Supplementary Material
Real-Time Ultra-Fine-Grained Surgical Instrument Classification

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Appendix

In this supplementary material, we provide additional details on the following topics:

- Examples from our Dataset (Section A)
- User Interface (Section B)
- Visualization of Class Activation Map (Section C)
- Surgical Instrument Names (Section D)

A. Examples from our Dataset

Figure 1 presents sample image pairs from our dataset, specifically from the Major Laparotomy tray. The name of the surgical instrument is *Clamp Allis 11″*. To enhance the diversity of our dataset, we slightly vary the position of each instrument across images. Additionally, we capture images under different lighting conditions, including shadows cast by a large board and illumination using a flashlight. Figure 1 highlights the diversity of our used dataset, showcasing variations in the position, lighting, orientation, and open-close status of the surgical instrument. However, our image collection platform constrains instruments to designated focus areas, which reduces the typical challenges of fine-grained classification such as extreme variations in position, background, and viewing angle. While this standardized capture process enables reliable instrument identification, it suggests that deployment in unconstrained hospital environments may require additional model adaptation to handle more diverse real-world scenarios.

B. User Interface

We develop a primary user interface (UI) for real-time testing and target-user interaction within the CSSD. Figure 2 represents our designed UI. The UI displays live feeds from UVC cameras and prompts users to select a target tray type: Eye Vitrectomy, Major Laparotomy, Minor Laparotomy, or Unknown (for all categories combined). Upon selection, the system loads the corresponding model and begins continuous inference.

Users can place instruments on the platform for identification, with the system updating and displaying the top three predictions along with their confidence scores every 0.5 seconds. With a single click, users can add the top prediction to a "count" sheet, which tracks accounted and inspected instruments. Once tray assembly is complete, users can click "Finish" to proceed to another tray.

The primary goal of this interface is to provide CSSD technicians with an intuitive and efficient way to interact with the model's predictions during their workflow. While budget constraints prevent the development of a fully professional user interface at this stage, we are actively working on improvements to enhance its functionality and user experience.

C. Visualization of Class Activation Map

To better understand our models' performance on ultra-fine-grained surgical instrument classification, we analyze class activation maps using Grad-CAM. The heatmap visualizations in Figure 3 provide valuable insights into the regions of focus used by our CNN-based model with Add fusion. The analysis of activation regions in both side-view and top-view images demonstrates that the model primarily focuses on key differentiating features of each instrument.

Correctly classified instruments (indicated by green borders) show focused activation on critical areas that distinguish them from nearly identical surgical instruments. Conversely, misclassified instruments (highlighted by red borders) show activation patterns almost identical to correctly classified instances, leading to errors due to the dataset's ultra-fine-grained nature. In some misclassified cases, the model's activation appears either diffused or slightly off-center, focusing on less relevant features. These observa-

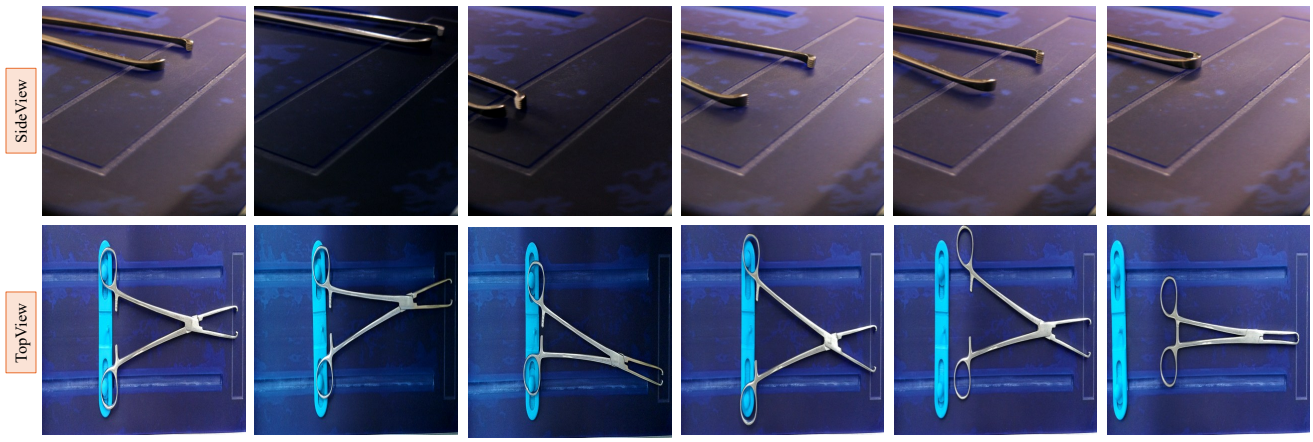

Figure 1. Example image pairs from our dataset, specifically from the Major Laparotomy tray. We collected our dataset in an open-environment setting with variations in position, orientation, lighting, and more.

