizes). PAWS is less efficient with larger window sizes due the grouping of diaphragm positions the algorithm requires whereas CLAWS is even more robust with larger window sizes. CLAWS also allows an image to be acquired after x cardiac cycles where x is the number of ky groups which must be acquired.

Conclusion

The CLAWS technique allows images to be constructed much sooner than PAWS whilst providing a very robust method of achieving the most optimal scan time for the given window size required. The operator may also terminate early in the knowledge that the best image possible at this time will be available. In all tests the CLAWS technique was found to be much more robust than PAWS and is appropriate for any imaging situation in which data acquisition is to be limited by motion. The technique is also equally effective for all window sizes, a flaw in the PAWS technique.