

Human hand detection and segmentation

Computer Vision: Summer Project 2022

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1 Usage

The application is written in C++ using OpenCV and after the build the usage is:

```
1 HandDetection [params] path model
2
3 -?, -h, --help, --usage
4         print help message
5 --boxes
6         ground-truth bounding boxes path
7 --display
8         show images during detection and segmentation
9 --masks
10        ground-truth masks path
11 --output
12        output path
13 path
14        image path
15 model
16        yolo model path
17 --timings (value:false)
18         show timings
```

An example:

```
1 ./HandDetection ./test-dataset/rgb/ best_m_32_2.onnx --boxes=./test-
    dataset/det/ --masks=./test-dataset/mask --output=./output --display
    --timings
```

There are 2 required params:

- **path**: the path to the image or the folder containing the images on which detection and segmentation will be performed;
- **model**: the path of the YOLOv5 model.

The optional params are:

- **--boxes**: the path to the txt file or the folder containing the txt file of the ground truth boxes, needed for the calculation of IOU;

- `--masks`: the path to the ground truth mask or the folder containing the ground truth masks, needed for the calculation of pixel accuracy;
- `--output`: the path to the output folder (default is `./output`);
- `--display`: if present the application show the detection and the mask one by one, it's necessary user interaction after the display of the mask to move to the next image;
- `--timing`: if present the application show the timings of detection and segmentation.

2 Detection

To perform hand detection, the best method, among the tested ones, is YOLOv5.

YOLOv5¹ is a family of object detection architectures and models pretrained on the COCO dataset.

Since the pretrained models are trained in the COCO dataset, a new model is trained with a custom dataset. This dataset is built by the combination of 3 dataset:

- EgoHands²
- HandsOverFace³
- GTEA Gaze+⁴
- The Caltech Database⁵

EgoHands and GTEA Gaze+ are two similar datasets of egocentric activity images, in total about 6000 egocentric images.

HandsOverFace instead is a dataset of images where the hands are often interacting with faces and heads. HandsOverFace is very small, only 300 images. Therefore, another additional dataset (VLM-HandOverFace⁶) was tested but the result was worse so it is not included in the final dataset.

The Caltech Database is a dataset of profile views of airplanes and motorbikes, rear views of cars, car backgrounds, front views of faces and general background scenes. A portion of this dataset is used as background images.

Since the datasets are structured differently and some parameters can be changed, a tool for managing and create a YOLOv5 dataset was developed. The tool creates a standard YOLOv5 dataset with 70% of the images that are for training and 30% for validation. The tool can convert a percentage of the images in gray-scale.

This tool is written in Python and its usage is:

¹<https://github.com/ultralytics/yolov5>

²<http://vision.soic.indiana.edu/projects/egohands/>

³<https://drive.google.com/file/d/1hHUvINGICvOGcaDgA5zMbzAIUv7ewDd3/>

⁴<https://cbs.ic.gatech.edu/fpv/>

⁵<http://host.robots.ox.ac.uk/pascal/VOC/databases.html#Caltech>

⁶<https://sites.google.com/view/sghanem/vlm-handoverface>

```
1 python yolo.py [-h] [--ego EGO] [--hof HOF] [--gtea GTEA] [--sakher  
SAKHER] [--bg BG] [--bw BW] [-o OUTPUT]
```

where the arguments `--ego`, `--hof`, `--gtea`, `--sakher` and `--bg` are the paths of the correspondent datasets; the argument `--bw` specifies the percentage of gray-scale images; the argument `-o` is the output path of the new dataset.

The final dataset consists of 7319 images and labels in total, 5124 for training and 2195 for validation. The gray-scale images are 20% of the total.

The training was run through a Jupyter Notebook in Google Colab⁷ and in about 2 hours (32 epochs) it trains a model that perform quite well. Thanks to the transfer learning technique the model was initialized with the COCO pretrained model provided by YOLOv5. Therefore, the training process took less time and iterations.

Transfer learning is a technique by which the structure or knowledge derived from a learning problem solution is used to enhance learning on a related problem⁸.

YOLOv5 has a tool for exporting the models in several different formats. The model is exported in the ONNX format and loaded in OpenCV with the function `cv::dnn::readNetFromONNX()`.