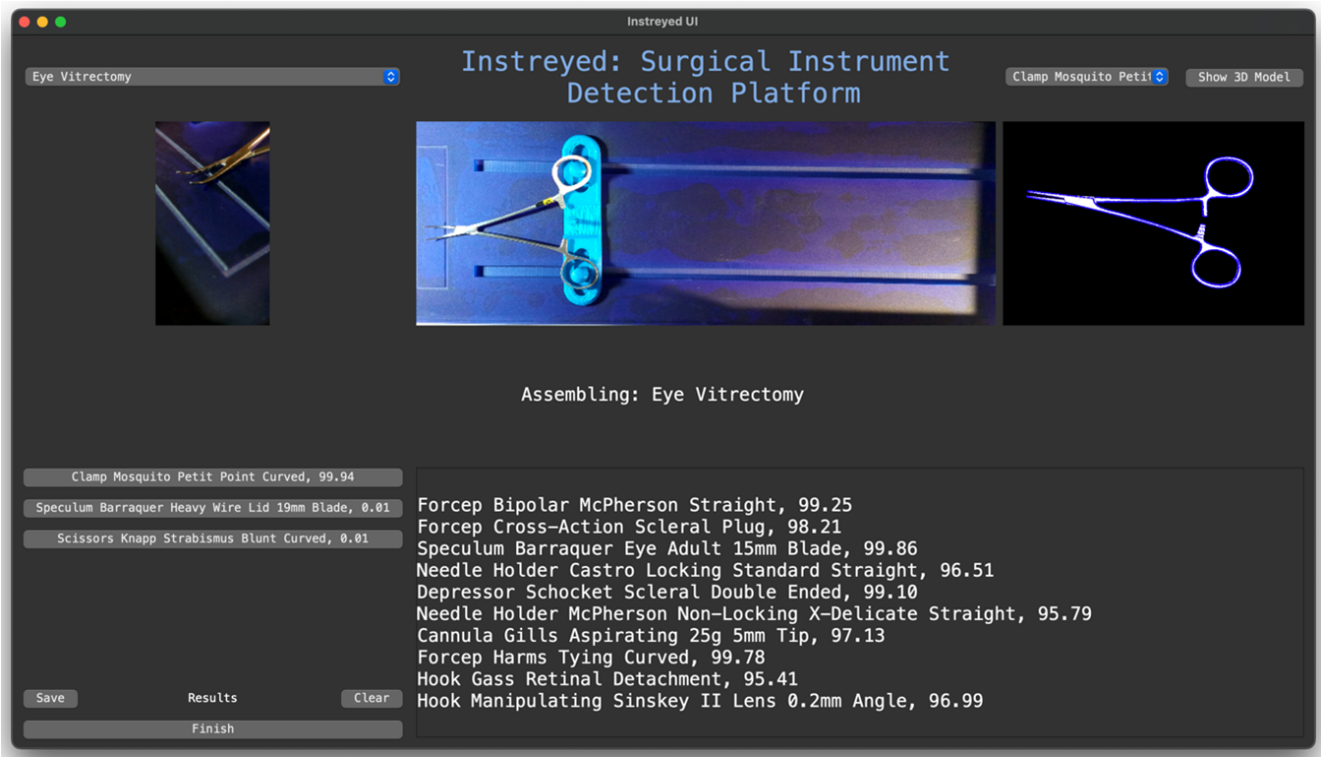

Figure 2. Our primary User-Interface (UI) of our system.

tions emphasize the importance of multi-view image data in enhancing the model's ability to identify and classify ultra-fine-grained surgical instruments, particularly in challenging scenarios where subtle visual distinctions are crucial.

D. Surgical Instrument Names

The following are the names of the surgical instruments we have used for our system. These names also highlight the ultra-fine-grained nature of the instruments.

