Computer Vision – Assignment 1

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0.1 image_segmentation.py

```python
import os
import cv2
from cv2.typing import MatLike
import numpy as np
from segmentation.utils import fill
import math

class ImageSegmentation:
    def __init__(self, image_path: str, save_dir: str = None):
        self.processing_data = []
        self.image_path = image_path
        self.image = cv2.imread(image_path)
        self.processing_images = []
        self.save_dir = save_dir

    def log_image_processing(self, image, operation: str):
        """log the image processing"""
        self.processing_data.append(operation)
        self.processing_images.append(image)

    def gblur(self, image, ksize=(3, 3), iterations=1):
        """apply gaussian blur to the image"""
        blur = image.copy()
        for _ in range(iterations):
            blur = cv2.GaussianBlur(blur, ksize, cv2.BORDER_DEFAULT)
        self.log_image_processing(blur, f"gblur,kernel:{ksize},iterations:{iterations}")
        return blur

    def mblur(self, image, ksize=3, iterations=1):
        """apply gaussian blur to the image"""
        blur = image.copy()
        for _ in range(iterations):
            blur = cv2.medianBlur(blur, ksize)
        self.log_image_processing(
            blur, f"medianblur,kernel:{ksize},iterations:{iterations}"
        )
        return blur

    def adaptive_threshold(self, image, blockSize=15, C=3):
        """apply adaptive threshold to the image"""
        image = image.copy()
        adaptive_gaussian_threshold = cv2.adaptiveThreshold(
            src=image,
            maxValue=255,
            adaptiveMethod=cv2.ADAPTIVE_THRESH_GAUSSIAN_C,
            thresholdType=cv2.THRESH_BINARY,
            blockSize=blockSize,
            C=C,
        )
        self.log_image_processing(
            adaptive_gaussian_threshold,
            f"adaptive_threshold,blockSize:{blockSize},C:{C}",
        )
        return adaptive_gaussian_threshold
```

```
    def dilate(self, image, kernel=(3, 3), iterations=1, op=cv2.MORPH_ELLIPSE):
        """apply dilation to the image"""
        image = image.copy()
        kernel = cv2.getStructuringElement(op, kernel)
        dilation = cv2.dilate(
            src=image,
            kernel=kernel,
            iterations=iterations,
        )

        self.log_image_processing(
            dilation,
            f"erode,kernel:{kernel},iterations:{iterations}",
        )
        return dilation

    def erode(self, image, kernel=(3, 3), iterations=1, op=cv2.MORPH_ELLIPSE):
        """apply dilation to the image"""
        image = image.copy()
        kernel = cv2.getStructuringElement(op, kernel)
        dilation = cv2.erode(
            src=image,
            kernel=kernel,
            iterations=iterations,
        )

        self.log_image_processing(
            dilation,
            f"dilate,kernel:{kernel},iterations:{iterations}",
        )
        return dilation

    def closing(self, image, kernel=(5, 5), iterations=10):
        """apply closing to the image"""
        image = image.copy()
        kernel = cv2.getStructuringElement(cv2.MORPH_ELLIPSE, kernel)
        closing = cv2.morphologyEx(
            src=image,
            op=cv2.MORPH_CLOSE,
            kernel=kernel,
            iterations=iterations,
        )

        self.log_image_processing(
            closing,
            f"closing,kernel:{kernel},iterations:{iterations}",
        )
        return closing
```

```
    def opening(self, image, kernel=(5, 5), iterations=1, op=cv2.MORPH_ELLIPSE):
        """apply opening to the image"""
        image = image.copy()
        kernel = cv2.getStructuringElement(op, kernel)
        opening = cv2.morphologyEx(
            src=image,
            op=cv2.MORPH_OPEN,
            kernel=kernel,
            iterations=iterations,