[Idea and implementation by Zanardo Damiano]

2.1 Other tested approaches for detection

For the detection task, the OpenCV implementation of Cascade Classifier with Haar features was also tried. The number of positive samples was 3000 while the number of negative samples was 6000. The positive samples were taken uniformly from the two datasets provided (EgoHands and HandsOverFace). The negative samples consisted in the positive samples but the pixels corresponding to hands were set to 0. The training process took more than 72 hours and eventually there were still a lot of false positives, around 50%. *[Idea and implementation by Zaccaria Valentina]*

3 Segmentation

To perform hand segmentation, the best method among the tested ones, is the sequence of GrabCut, SLIC Superpixel clustering and segmentation by thresholding.

⁷https://colab.research.google.com/drive/1ln03n_uRMvx8z6clgnetsagocY12O1ai?usp=sharing

⁸<https://web.archive.org/web/20070801120743/http://cpms.byu.edu/springresearch/abstract-entry?id=861>

GrabCut is a graph-cuts-based method for image segmentation and in particular for foreground extraction. It is an interactive optimization algorithm that used Gaussian Mixture Model and Markov Random Field⁹.

The OpenCV implementation¹⁰ is used:

- the algorithm is automatically initialized with a rectangular which corresponds to the bounding box found at the detection step;
- the input image is not the full-size original one, but a new image composed by the content of the bounding box plus a border of two pixels on each side. The additional border is necessary to initialize the background, which can not be empty according to this implementation.

Moreover, each input image is scaled by a factor of 1.5 (within a maximum size). Some trials were made: with original and with fixed sizes in width or/and height. This choice seems to be the right trade-off between the quality of the results and the computational time. With a scale factor of 2 the results were more precise but the algorithm becomes much slower.

- the number of iterations is 10. Beyond this number, results do not substantially change and the algorithm becomes much slower.

The result of GrabCut is processed with the opening morphological operation to separate weakly connected component and then very small connected components are discharged. The resulting mask is intersected with the original image and a BIMEF intensity transformation is performed to enhance low-light images.

At this point, few non-hands part are still present in some images. In the test images, for example, there are some cards, part of tables and puzzles. A skin color segmentation using HSV color-space threshold is used for refinement. As first attempt, the thresholds values were chosen according to the paper Skin Color Segmentation Using Multi-Color Space Threshold¹¹ and then they were adjusted.

Since the thresholds are absolute values, this step is meaningful only on color images and if the hands are not covered by gloves. If this is not the case, the algorithm does not consider this step.

To reduce the variability of colors, a SLIC Superpixel segmentation is performed before thresholding. The color of each superpixel is the mean of the colors of pixels that compose it.

[Idea and implementation by Zaccaria Valentina]

⁹<https://www.microsoft.com/en-us/research/wp-content/uploads/2004/08/siggraph04-grabcut.pdf>

¹⁰https://docs.opencv.org/3.4/d8/d83/tutorial_py_grabcut.html

¹¹https://www.researchgate.net/publication/311402007_Skin_Color_Segmentation_Using_Multi-Color_Space_Threshold

3.1 Other tested approaches for segmentation

All the tested methods are performed on the reduced image inside the detected bounding box.

- SLIC Superpixel segmentation before than GrabCut, to reduce the computational effort required by the latter [**Idea and implementation by Zaccaria Valentina**];
- GrabCut, SLIC Superpixel segmentation and region growing with predicate based on 8-connectivity and thresholds on pixel intensities in the HSV color-space [*Idea and implementation by Zaccaria Valentina*];
- Region growing alone with the same predicate of the previous point [*Idea and implementation by Capraro Giacomo*];
- Scale Space Canny edge detection with automatic thresholds¹², to keep detailed but persistent edges and on different channels of different color-spaces, such as HSV, to neglect the illumination component. The aim was to isolate connected components and keep only the largest one (which in principle should have been the one corresponding to the hand). [*Idea and implementation by Zaccaria Valentina*].

In all these cases results are poorer.

- A different tested approach relies on Machine Learning. Both SVM and Random Forest Classifier have been tried, with features vector made of various combinations of:
 - R, G, B intensities
 - Hue and Saturation intensities
 - Local Binary Pattern
 - Haralick Features
 - Gabor features
 - Canny edges
 - Sobel
 - Scharr
 - Gaussian of size 3x3
 - Gaussian of size 7x7
 - Median of size 3x3

The dimension of the features vector drastically increases as the number of training samples does. The training process becomes extremely slow. The maximum number of training samples we were able to use was 200 (chosen randomly and uniformly). In all the cases, the results were meaningless. [*Idea and implementation by Zaccaria Valentina and Zanardo Damiano*].