Eye Vitrectomy Tray

1. Adapter Female Flusing White Plastic
2. Adapter Male Flusing White Plastic
3. Bull Dog Serrefine Small Straight
4. Caliper Castroviejo Straight
5. Cannula Angled Viscoelastic Aspirating 19g
6. Cannula Gills Aspirating 25g 5mm Tip

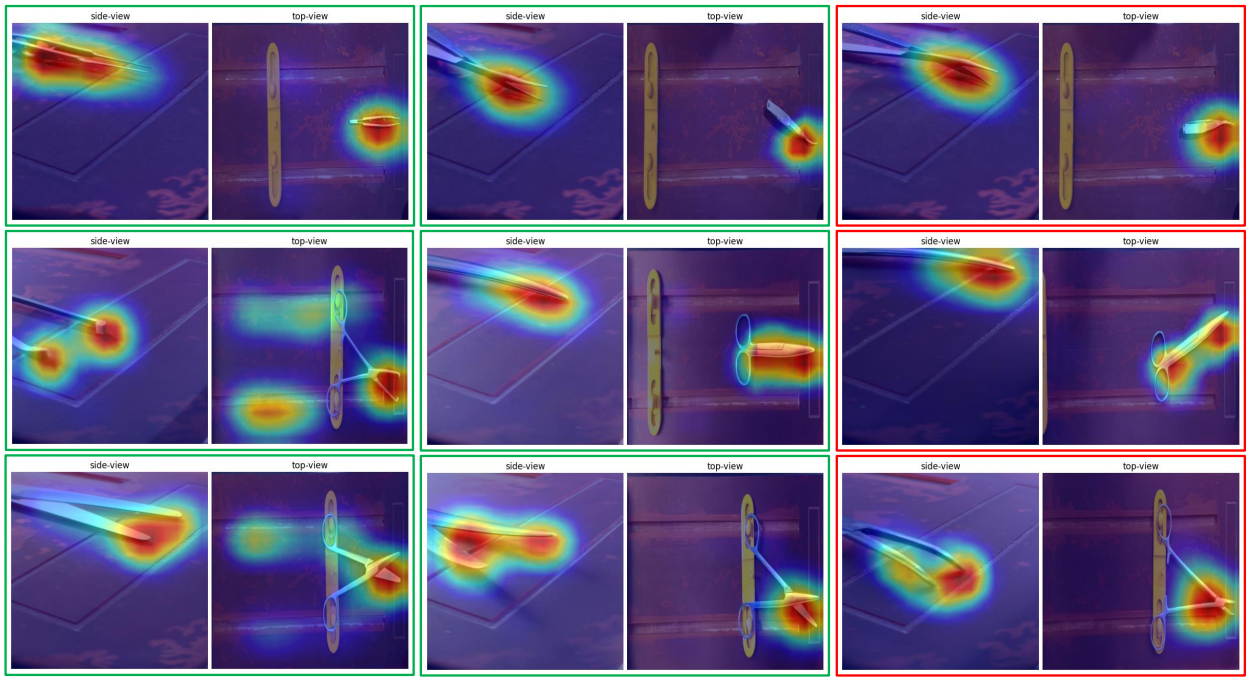

Figure 3. Grad-CAM heatmap visualization illustrating the model's focus on ultra-fine-grained surgical instruments. Each pair of images (side-view and top-view) demonstrates where the model concentrates its attention. The green borders indicate correctly classified instruments, while the red borders denote misclassifications. The top row corresponds to instruments from the Eye tray, whereas the second and third rows represent instruments from the Minor and Major trays. The heatmaps reveal that the model effectively focuses on the key differentiating features of the instruments, which aids in their classification.

7. Cannula Perfluoron Chang IA
8. Clamp Edna 3 1/2″
9. Clamp Mosquito Petit Point Curved
10. Depressor OConnor Scleral Marker
11. Depressor Schocket Scleral Double Ended
12. Forcep Bipolar McPherson Straight
13. Forcep Bishop Harmon w Teeth
14. Forcep Bonaccolto Conjuctivia
15. Forcep Castroviejo Suturing .12mm
16. Forcep Castroviejo Suturing .3mm
17. Forcep Castroviejo Suturing .5mm
18. Forcep Cross-Action Scleral Plug
19. Forcep Harms Tying Curved
20. Forcep Landers Vitrectomy Lens
21. Forcep McPherson Tying Angled
22. Forcep McPherson Tying Straight
23. Forcep Nugent Utility Angled 45 Deg Serrated Jaw
24. Handle Beaver Blade #3 with Collet Screw
25. Hook Gass Retinal Detachment
26. Hook Manipulating Sinskey II Lens 0.2mm Angled
27. Hook Muscle Graefe Size 1
28. Hook Muscle Jameson SM
29. Needle Holder Castro Locking Standard Curved
30. Needle Holder Castro Locking Standard Straight
31. Needle Holder McPherson Locking X-Delicate Curved
32. Needle Holder McPherson Non-Locking X-Delicate Straight
33. Retractor Schepens Orbital
34. Scissors Knapp Strabismus Blunt Curved
35. Scissors Vannas Capsulotomy Straight
36. Scissors Wescott Stitch Curved Sharp Tips
37. Scissors Wescott Tenotomy Curved Blunt
38. Speculum Barraquer Eye Adult 15mm Blade
39. Speculum Barraquer Eye Pediatric 9mm Blade
40. Speculum Barraquer Heavy Wire Lid 19mm Blade
41. Speculum Lieberman Eye w Adjustable V-Wire Blade