        )
        self.log_image_processing(
            opening,
            f"opening,kernel:{kernel},iterations:{iterations}",
        )
        return opening

    def generic_filter(self, image, kernel, iterations=1, custom_msg="genertic_filter"):
        result = image.copy()

        for i in range(iterations):
            result = cv2.filter2D(result, -1, kernel)

        self.log_image_processing(
            result, f"{custom_msg},kernel:{kernel},iterations:{iterations}"
        )
        return result

    def dilate_and_erode(
        self, image, k_d, i_d, k_e, i_e, iterations=1, op=cv2.MORPH_ELLIPSE
    ):
        image = image.copy()
        for _ in range(iterations):
            for _ in range(i_d):
                image = self.dilate(image, (k_d, k_d), op=op)
            for _ in range(i_e):
                image = self.erode(image, (k_e, k_e), op=op)
        self.log_image_processing(
            image,
            f"dilate_and_erode,k_d:{(k_d,k_d)},i_d={i_d},k_e:{(k_e, k_e)},i_e={i_e},iterations:{iterations}",
        )
        return image

    def fill_image(self, image_data, name, show=True):
        self.log_image_processing(
            image_data[name],
            f"fill_{name}",
        )
        image_data[f"fill_{name}"] = {
            "image": fill(image_data[name]["image"].copy()),
            "show": show,
        }
```

```
    def find_ball_contours(
        self,
        image,
        circ_thresh,
        min_area=400,
        max_area=4900,
        convex_hull=False,
    ):
        img = image.copy()
        cnts = cv2.findContours(img, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
        cnts = cnts[0] if len(cnts) == 2 else cnts[1]

        blank_image = np.zeros(img.shape, dtype=img.dtype)

        for c in cnts:
            # Calculate properties
            peri = cv2.arcLength(c, True)
            # Douglas-Peucker algorithm
            approx = cv2.approxPolyDP(c, 0.0001 * peri, True)

            # applying a convex hull
            if convex_hull == True:
                c = cv2.convexHull(c)

            # get contour area
            area = cv2.contourArea(c)
            if area == 0:
                continue  # Skip to the next iteration if area is zero

            circularity = 4 * math.pi * area / (peri**2)

            if (
                (len(approx) > 5)
                and (area > min_area and area < max_area)
                and circularity > circ_thresh
            ):
                cv2.drawContours(blank_image, [c], -1, (255), cv2.FILLED)

        return blank_image


    @staticmethod
    def preprocessing(image):
        image_data = {}

        image_data["original"] = {
            "image": image.image,
            "show": True,
        }
        image_data["grayscale"] = {
            "image": cv2.cvtColor(image.image, cv2.COLOR_BGRA2GRAY),
            "show": False,
        }
```

```
        image_data["hsv"] = {
            "image": cv2.cvtColor(image.image.copy(), cv2.COLOR_BGR2HSV),
            "show": False,
        }
        (_, _, intensity) = cv2.split(image_data["hsv"]["image"])
        image_data["intensity"] = {
            "image": intensity,
            "show": False,
        }
        image_data["gblur"] = {
            "image": image.gblur(
                image_data["intensity"]["image"], ksize=(3, 3), iterations=2
            ),
            "show": False,
        }
        image_data["blur"] = {
            "image": image.mblur(
                image_data["intensity"]["image"], ksize=3, iterations=2
            ),
            "show": False,
        }

        intensity_threshold = cv2.threshold(
            image_data["intensity"]["image"], 125, 255, cv2.THRESH_BINARY
        )[1]

        image_data["intensity_threshold"] = {
            "image": intensity_threshold,
            "show": False,
        }

