Illinois Eye AND EAR INFIRMARY

Real-time Ai-based *Platform for* ***Cataract*** *Surgery Provides Ground for the Development of* ***Future Intraoperative Tools***

Surgical Phase Identification and Pupil Tracking in Phacoemulsification Cataract Surgery as a Foundation for Surgical Guidance

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INTRODUCTION

To produce surgical decision-making information in real-time, we developed an agent capable of autonomously identifying the various steps and phases of phacoemulsification cataract surgery in real-time, together with pupil tracking and segmentation, such that the generated output can be combined with future tools to be developed upon this platform.

METHODS

Heterogeneous videos were annotated by ophthalmic surgeons regarding pupil location and phase identification. The developed application acquires video frames, in real time, from a surgical microscope-based video capture device. Then, a Region Based Convolutional Neural Network (R-CNN) performs the following functions for each frame (figure 1):

I. Pupil location and area;
II. Surgical phase identification according to the instruments located within the pupil.

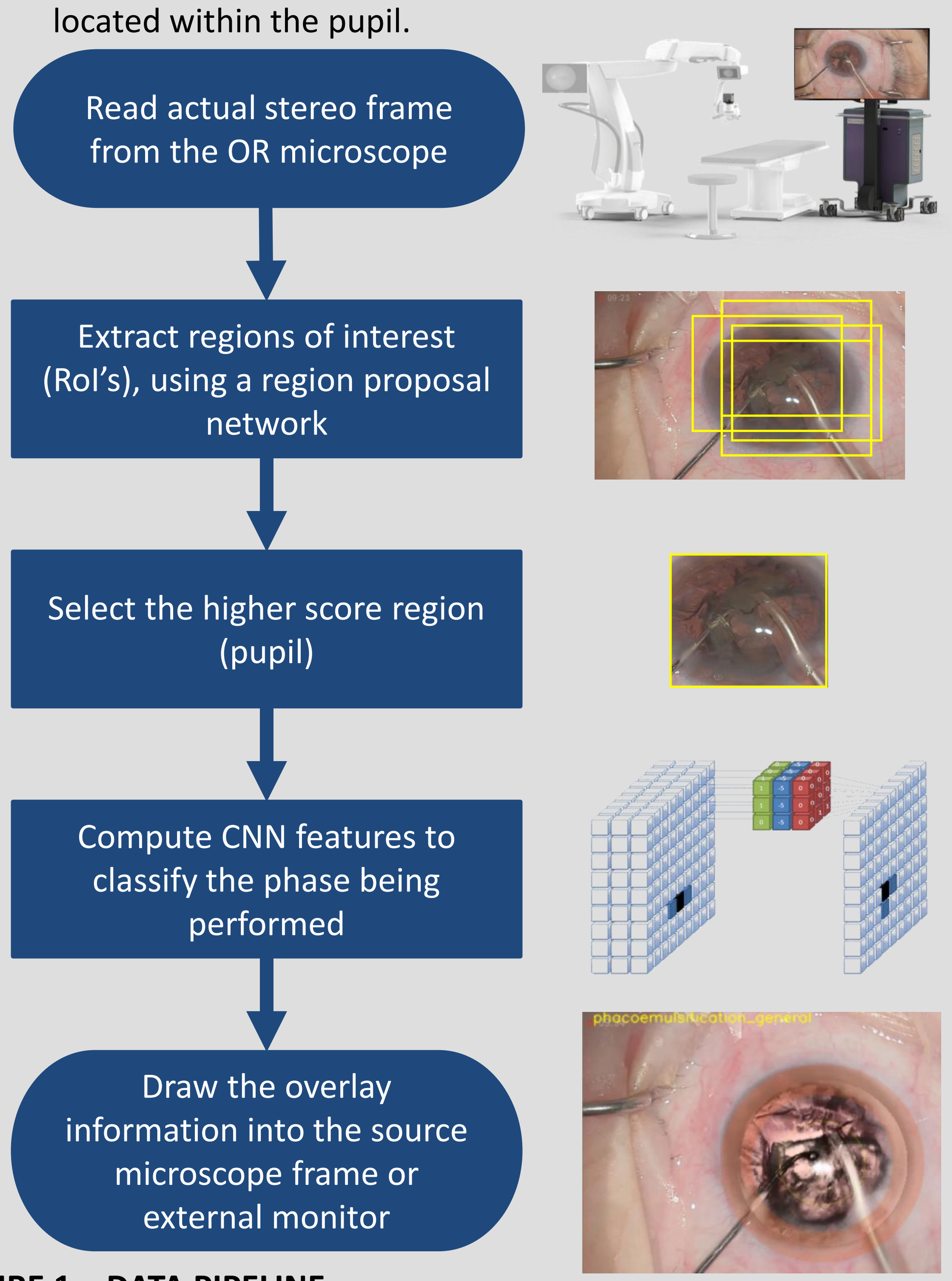
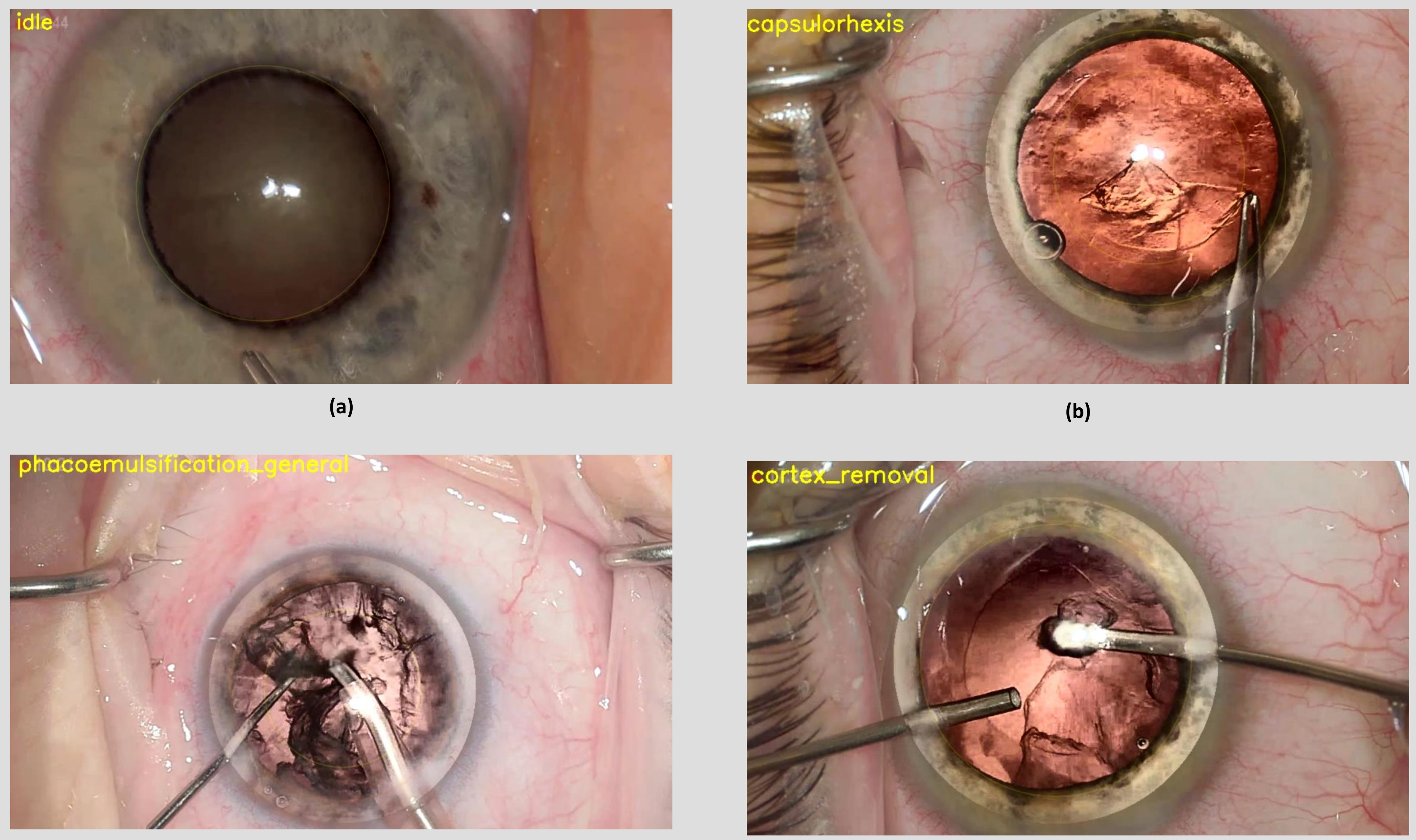