Minor Laparotomy Tray

1. Clamp Crile Curved 5 1/2″
2. Clamp Allis 6″
3. Clamp Babcock 6″
4. Clamp Backhaus 4″
5. Clamp Backhaus 5 1/4″
6. Clamp Edna 5 1/2″
7. Clamp Hemostat Straight 5 1/2″
8. Clamp Kelly 6″
9. Forcep Adson W Teeth
10. Forcep Debakey 6″ Thoracic Tip
11. Clamp Mosquito Curved 5″
12. Clamp Sponge 9″
13. Clamp Tonsil 7.5″
14. Knife Handle 3″ Short

15. Forcep Debakey 8″ Thoracic Tip
16. Forcep Ferris Smith
17. Forcep Smooth 6″
18. Forcep W Teeth 6″
19. Retractor Gelpi 7.5″
20. Needle Holder Mayo-Hegar 6″
21. Needle Holder Mayo-Hegar 8″
22. Needle Holder Webster Smooth 5 1/4″
23. Retractor Army Navy
24. Retractor Rake 6″ Prong Dull
25. Retractor Goulet
26. Retractor Lobe
27. Retractor Rake 3″ Prong Dull
28. Retractor Rake 4″ Prong Dull
29. Scissors Mayo Curved 7″
30. Retractor Senn Dull
31. Retractor Vein
32. Retractor Weitlaner Blunt 6.5″
33. Right Angle Regular Tip 7.5″
34. Scissors Metz Curved 7″
35. Scissors Mayo Straight 7″
36. Scissors Metz Curved 5 3/4″
37. Clamp Kelly 8″
38. Clamp Kocher 6″

Major Laparotomy Tray

1. Clamp Edna 5 1/2″
2. Clamp Allis 6″
3. Clamp Babcock 6″
4. Clamp Backhaus 5 1/4″
5. Clamp Crile Curved 5 1/2″
6. Forcep Adson W Teeth
7. Clamp Kelly 6″
8. Clamp Kelly 8″
9. Clamp Kocher 6″
10. Clamp SPONGE 9″
11. Clamp Tonsil 7.5″
12. Scissors Mayo Curved 7″
13. Forcep Debakey 8″ Thoracic Tip
14. Forcep Ferris Smith
15. Knife Handle 3″ Short
16. Needle Holder Mayo-Hegar 8″
17. Scissors Mayo Straight 7″
18. Scissors Metz Curved 7″
19. Clamp Adson Tonsil 11″
20. Clamp Allis 11″
21. Clamp Babcock 12″
22. Clamp Babcock 9.5″
23. Clamp Debakey Aneurysm 10″
24. Clamp Kelly 12″
25. Clamp Kocher 8″
26. Clamp Right Angle 10.5″
27. Clamp Right Angle REG Tip 7″
28. Forcep Debakey 12″ Thoracic Tip
29. Forcep Debakey 9.5″ Thoracic Tip
30. Knife Handle 3″ Long
31. Needle Driver Mayo Hegar 7″
32. Needle Driver Mayo Hegar 10″
33. Scissors Metz Curved 10″
34. Scissors Metz Curved 9″

Common Categories Between Minor and Major Laparotomy Trays

1. Clamp Edna 5 1/2″
2. Clamp Allis 6″
3. Clamp Babcock 6″
4. Clamp Backhaus 5 1/4″
5. Clamp Crile Curved 5 1/2″
6. Forcep Adson W Teeth
7. Clamp Kelly 6″
8. Clamp Kelly 8″
9. Clamp Kocher 6″
10. Clamp SPONGE 9″
11. Clamp Tonsil 7.5″
12. Scissors Mayo Curved 7″
13. Forcep Debakey 8″ Thoracic Tip
14. Forcep Ferris Smith
15. Knife Handle 3″ Short
16. Needle Holder Mayo-Hegar 8″
17. Scissors Mayo Straight 7″
18. Scissors Metz Curved 7″