        name = "adap_gaus_thrsh"
        image_data[name] = {
            "image": image.adaptive_threshold(
                image=image_data["blur"]["image"].copy(),
                blockSize=19,
                C=5,
            ),
            "show": False,
        }

        image_data["open"] = {
            "image": image.opening(
                image=image_data["adap_gaus_thrsh"]["image"].copy(),
                kernel=(5, 5),
                iterations=4,
            ),
            "show": False,
        }
```

```
        image_data["dilate"] = {
            "image": image.dilate(
                image=image_data["open"]["image"].copy(),
                kernel=(3, 3),
                iterations=2,
            ),
            "show": False,
        }
        image_data["erode"] = {
            "image": image.erode(
                image=image_data["open"]["image"].copy(),
                kernel=(3, 3),
                iterations=2,
            ),
            "show": True,
        }
        fill_erode = image.fill_image(image_data, "erode")

        image_data["dilate_and_erode"] = {
            "image": image.dilate_and_erode(
                image_data["fill_erode"]["image"],
                k_d=4,
                i_d=5,
                k_e=5,
                i_e=2,
                iterations=1,
            ),
            "show": False,
        }

        contours = image.find_ball_contours(
            cv2.bitwise_not(image_data["dilate_and_erode"]["image"]),
            0.32,
        )

        image_data["contours"] = {
            "image": contours,
            "show": False,
        }

        image_data["im_1"] = {
            "image": cv2.bitwise_not(
                image_data["intensity_threshold"]["image"],
            ),
            "show": False,
        }

        image_data["im_2"] = {
            "image": cv2.bitwise_not(
                image_data["contours"]["image"],
            ),
            "show": False,
        }
```

```
        image_data["segmentation_before_recontour"] = {
            "image": cv2.bitwise_not(
                cv2.bitwise_or(
                    image_data["im_1"]["image"], image_data["im_2"]["image"]
                ),
            ),
            "show": True,
        }

        recontours = image.find_ball_contours(
            image_data["segmentation_before_recontour"]["image"],
            0.0,
            min_area=100,
            max_area=4900,
            convex_hull=True,
        )

         image_data["convex_hull"] = {
             "image": recontours,
             "show": True,
        }

        image_data["opening_after_segmentation"] = {
            "image": image.opening(
                image_data["convex_hull"]["image"],
                kernel=(3, 3),
                iterations=5,
            ),
            "show": True,
        }

        image_data["segmentation"] = {
            "image": image.find_ball_contours(
                image_data["opening_after_segmentation"]["image"],
                0.72,
                250,
                5000,
                True,
            ),
            "show": True,
        }
        return image_data
```

0.1.a.i utils.py

```python
import os
import glob
from natsort import natsorted
import numpy as np
import matplotlib.pyplot as plt
import cv2


def get_images_and_masks_in_path(folder_path):
    images = sorted(filter(os.path.isfile, glob.glob(folder_path + "/*")))
    image_list = []
    mask_list = []
    for file_path in images:
        if "data.txt" not in file_path:
            if "GT" not in file_path:
                image_list.append(file_path)
            else:
                mask_list.append(file_path)

    return natsorted(image_list), natsorted(mask_list)


# source and modofied from https://stackoverflow.com/a/67992521
def img_is_color(img):

    if len(img.shape) == 3:
        # Check the color channels to see if they're all the same.
        c1, c2, c3 = img[:, :, 0], img[:, :, 1], img[:, :, 2]
        if (c1 == c2).all() and (c2 == c3).all():
            return True

    return False


from heapq import nlargest, nsmallest


def dice_score(processed_images, masks, save_path):
    eval = []
    score_dict = {}
    for idx, image in enumerate(processed_images):
        score = dice_similarity_score(image, masks[idx], save_path)
        score_dict[image] = score
        if len(eval) == 0 or max(eval) < score:
            max_score = score
            max_score_image = image
        if len(eval) == 0 or min(eval) > score:
            min_score = score
            min_score_image = image
        eval.append(score)
    avg_score = sum(eval) / len(eval)
    max_text = f"Max Score: {max_score} - {max_score_image}\n"
    min_text = f"Min Score: {min_score} - {min_score_image}\n"
    avg_text = f"Avg Score: {avg_score}\n"
    print("--- " + save_path + "\n")
    print(max_text)
```

```
    print(min_text)
    print(avg_text)
    print("---")

    FiveHighest = nlargest(5, score_dict, key=score_dict.get)
    FiveLowest = nsmallest(5, score_dict, key=score_dict.get)
    with open(f"{save_path}/dice_score.txt", "w") as f:
        f.write("---\n")
        f.write(max_text)
        f.write(min_text)
        f.write(avg_text)
        f.write("---\n")
        f.write("Scores:\n")
        for idx, score in enumerate(eval):
            f.write(f"\t{score}\t{masks[idx]}\n")
        f.write("---\n")
        f.write("5 highest:\n")
        for v in FiveHighest:
            f.write(f"{v}, {score_dict[v]}\n")
        f.write("---\n")
        f.write("5 lowest:\n")
        for v in FiveLowest:
            f.write(f"{v}, {score_dict[v]}\n")

    frame_numbers = [extract_frame_number(key) for key in score_dict.keys()]

    plt.figure(figsize=(12, 3))
    plt.bar(frame_numbers, score_dict.values(), color="c")
    plt.title("Dice Score for Each Image Frame")
    plt.xlabel("Image Frame")
    plt.ylabel("Dice Similarity Similarity Score")
    plt.ylim([0.8, 1])
    plt.xticks(
        frame_numbers, rotation=90
    )  # Rotate the x-axis labels for better readability
    plt.grid(True)
    plt.tight_layout()  # Adjust the layout for better readability
    plt.savefig(f"Report/assets/dice_score_barchart.png")

    # standard deviation
    std_dev = np.std(eval)
    print(f"Standard Deviation: {std_dev}")
    mean = np.mean(eval)
    print(f"Mean: {mean}")

    # plot boxplot
    plt.figure(figsize=(12, 3))
    plt.violinplot(eval, vert=False, showmeans=True)
    plt.title("Dice Score Distribution")
    plt.xlabel("Dice Similarity Score")
    plt.grid(True)
    plt.tight_layout()
    plt.text(0.83, 0.9, f'Standard Deviation: {std_dev:.2f}', transform=plt.gca().transAxes)
    plt.text(0.83, 0.80, f'Mean: {mean:.2f}', transform=plt.gca().transAxes)
```

```python
    plt.savefig(f"Report/assets/dice_score_violin.png")

def extract_frame_number(path):
    components = path.split("/")
    filename = components[-1]
    parts = filename.split("-")
    frame_number_part = parts[-1]
    frame_number = frame_number_part.split(".")[0]
    return int(frame_number)


def dice_similarity_score(seg_path, mask_path, save_path):

    seg = cv2.threshold(cv2.imread(seg_path), 127, 255, cv2.THRESH_BINARY)[1]
    mask = cv2.threshold(cv2.imread(mask_path), 127, 255, cv2.THRESH_BINARY)[1]
    intersection = cv2.bitwise_and(seg, mask)
    dice_score = 2.0 * intersection.sum() / (seg.sum() + mask.sum())

    difference = cv2.bitwise_not(cv2.bitwise_or(cv2.bitwise_not(seg), mask))
    cv2.imwrite(save_path + f"/difference_ds_{dice_score}.jpg", difference)
    return dice_score


def show_image_list(
    image_dict: dict = {},
    list_cmaps=None,
    grid=False,
    num_cols=2,
    figsize=(20, 10),
    title_fontsize=12,
    save_path=None,
):

    list_titles, list_images = list(image_dict.keys()), list(image_dict.values())

    assert isinstance(list_images, list)
    assert len(list_images) > 0
    assert isinstance(list_images[0], np.ndarray)

    if list_titles is not None:
        assert isinstance(list_titles, list)
        assert len(list_images) == len(list_titles), "%d imgs != %d titles" % (
            len(list_images),
            len(list_titles),
        )

    if list_cmaps is not None:
        assert isinstance(list_cmaps, list)
        assert len(list_images) == len(list_cmaps), "%d imgs != %d cmaps" % (
            len(list_images),
            len(list_cmaps),
        )
```

```
    num_images = len(list_images)
    num_cols = min(num_images, num_cols)
    num_rows = int(num_images / num_cols) + (1 if num_images % num_cols != 0 else 0)