- In the first place, we have tried Mask R-CNN to perform both tasks, which is the state of the art in term of image segmentation. We discharge this idea at the very beginning because not compliant

¹²<https://pyimagesearch.com/2015/04/06/zero-parameter-automatic-canny-edge-detection-with-python-and-opencv/>

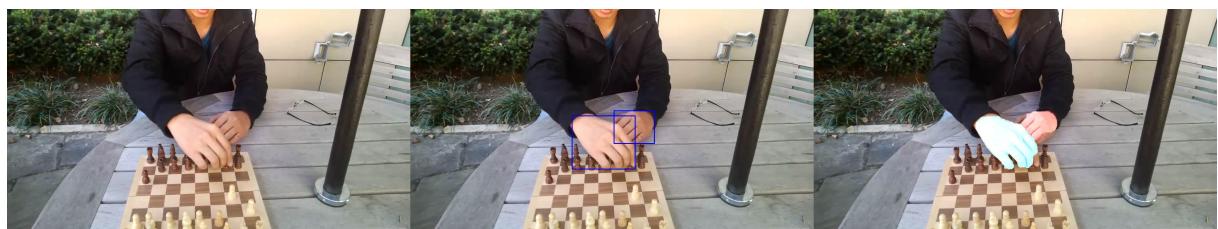
with the project rules, even if the results were very promising [*Idea and implementation by Zanardo Damiano*].

