NON-METALLIC ULTRASOUND PROBE HOLDER FOR CO-COLLECTION AND CO-REGISTRATION WITH EMA

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ABSTRACT

Co-collection and co-registration of ultrasound images of the tongue and articulometry data requires the stabilization of the ultrasound probe relative to the head using a non-metallic system. Audio, ultrasound, and articulometry data were recorded from 11 North American English speakers reading 10 blocks of 25 sentences, speaking for 2 minutes at a time, spanning a recording time of 45 minutes. The 95% confidence interval for ultrasound probe roll relative to head motion was 1.35°, and 2.12 mm for lateral displacement, such that ultrasound probe displacement is within acceptable rotational and translational parameters as described in the HOCUS paper [9]. The proper use of this probe holder could also allow for adequate ultrasound probe stabilization without external marker tracking for post-processing correction, making this probe holder suitable for field research.

Keywords: Articulatory Phonetics, Phonetics Methods, Ultrasound, Articulometry, Field Methods

1. INTRODUCTION

Ultrasound imaging of the tongue is suitable for tracking the shape and displacement of the tongue surface [3], but cannot track the position of flesh points. Articulometry allows the tracking of individual flesh points, but does not record the overall shape of the tongue surface. This limitation is particularly problematic when trying to identify retroflexion or other complex motions. Collecting both types of data at the same time would resolve many of the complementary limitations.

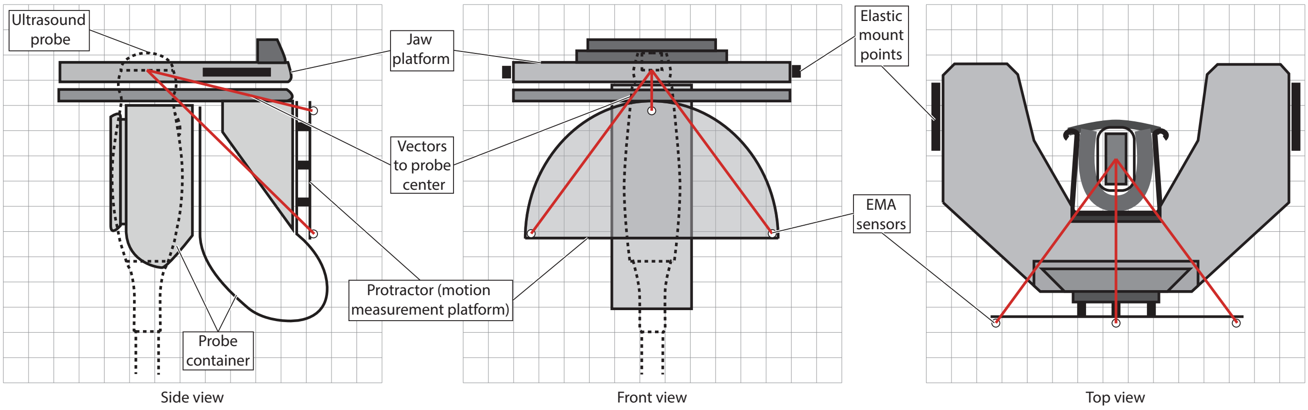
In order to co-collect and co-register 2D midsagittal ultrasound and electromagnetic articulometry (EMA) data, it is necessary to simultaneously stabilize the ultrasound probe along the midsagittal plane enough to avoid serious deviations in measurement data, and to do so in such a way that metal does not interfere with accurate articulometry data collection. Carefully stabilizing an ultrasound probe relative to the head is not especially important for research into tongue shape, but it is important for other types of measurements, such as tongue height displacement [3]. Such a probe-holder system should also be stable enough to allow ultrasound recording without using a secondary system to correct for head motion, e.g. for fieldwork.

Fortunately, due to Whalen et al.'s work [9] on the Haskins Optically Corrected Ultrasound System (HOCUS), it has already been determined how much an ultrasound probe can deviate in displacement and rotation from the midsagittal plane and still provide reasonably accurate representations of the midsagittal plane that merely deviate in predictable ways. Acceptable lateral motion is 2-4 mm, and roll and yaw of less than 5-7° are acceptable [9].