    # Create a grid of subplots.
    fig, axes = plt.subplots(num_rows, num_cols, figsize=figsize)

    # Create list of axes for easy iteration.
    if isinstance(axes, np.ndarray):
        list_axes = list(axes.flat)
    else:
        list_axes = [axes]

    for i in range(num_images):

        img = list_images[i]
        title = list_titles[i] if list_titles is not None else "Image %d" % (i)
        cmap = (
            list_cmaps[i]
            if list_cmaps is not None
            else (None if img_is_color(img) else "gray")
        )

        list_axes[i].imshow(img, cmap=cmap)
        list_axes[i].set_title(title, fontsize=title_fontsize)
        list_axes[i].grid(grid)
        list_axes[i].axis("off")

    for i in range(num_images, len(list_axes)):
        list_axes[i].set_visible(False)

    fig.tight_layout()

    if save_path is not None:
        fig.savefig(save_path)

    plt.close(fig)


def fill(img):
    des = cv2.bitwise_not(img.copy())
    contour, hier = cv2.findContours(des, cv2.RETR_CCOMP, cv2.CHAIN_APPROX_SIMPLE)
    for cnt in contour:
        cv2.drawContours(des, [cnt], 0, 255, -1)
    return cv2.bitwise_not(des)
```

0.2 seg_main.py

```python
import os
import cv2
from tqdm import tqdm

from datetime import datetime
from segmentation.image_segmentation import ImageSegmentation
from segmentation.utils import (
    dice_score,
    get_images_and_masks_in_path,
    show_image_list,
)

import multiprocessing as mp

dir_path = os.path.dirname(os.path.realpath(__file__))
path = "data/ball_frames"


def store_image_data(log_data, time: datetime):
    """method to store in a text file the image data for processing"""
    check_path = os.path.exists(f"process_data/{time}/data.txt")
    if not check_path:
        with open(f"process_data/{time}/data.txt", "w") as f:
            for log in log_data:
                f.write(f"{log}\n")


def process_image(inputs: list[list, bool]) -> None:
    """method to process the image"""
    [image_path, save, time, save_dir] = inputs
    image = ImageSegmentation(image_path, save_dir)
    data = image.preprocessing(image)
    processed_images = {}
    for key in data.keys():
        if data[key]["show"] is not False:
            processed_images[key] = data[key]["image"]
    log_data = image.processing_data

    name = os.path.splitext(os.path.basename(image_path))[0]

    save_path = None
    if save:
        save_path = f"{save_dir}/{name}"
        if not os.path.exists(save_dir):
            os.mkdir(save_dir)
        store_image_data(log_data, time)

        if data["segmentation"]["image"] is not None:
            segmentation_path = f"{save_dir}/segmentation/"
            if not os.path.exists(segmentation_path):
                os.mkdir(segmentation_path)
            seg_path = f"{segmentation_path}{os.path.basename(image.image_path)}"
            cv2.imwrite(seg_path, data["segmentation"]["image"])
```

```python
    show_image_list(
        image_dict=processed_images,
        figsize=(10, 10),
        save_path=save_path,
    )

def process_all_images(images, save=False):
    time = datetime.now().isoformat("_", timespec="seconds")
    save_path = f"process_data/{time}"
    seg_path = f"{save_path}/segmentation"

    with mp.Pool() as pool:
        inputs = [[image, save, time, save_path] for image in images]
        list(
            tqdm(
                pool.imap_unordered(process_image, inputs, chunksize=4),
                total=len(images),
            )
        )
        pool.close()
        pool.join()

    return save_path, seg_path


def main():
    images, masks = get_images_and_masks_in_path(path)
    processed_image_path, seg_path = process_all_images(images, True)
    processed_images, _ = get_images_and_masks_in_path(seg_path)
    dice_score(processed_images, masks, seg_path)


if __name__ == "__main__":
    main()

```

seg_main.py

```
import os
import re
import cv2

from cv2.gapi import bitwise_and