4 Results



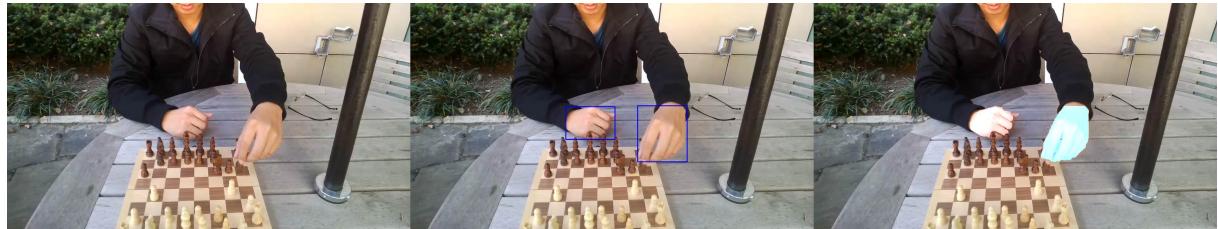
01.jpg

Pixel accuracy	0.991440
IOU (hand 1)	0.829354
IOU (hand 2)	0.884960



02.jpg

Pixel accuracy	0.995538
IOU (hand 1)	0.944244
IOU (hand 2)	0.882239



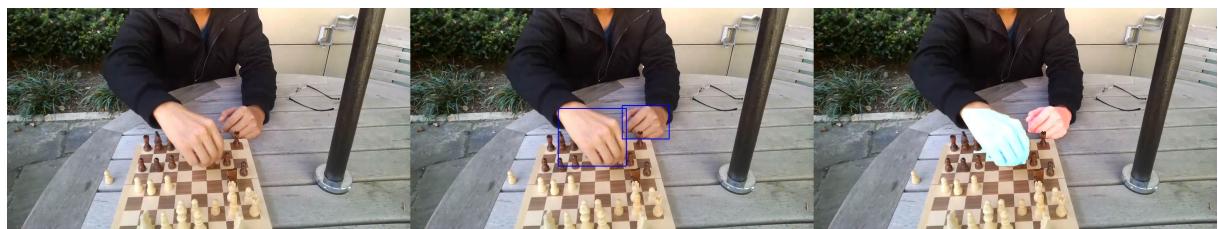
03.jpg

Pixel accuracy 0.995691
IOU (hand 1) 0.942019
IOU (hand 2) 0.932831



04.jpg

Pixel accuracy 0.995994
IOU (hand 1) 0.941958
IOU (hand 2) 0.936200

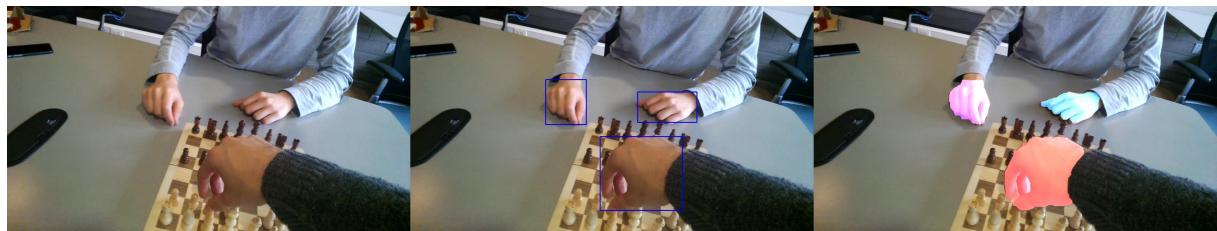


05.jpg

Pixel accuracy 0.995340

IOU (hand 1) 0.873500

IOU (hand 2) 0.877507



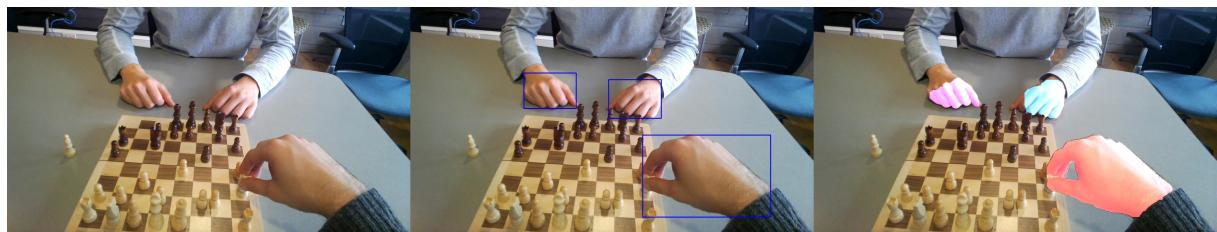
06.jpg

Pixel accuracy 0.990544

IOU (hand 1) 0.873944

IOU (hand 2) 0.889280

IOU (hand 3) 0.928053



07.jpg

Pixel accuracy 0.985010

IOU (hand 1) 0.771126

IOU (hand 2) 0.846182