While excellent techniques exist for direct high-stability holding of an ultrasound probe under the chin [5], none can ensure the precision of measurement during co-collection with EMA, and all introduce substantial risk of pulling on EMA sensor wires. The ideal mechanical stabilization system must avoid placement of metal objects into the electromagnetic articulometry field because metal interferes with the accurate tracking of sensor motion within the electromagnetic field. This need for a non-metallic solution precludes using an ophthalmic/dental chair head-rest [2], rigid-frame [6], or spring-arm mounted [9] solution, all of which have solid metal components. The need for extra comfort for participants, and reduced clutter, during co-collection procedures precludes using a board or wall head-rest solution [1]. All of this lead us to create a non-metallic head-mounted device that allowed stabilization of an ultrasound probe under the chin.

It is fortunate that today we have access not only to elastic materials but also to low-temperature thermoplastics, commonly used in splints. The use of such materials makes it reasonably easy to construct a non-metallic probe holder with the flexibility needed to make it comfortable and durable enough for field work, and without metal to interfere with electromagnetic measurement tools.

Figure 1: Non-metallic ultrasound probe holder schematics in side, front, and and top view. True to scale: 1 cm grid.



So an ideal solution would use a head-mounted system to affix the ultrasound probe to a participant's head. But two choices remained: Whether to make a non-metallic rigid ultrasound probe holder analogous to the Scobbie, et al. rigid-frame head-probe stabilisation unit [4], which does not readily move with the jaw, or an elastic head mounting system that is designed to float under the jaw and therefore allow freer jaw movement. We opted for allowing free jaw motion because it is much more comfortable, permits more natural-like test conditions, works better for people with large or small heads, and is more likely to be usable with children in the future.

The system consists of a padded jaw-rest with the ultrasound probe mounted underneath and within a semi-rigid probe holder. The jaw-rest has two mount points for a cloth elastic system that wraps around the top and back of the head. The elastic itself has adjustment points to allow comfortable yet snug adjustment for each participant. The jaw padding is replaceable to allow for customization based on head size. The system allows the use of different ultrasound probe shapes and sizes while greatly restricting the motion of the probe in relation to the jaw-rest. A protractor was mounted to the front of the system allowing the placement of three articulometry sensors for probe motion tracking, as seen in Figure 1.

The non-metallic probe holder, described here and shown in Figure 1, when adjusted tightly enough to remain in stable position under the chin, should provide stabilization of the probe relative to the chin such that 95% of all data points collected in an experiment will not deviate more than 4 mm in displacement in any direction after head position correction - especially laterally, or more than 7° in rotation in any direction, especially roll, which are the acceptable limits according to [9].

2. METHODS

Data for this evaluation of the new probe-holder for co-collection and co-registration of ultrasound and EMA was gathered in an experiment on flap/tap production at different speech rates. The whole experiment collected 30 minutes of speech from participants reading sentences off a computer screen, collected over 45 minutes, providing sufficient data for analysis of the motion of the ultrasound probe relative to the head. The 11 experiment participants spoke North American English. Eleven people, (9 females and 2 males) were recorded. They were 20-50 (8 under 26) years old, and they all reporting normal hearing, with no difficulty understanding TV shows at normal volume and little or no difficulty understanding conversation in large crowds.

2.1. Equipment and setup

A GE 8C-RS ultrasound probe was connected to a GE Logiq-E (version 11) portable ultrasound machine. The ultrasound was connected to an Epiphan VGA2USB Pro frame grabber plugged into a USB port for a MacBook Pro late 2013 model with 2.6 quad core i7 and 16 GB of RAM. The ultrasound was set 6 mHz, B/M mode, and a 90° angle, with visual image settings to the fastest possible speed, allowing a frame rate at a minimum of 150 Hz and higher depending on tongue depth. A Sennheiser MKH 416 microphone was plugged into a Sound

Devices LLC USB Pre 2, which was itself plugged into the other USB port of the MacBook Pro.