from matplotlib import pyplot as plt
from matplotlib.artist import get

from segmentation.utils import get_images_and_masks_in_path
import numpy as np
from segmentation.utils import fill
import math
from skimage.feature import graycomatrix, graycoprops

BALL_SMALL = "Tennis"
BALL_MEDIUM = "Football"
BALL_LARGE = "American\nFootball"


def shape_features_eval(contour):
    area = cv2.contourArea(contour)

    # getting non-compactness
    perimeter = cv2.arcLength(contour, closed=True)
    non_compactness = 1 - (4 * math.pi * area) / (perimeter**2)

    # getting solidity
    convex_hull = cv2.convexHull(contour)
    convex_area = cv2.contourArea(convex_hull)
    solidity = area / convex_area

    # getting circularity
    circularity = (4 * math.pi * area) / (perimeter**2)

    # getting eccentricity
    ellipse = cv2.fitEllipse(contour)
    a = max(ellipse[1])
    b = min(ellipse[1])
    eccentricity = (1 - (b**2) / (a**2)) ** 0.5

    return {
        "non_compactness": non_compactness,
        "solidity": solidity,
        "circularity": circularity,
        "eccentricity": eccentricity,
    }


def texture_features_eval(patch):
    # # Define the co-occurrence matrix parameters
    distances = [1]
    angles = np.radians([0, 45, 90, 135])
    levels = 256
    symmetric = True
    normed = True
```

```python
    glcm = graycomatrix(
        patch, distances, angles, levels, symmetric=symmetric, normed=normed
    )
    filt_glcm = glcm[1:, 1:, :, :]

    # Calculate the Haralick features
    asm = graycoprops(filt_glcm, "ASM").flatten()
    contrast = graycoprops(filt_glcm, "contrast").flatten()
    correlation = graycoprops(filt_glcm, "correlation").flatten()

    # Calculate the feature average and range across the 4 orientations
    asm_avg = np.mean(asm)
    contrast_avg = np.mean(contrast)
    correlation_avg = np.mean(correlation)
    asm_range = np.ptp(asm)
    contrast_range = np.ptp(contrast)
    correlation_range = np.ptp(correlation)

    return {
        "asm": asm,
        "contrast": contrast,
        "correlation": correlation,
        "asm_avg": asm_avg,
        "contrast_avg": contrast_avg,
        "correlation_avg": correlation_avg,
        "asm_range": asm_range,
        "contrast_range": contrast_range,
        "correlation_range": correlation_range,
    }


def initialise_channels_features():
    def initialise_channel_texture_features():
        return {
            "asm": [],
            "contrast": [],
            "correlation": [],
            "asm_avg": [],
            "contrast_avg": [],
            "correlation_avg": [],
            "asm_range": [],
            "contrast_range": [],
            "correlation_range": [],
        }

    return {
        "blue": initialise_channel_texture_features(),
        "green": initialise_channel_texture_features(),
        "red": initialise_channel_texture_features(),
    }

```

```python
def initialise_shape_features():
    return {
        "non_compactness": [],
        "solidity": [],
        "circularity": [],
        "eccentricity": [],
    }


def get_all_features_balls(path):
    features = {
        BALL_LARGE: {
            "shape_features": initialise_shape_features(),
            "texture_features": initialise_channels_features(),
        },
        BALL_MEDIUM: {
            "shape_features": initialise_shape_features(),
            "texture_features": initialise_channels_features(),
        },
        BALL_SMALL: {
            "shape_features": initialise_shape_features(),
            "texture_features": initialise_channels_features(),
        },
    }

    images, masks = get_images_and_masks_in_path(path)
    for idx, _ in enumerate(images):
        image = images[idx]
        mask = masks[idx]
        msk = cv2.imread(mask, cv2.IMREAD_GRAYSCALE)
        _, msk = cv2.threshold(msk, 127, 255, cv2.THRESH_BINARY)

        # overlay binay image over it's rgb counterpart
        img = cv2.imread(image)