07.jpg

IOU (hand 3) 0.941221

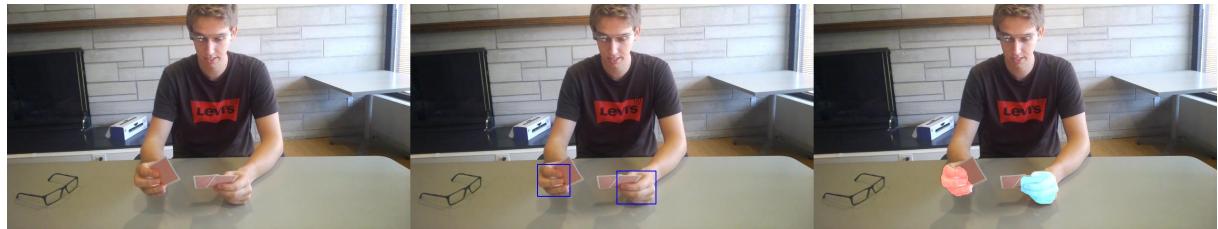


08.jpg

Pixel accuracy 0.988653

IOU (hand 1) 0.831083

IOU (hand 2) 0.906601

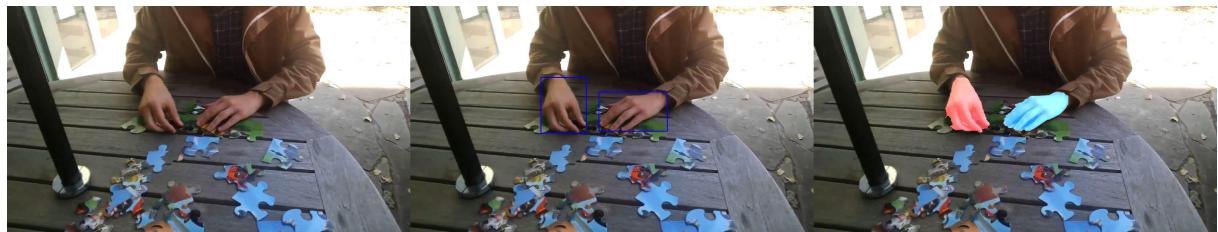


09.jpg

Pixel accuracy 0.995507

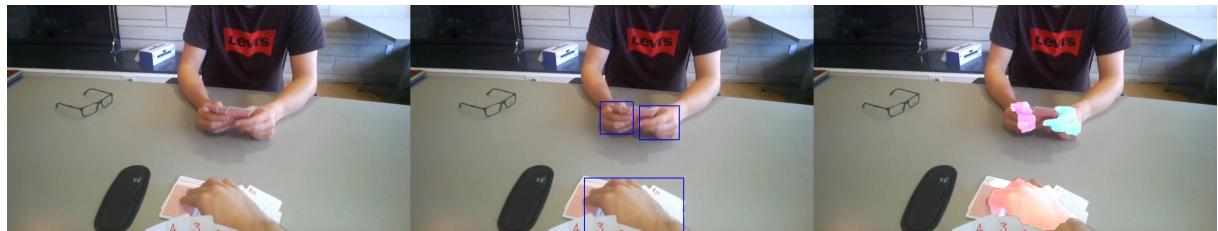
IOU (hand 1) 0.804862

IOU (hand 2) 0.772343



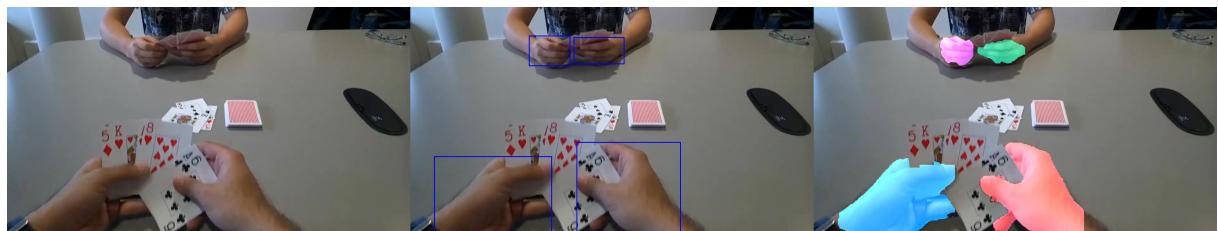
10.jpg

Pixel accuracy	0.994219
IOU (hand 1)	0.872850
IOU (hand 2)	0.897257



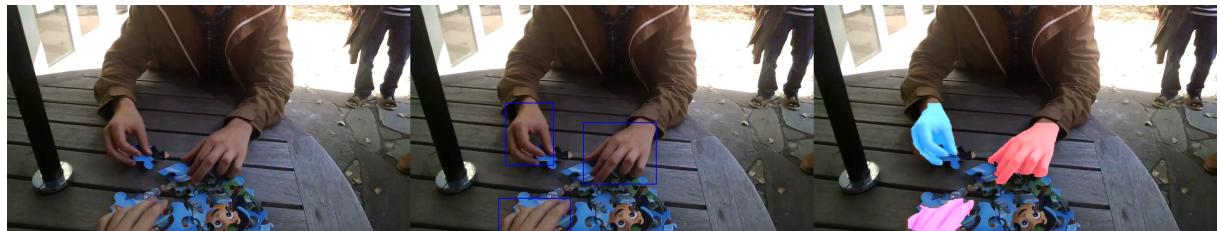
11.jpg

Pixel accuracy	0.983394
IOU (hand 1)	0.822027
IOU (hand 2)	0.859609
IOU (hand 3)	0.869155



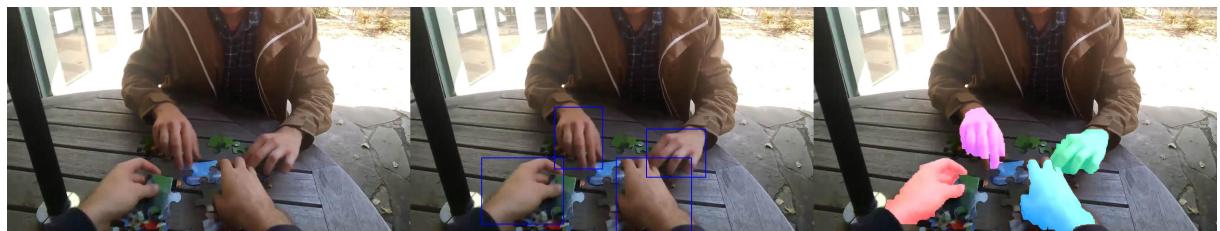
12.jpg

Pixel accuracy	0.968104
IOU (hand 1)	0.939372
IOU (hand 2)	0.742011
IOU (hand 3)	0.857597
IOU (hand 4)	0.937695



