Advancing Sensorless Freehand 3D Ultrasound Reconstruction with a Novel Coupling Pad: Supplementary Materials

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1 9-line extraction

After obtaining a volume of dimensions $H \times W \times D$. We extract slices along the volume's D direction at each step d, obtaining slices on the $H \times W$ plane. For each slice image, we apply k-means clustering to determine the centers of each cluster, denoted as $centers_{xy}$. Subsequently, we identify the coordinates of the brightest points surrounding each center, represented by $brightest_{xy}$. These two-dimensional coordinates are concatenated with d and multiplied by the volume resolution r to obtain 3D coordinates $r \cdot brightest_{xyz}$.Utilizing this algorithm, a point cloud $\mathcal{S}_{lines}$ is generated.

Algorithm 1 9-line extraction

Input: *image*
$\mathcal{S}_{lines} \leftarrow$ Empty point cloud
for d from 1 to D **do**
  $image \leftarrow volume[:, :, d]$
  $(x, y) \leftarrow X, Y$ coordinates where $image(y, x)$ intensities $> intensity\_threshold$
  $centers_y \leftarrow$Cluster (x, y) into 3 groups using K-means on Y
  for each center c_y in $centers_y$ **do**
    $(x, y) \leftarrow$ Filter (x, y) where $c_y - \delta < y < c_y + \delta$
    $centers_{xy} \leftarrow$Cluster (x, y) into 3 groups using K-means on X, Y
    for each center c_{xy} in $centers_{xy}$ **do**
      $brightest_{xy} \leftarrow$ the brightest point coordinate within a δ offset around c_{xy}
      $brightest_{xyz} \leftarrow$ Concatenate $brightest_{xy}$ and d
      Append $(r \cdot brightest_{xyz})$ to $\mathcal{S}_{lines}$
    end for
  end for
end for
Return $\mathcal{S}_{lines}$

2 The Composition of the Coupling Pad

The coupling pad is composed mainly of deionized water and other ingredients: sodium alginate polymer 1.0% to 6.0%, carrageenan 1.0% to 5.0%, xanthan gum 0.03% to 0.05%, hydroxypropyl cellulose 0.1% to 0.8%, propylene glycol 2.0% to 15%, glycerin 2.0% to 15%, preservative 0.01% to 0.12%.

3 Detailed Measurement data on a Solid Phantom

Table 1. Solid phantom measurement data and distance error.

Mode	Part	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	mean error (mm)
Linear	1	13.33	14.05	13.55	13.96	14.06	0.25
	2	9.87	10.36	10.33	10.12	10.04	0.20
	3	27.22	27.53	27.58	27.33	27.63	0.46
	4	14.58	14.40	15.13	14.84	14.56	0.35
	5	25.34	25.30	25.36	25.45	25.53	0.40
Oscillating	1	14.29	14.31	14.76	14.81	14.05	0.44
	2	10.29	10.32	10.74	10.47	10.38	0.44
	3	27.59	27.68	27.68	27.74	27.77	0.69
	4	14.91	15.36	15.23	15.03	15.48	0.24
	5	25.32	26.04	26.30	25.75	25.57	0.80
Back-and-forth	1	14.31	14.07	13.86	13.94	14.30	0.18
	2	10.34	10.18	10.38	10.06	10.15	0.22
	3	27.88	27.58	27.46	27.18	27.19	0.46
	4	14.69	15.19	15.06	15.01	14.76	0.16
	5	25.90	24.80	24.78	25.20	25.32	0.37