The 8C-RS ultrasound probe was mounted into the non-metallic ultrasound probe holder as shown in Figure 1. The probe holder was strapped onto the head of each participant with an elastic band attached to the mount points highlighted on Figure 1. The elastic band wrapped above and behind the head, holding the jaw mount under the jaw, and allowing the ultrasound probe to rest on the floor of the underside of the jaw and in proximity to the skin covering the suprasternal notch of the larynx, which aligns the probe along the mid-sagittal plane. Ultrasound probe gel was applied to the probe head to improve ultrasound image quality, and the elastic was adjusted to allow maximum comfort and stability.

Participants were seated in a chair with their head positioned next to the NDI Wave EMA field projector. The MKH 416 microphone was mounted on a Manfrotto 244 variable grip arm and placed to the side of the mouth, 5-10 cm away from the speaker and outside the range of the EMA field projector.

NDI wave sensors were previously attached to the ultrasound probe holder on a protractor firmly taped to the surface. The sensors were placed at the midpoint, bottom left and bottom right edges of the protractor at the precise points indicated in Figure 1.

NDI wave sensors were also taped to the participant's nasion, left mastoid, and right mastoid, and glued to the midsagittal line of the tongue tip, tongue dorsum as far back as comfortable for the participant, and mid-way on the tongue blade. Sensors were also glued to the gum just under the inner lower left incisor, and the midsagittal line of the upper and lower lip next to the vermillion border.

2.2. Procedure

At the beginning and end of each block, participants were asked to say 'tatatatata' before and after each take in order to record rapid transients in both the audio signal and downward motion of the tongue tip for hand-alignment of ultrasound data if required.

For this experiment, speakers were presented with auditory reiterant speech at rates ranging from 1.5 to 3.5 feet/second (3-7 syllables/second), and then asked to read sentences at the same speech rate, containing one of eight phrases as seen in Table 1, presented in randomized order on a computer screen 1 meter away from their seated position. Each block took about 175 seconds to read, and 10 blocks of data were collected, representing about 30 minutes of data over about 45 minutes of experiment time.

EMA data was collected on the NDI Wave system on a PC computer. Ultrasound data was collected on the MacBook Pro described above using FFMPEG, running an X.264 encoder. Video data was captured at 60 Hz, with only a few easily-identified frames dropped during each 3-minute recording block, representing less than 1% of the data.

Table 1: Experiment phrases

Phrase
We may edit a book
We may audit a book
We have editor books
We have auditor books
We have bettered a book
We have Saturday books
We have herded her books
We have worded her books

Afterwards, palate data was collected by recording ultrasound of the tongue while water was being swallowed, and by having the speaker use the NDI Wave palate probe to trace along the midsagittal plane of the hard palate to the back of the upper incisors. The occlusal plane of each participant was then recorded by having them hold a protractor in their mouth to calibrate head position using 3 EMA sensors taped to each corner of the protractor.

2.3. Analysis

The triangle of the occlusal protractor was translated and rotated onto an ideal projection, and so used to calculate a head rotation matrix via the nasion/mastoid triangle. This matrix then was used to transform the positions of all the sensors to an ideal head position, confirmed visually in MVIEW [7, 8].

In order to compare the angle of the probe with respect to the head rotation angle, three sensors were placed on the ultrasound probe, and we carefully measured their distance relative to the probe centre, as seen in the red lines in Figure 1. Because they were further from the center of rotation of the head, the measurement points were displaced considerably more than the ultrasound probe center. Therefore, its rotation matrix was used to rotate and move the ideal probe centre to the actual location of the probe relative to head position. The X (sagittal), Y (coronal), and Z (transverse) displacements of the probe center was thereby obtained for each NDI wave recording sample in the experiment. The rotation matrix was also used to obtain the pitch, yaw, and roll for each sample.

All the data recorded in the experiment was used, including that for participant 4, who we noticed gently nudged the probe holder a couple of times during the experiment.

3. RESULTS

Presented are the rotations and translations of ultrasound probe motion relative to head position.

3.1. 3 minute block results

For each block, translational and rotational standard deviations were calculated. The results for all 10 blocks were then averaged and are shown in Table 2. The averages for all 11 participants, along with the 95% variance interval (1.98 x SD), are shown at the bottom. Results show no more than 2.28°of rotations and 3.03 mm displacement, well within the aim of achieving ≤ 5-7°and 4 mm displacement.