13.jpg

Pixel accuracy	0.986934
IOU (hand 1)	0.922360
IOU (hand 2)	0.952820
IOU (hand 3)	0.941224

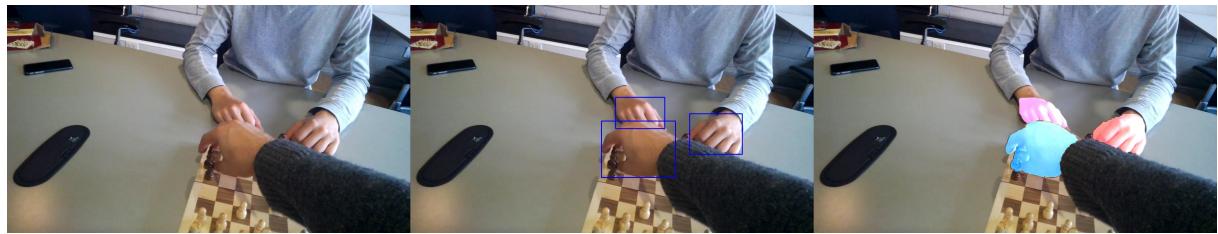


14.jpg

Pixel accuracy	0.977371
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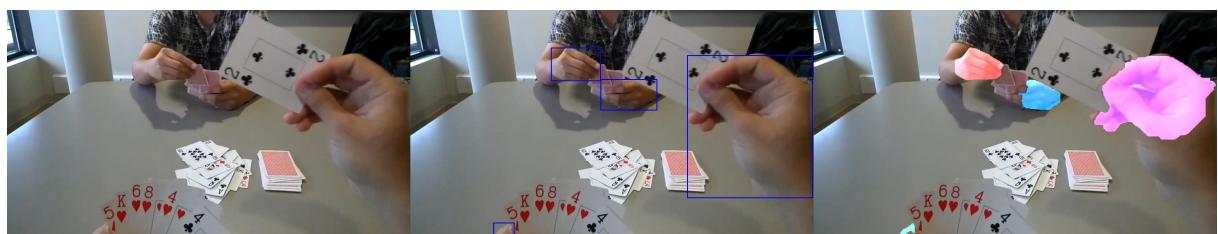
14.jpg

IOU (hand 1)	0.843052
IOU (hand 2)	0.973763
IOU (hand 3)	0.750103
IOU (hand 4)	0.849622



15.jpg

Pixel accuracy	0.987554
IOU (hand 1)	0.846766
IOU (hand 2)	0.778655
IOU (hand 3)	0.874001

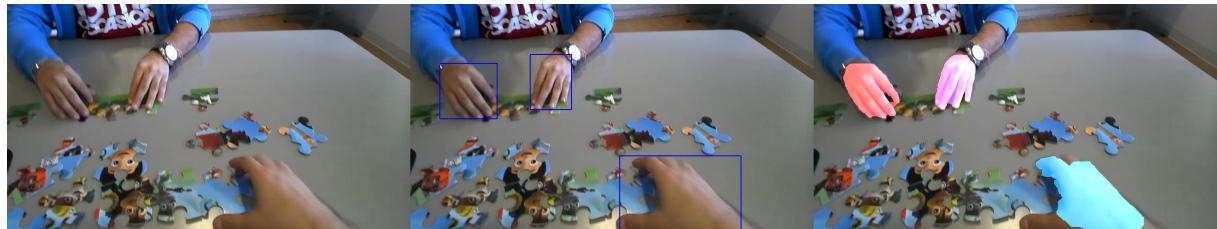


16.jpg

Pixel accuracy	0.938699
IOU (hand 1)	0.796620

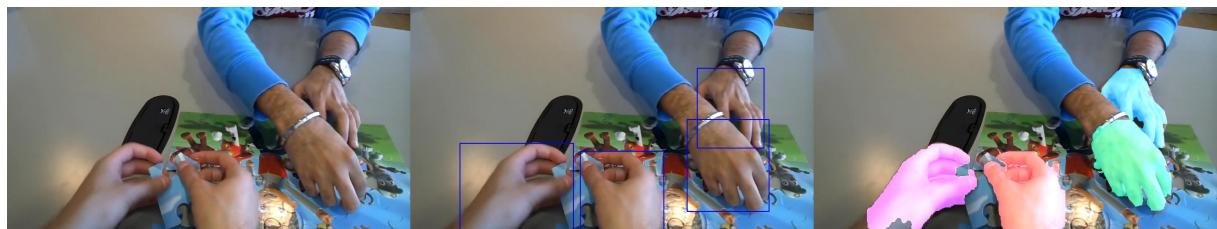
16.jpg

IOU (hand 2)	0.865642
IOU (hand 3)	0.759062
IOU (hand 4)	0.940069



17.jpg

Pixel accuracy	0.981412
IOU (hand 1)	0.941428
IOU (hand 2)	0.894777
IOU (hand 3)	0.883484



