Ultrasound visualization and analysis using WASL

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Background: Once data collection is finished, ultrasound recordings of speech articulation must be visualized and analyzed. A number of integrated software packages have been developed for this purpose, from general purpose biomedical image software such as ImageJ (Rueden *et al*., 2017) to speech-specific software such as UltraPraat (Archangeli *et al*., 2013), GetContours (Tiede, 2020), and Articulate Assistant Advanced (AAA; Articulate Instruments Ltd). The open-source WASL application is speech-specific, MATLAB-based software that was originally developed to handle 3D/4D ultrasound data (Lulich *et al*., 2018). The installation file for the most recent release of WASL is available at https://spliu.sitehost.iu.edu/software/software.html.

Programmability: WASL is programmable in two ways. First, several of its most important functions can be accessed from the MATLAB command line, which enables batch processing of data spread across multiple files. Second, the architecture of WASL is designed to encourage rapid development of independent, customized modules (i.e. plugins) for specialized tasks. This will be demonstrated by developing a new plugin, live during the presentation. The new plugin will enable WASL to load 2D ultrasound images or videos in a variety of file formats (e.g. JPG, MP4). A useless but simple plugin is standardly provided with WASL, and documents the process of developing new plugins.

Audio integration: Time-domain signals such as audio are standardly handled within a specific WASL plugin (although alternative, customized plugins can be developed). Real-time playback and export of ultrasound videos with synchronous audio is supported, using a combination of WASL-specific functions and the 3rd party open-source MATLAB tool *mmwrite* (Richert, 2010). Simple speech signal processing options are also supported, including spectrum and spectrogram visualization, and a rudimentary formant estimator. Future plans for development include integration of advanced speech signal processing and labeling tools, perhaps using *mPraat* (Bořil & Skarnitzl, 2016).

Visualization: Three-dimensional ultrasound data places special interpretive demands on users, which are more familiar in the context of MRI data, but with the added challenge that ultrasound data are noisier than MRI data and lack helpful anatomical landmarks such as the hard palate or vertebral column. Practical navigation of 3D/4D ultrasound data using WASL will be demonstrated during the presentation. For comparison, navigation of 3D MRI data will also be demonstrated.

Analysis: There are a number of ways to analyze ultrasound data. WASL (v 10.1) integrates options for 1) making simple distance measures, 2) highlighting edges using MATLAB's Canny edge detection algorithm, and 3) segmenting the tongue surface manually, semi-automatically (using the Canny edge detector), and fully automatically (using the 3D SLURP algorithm; Naga Karthik *et al*., 2020). WASL also standardly integrates the ability to view and analyze image kymograms (such as those familiar from M-mode ultrasound recordings). Additional analysis (and visualization) capabilities are available through the MATLAB command line. Figure 1 shows the WASL graphical user interface with a partially analyzed 3D/4D ultrasound file.

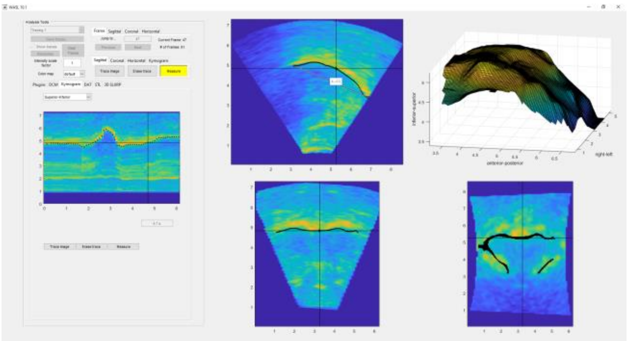

Figure 1: *Screen shot of WASL showing manually segmented kymogram (left), simple distance measurement (top middle), and an automatically segmented tongue surface (top right).*

Limitations: WASL has several important limitations. First, it is not a stand-alone software package, and requires users to have a current version of MATLAB installed, along with the Signal Processing and Image Processing toolboxes. (Additional toolboxes may be required for specific plugins.) Second, WASL's architecture and current plugins do not make optimally efficient use of computer memory. Third, although WASL is fairly stable, there are still some known bugs, and user documentation is still underdeveloped. WASL is not currently able to read 3D/4D ultrasound recordings made with systems other than Philips, and it is not capable of reading Philips xPlane ultrasound recordings. Finally, WASL does not currently allow users to view oblique slices through the ultrasound image volume.

Conclusion: Although WASL was originally developed to handle 3D/4D ultrasound data, its programmable architecture, integrated handling of audio and other time-domain signals, and integrated visualization and analysis capabilities hold promise for current use and future development.

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