Table 2: SD of rotation and translation within each 3 minute block.

Sub.	angle (degrees)			displacement (mm)		
	roll	pitch	yaw	X	Y	Z
1	0.38	0.99	0.45	1.45	0.82	1.17
2	0.22	1.00	0.40	0.99	0.54	1.30
3	0.54	1.25	0.57	1.67	1.01	2.53
4	0.61	1.63	0.48	1.87	1.55	2.00
5	0.49	1.49	0.40	1.54	1.01	1.36
6	0.41	0.85	0.36	1.07	0.84	1.14
7	0.37	1.15	0.38	1.43	0.73	1.60
8	0.33	1.08	0.40	1.76	0.68	1.35
9	0.33	1.03	0.34	1.41	0.82	1.99
10	0.32	0.77	0.30	0.98	0.63	0.79
11	0.50	1.33	0.45	1.13	0.96	1.60
Mean	0.41	1.15	0.41	1.39	0.87	1.53
95%	0.81	2.28	0.81	2.75	1.72	3.03

3.2. 45 minute experiment results

Translational and rotational standard deviations for all of the data in the experiment were calculated for each subject, as seen in Table 3. The average for all 11 participants, along with the 95% variance interval, are shown at the bottom of the table. Results show no more than 2.95°of rotations and 3.39 mm displacement, well within the aim of achieving ≤ 5-7°and 4 mm displacement. Results show low levels of long-term slippage that add only 0.56 mm X, 0.4 mm Y, and 0.36 mm Z to the 95% variance.

Table 3: SD of rotation and translation across all 10 blocks (45 minutes).

Sub.	angle (degrees)			displacement (mm)		
	roll	pitch	yaw	X	Y	Z
1	0.47	1.53	0.71	1.81	0.94	1.18
2	0.42	1.06	0.60	1.02	0.65	1.40
3	1.01	1.32	1.10	1.64	1.24	2.62
4	0.64	2.72	1.26	2.94	1.70	2.41
5	0.70	1.53	0.44	1.53	1.11	1.36
6	0.51	0.90	0.46	1.20	0.96	1.15
7	0.52	1.11	0.41	1.46	0.77	1.67
8	0.82	1.15	0.76	1.74	1.07	1.41
9	0.40	1.35	0.53	1.61	0.86	2.12
10	0.49	1.43	0.60	1.90	0.73	0.92
11	0.91	2.28	0.58	1.52	1.75	2.60
Mean	0.63	1.49	0.68	1.67	1.07	1.71
95%	1.25	2.95	1.35	3.31	2.12	3.39

4. DISCUSSION

The results show that use of this non-metallic ultrasound probe holder reduces motion of the ultrasound probe relative to the head to well below the thresholds identified in the HOCUS experiments [9]. It is worth noting that the most important motions to avoid are roll rotations and Y (coronal) translations. These are the motions that are most likely to result in measurement of tongue surfaces off the midsagittal plane, which would result in the most highly inaccurate analysis. Focusing there, the 95% variance of 1.35°roll, and 2.12 mm of lateral displacement is comfortably within the limits of the HOCUS results for rotation, and at the lower limits for acceptable translation. Comparing our measures to those used for the Scobbie et al.[4] metal frame system is difficult due to different assessment techniques, but we appear to have more short-term motion variability and less long-term slippage. Nevertheless, because translation is at the limits of acceptable performance, it is important to make sure that the probe holder is comfortable for the participant yet snug enough before beginning the experiment. If the probe holder slips or the participant tugs at it with more than gentle force, comparison of results between blocks will become more difficult due to higher variability, or at worst impossible.

Because the probe holder's elastic head connection is made of flexible materials, it allows the jaw to move somewhat freely during speech. This causes the pitch rotation and coronal displacement to be higher than it might otherwise be. These motions were greater than the lateral motions of that are of greatest concern, and it may be possible to factor out some of that motion by closely analyzing the acoustic correlates of jaw opening and closing during speech with changes in the ultrasound probe position, a topic we are currently pursuing.

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