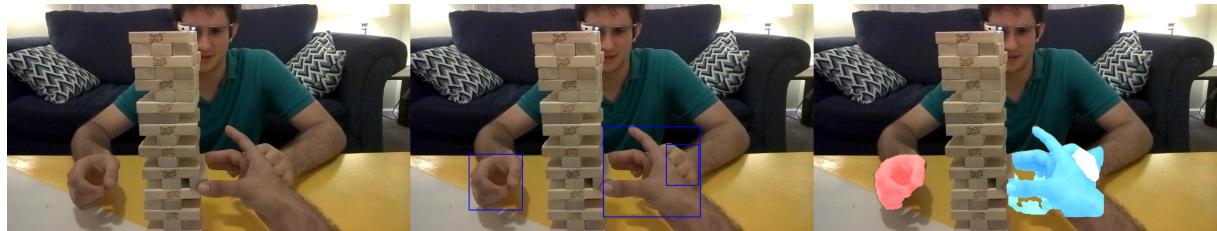
18.jpg

Pixel accuracy	0.977409
IOU (hand 1)	0.955960
IOU (hand 2)	0.941146

18.jpg

IOU (hand 3) 0.953209

IOU (hand 4) 0.949174



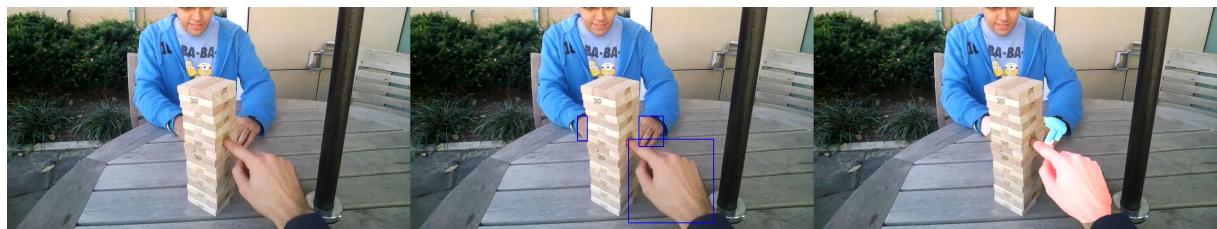
19.jpg

Pixel accuracy 0.98178

IOU (hand 1) 0.933883

IOU (hand 2) 0.914439

IOU (hand 3) 0.766931



20.jpg

Pixel accuracy 0.991144

IOU (hand 1) 0.479327

IOU (hand 2) 0.913141

20.jpg

IOU (hand 3) 0.880752



21.jpg

Pixel accuracy 0.995105

IOU (hand 1) 0.912831

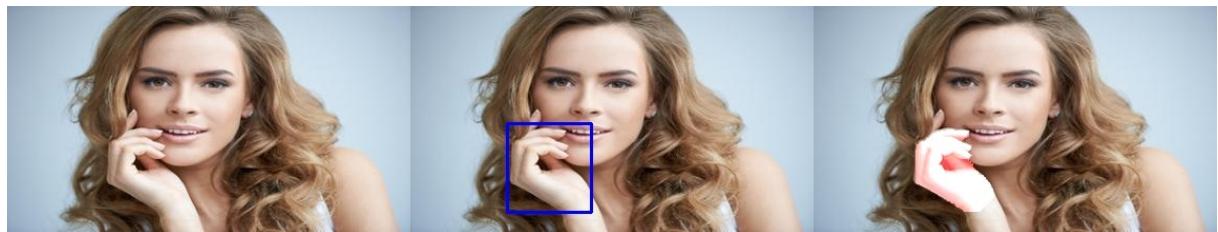


22.jpg

Pixel accuracy 0.975634

IOU (hand 1) 0.634222

IOU (hand 2) 0.882807



23.jpg

Pixel accuracy 0.990319

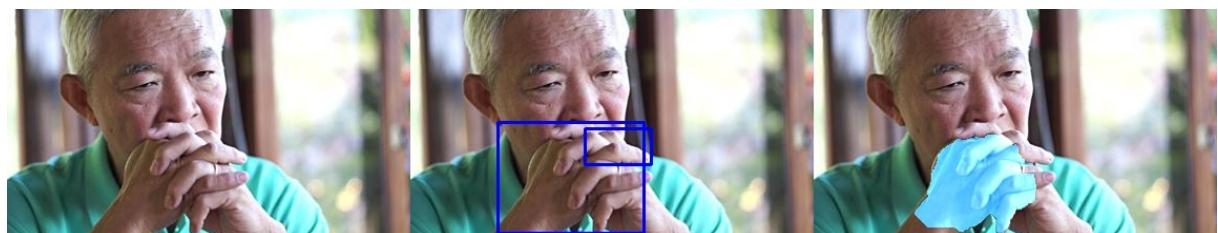
IOU (hand 1) 0.803485



24.jpg

Pixel accuracy 0.979444

IOU (hand 1) 0.740882



25.jpg

Pixel accuracy 0.945385

25.jpg

IOU (hand 1) 0.815366

IOU (hand 2) 0.154515



26.jpg

Pixel accuracy 0.987184

IOU (hand 1) 0.912963



27.jpg

Pixel accuracy 0.971017