FIGURE 1 – DATA PIPELINE
Overview of data pipeline for pupil detection and phase classification. The operation is made for each frame, always acquiring the last available frame from the intraoperative microscope.

RESULTS



(a) (b) (c) (d)

FIGURE 2 – OVERVIEW OF THE ALGORITHM OUTPUT
(a) When no tool is inserted in the pupil area, idle is displayed. In (b), the capsulorhexis is identified as soon as the tool is inserted. With (c) and (d), the contrast enhancement improves the visualization of lens fragments and cortical fibers according to the area segmented by the neural network. As a demonstration of tools that could be developed, a circular rhexis template was superimposed on frames (b) and (c), also applying contrast enhancement in the area within and around the pupil (outer yellow circle).

METRICS FOR PHASE IDENTIFICATION

	Idle	Capsulorhexis	Phacoemulsification	Cortex Removal
Accuracy	71.05%	88.77%	86.11%	87.99%
Precision	73.12%	97.99%	97.13%	97.56%
Sensitivity	96.16%	90.41%	88.36%	89.97%
F1-Score	83.07%	94.05%	92.54%	93.61%

TABLE 1
Accuracy, precision and sensitivity for the phases being recognized during the video streaming of the test dataset

METRICS FOR PUPIL SEGMENTATION

	Expert 1	Expert 2	Mean	SD
Intersection over Union (IoU)	82.40%	81.97%	82.19%	0.22%
Precision	88.08%	86.66%	87.37%	0.71%
Recall (sensitivity)	92.71%	93.86%	93.29%	0.58%

TABLE 2
Metrics for pupil area segmentation, accordingly to experts' annotation

DISCUSSION

We achieved high values in accuracy, precision, and sensitivity for phase classification, leading to F1-scores above 90%. There was also strong correlation among the graders' assessment of the size of the pupil with the pupil area detected by the algorithm, yielding to a sensitivity of 95%.

SUMMARY

- **No current machine learning solution combines phase identification with pupil tracking in real-time: Deep learning models can identify the phase being performed and track the pupil simultaneously.**
- **With the phase and pupil location identified, we can build new tools that take advantage of computer vision and machine learning algorithms. Such tools can be activated automatically when the instrument is inserted in the pupil area.**
- **The network design allows for the implementation of additional modular digital, tools, such as instrument - and tooltip tracking - all via a single neural network.**
- **The performance of these algorithms can match the output of commercially available surgical microscopes (performing above 60 Frames per Second).**

REFERENCES

Ren, S., He, K., Girshick, R., & Sun, J. (2016). ***Faster R-CNN: towards real-time object detection with region proposal networks.*** IEEE transactions on pattern analysis and machine intelligence, 39(6), 1137-1149.

SUPPORT

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DISCLOSURES

Yannek Leiderman - Alcon,Inc. C, R, S, E.