IOU (hand 1) 0.771726

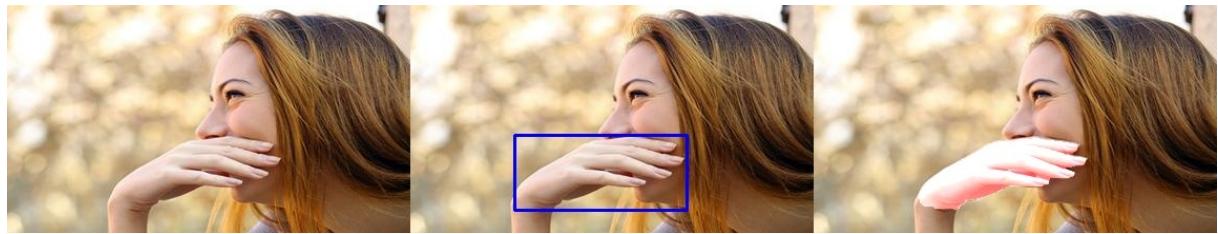
IOU (hand 2) 0.747626



28.jpg

Pixel accuracy 0.974573

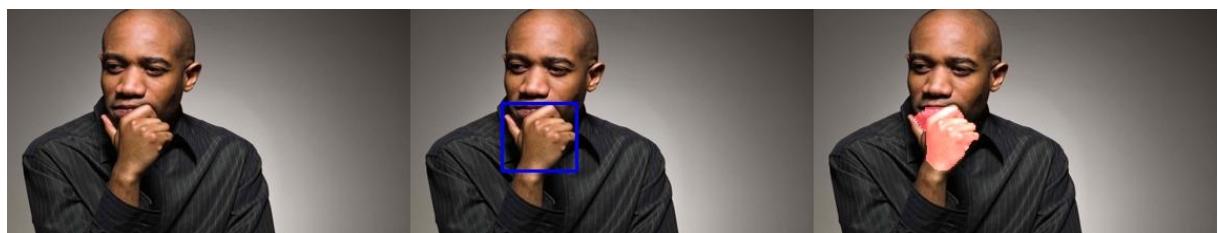
IOU (hand 1) 0.899952



29.jpg

Pixel accuracy 0.986099

IOU (hand 1) 0.858102



30.jpg

Pixel accuracy 0.990391

30.jpg

IOU (hand 1) 0.892569

Summary of the results metrics:

Metric	Mean
Pixel accuracy	0.9832296
IOU	0.8541382

5 Work organization

The project is developed by Zaccaria Valentina and Zanardo Damiano. In the final program the detection parts (including the training process, the detection, the visualization of results and the evaluation of the IoU metric) are developed by Damiano Zanardo. The segmentation parts, including visualization of results, are developed by Zaccaria Valentina. The implementation of the Pixel Accuracy Metric is by both Zanardo Damiano and Zaccaria Valentina. The code refactoring is by Damiano Zanardo.

Hours of work per person: about 140h.