        img = cv2.bitwise_and(cv2.cvtColor(msk, cv2.COLOR_GRAY2BGR), img)
        contours, _ = cv2.findContours(msk, cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_NONE)

        for contour in contours:
            area = cv2.contourArea(contour)
            ball_img = np.zeros(msk.shape, dtype=np.uint8)
            cv2.drawContours(ball_img, contour, -1, (255, 255, 255), -1)
            fill_img = cv2.bitwise_not(fill(cv2.bitwise_not(ball_img)))
            rgb_fill = cv2.bitwise_and(cv2.cvtColor(fill_img, cv2.COLOR_GRAY2BGR), img)

            out = fill_img.copy()
            out_colour = rgb_fill.copy()

            # Now crop image to ball size
            (y, x) = np.where(fill_img == 255)
            (topy, topx) = (np.min(y), np.min(x))
            (bottomy, bottomx) = (np.max(y), np.max(x))
            padding = 3
```

```
            out = out[
                topy - padding : bottomy + padding, topx - padding : bottomx + padding
            ]
            out_colour = out_colour[
                topy - padding : bottomy + padding, topx - padding : bottomx + padding
            ]

            # getting ball features
            shape_features = shape_features_eval(contour)
            texture_features_colour = {
                "blue": texture_features_eval(out_colour[:, :, 0]),
                "green": texture_features_eval(out_colour[:, :, 1]),
                "red": texture_features_eval(out_colour[:, :, 2]),
            }

            # segmenting ball by using area
            if area > 1300:  # football
                append_ball = BALL_LARGE
            elif area > 500:  # soccer_ball
                append_ball = BALL_MEDIUM
            else:  # tennis ball
                append_ball = BALL_SMALL

            for key in shape_features:
                features[append_ball]["shape_features"][key].append(shape_features[key])

            for colour in texture_features_colour.keys():
                for colour_feature in texture_features_colour[colour]:
                    features[append_ball]["texture_features"][colour][
                        colour_feature
                    ].append(texture_features_colour[colour][colour_feature])
    return features


def feature_stats(features, ball, colours=["blue", "green", "red"]):
    def get_stats(array):
        return {
            "mean": np.mean(array),
            "std": np.std(array),
            "min": np.min(array),
            "max": np.max(array),
        }

    def get_ball_shape_stats(features, ball):
        feature_find = ["non_compactness", "solidity", "circularity", "eccentricity"]
        return {
            feature: get_stats(features[ball]["shape_features"][feature])
            for feature in feature_find
        }
```

```
    def get_ball_texture_stats(features, ball, colour):
        feature_find = ["asm_avg", "contrast_avg", "correlation_avg"]
        return {
            texture: get_stats(features[ball]["texture_features"][colour][texture])
            for texture in feature_find
        }

    stats = {
        ball: {
            "shape_features": get_ball_shape_stats(features, ball),
            "texture_features": {
                colour: get_ball_texture_stats(features, ball, colour)
                for colour in colours
            },
        },
    }
    return stats


def get_histogram(data, Title):
    """
    data {ball: values}
    """
    for ball, values in data.items():
        plt.figure(figsize=(3,3))
        plt.hist(values, bins=20, alpha=0.5, label=ball)
        plt.xlabel(Title)
        plt.ylabel("Frequency")
        plt.legend()
        plt.tight_layout()
        plt.savefig("Report/assets/features/"+ Title + "_histogram_" + ball.replace("\n", "_"))
    # plt.show()


if __name__ == "__main__":
    features = get_all_features_balls("data/ball_frames")

    balls = [
        BALL_SMALL,
        BALL_MEDIUM,
        BALL_LARGE,
    ]

    non_compactness = {
        ball: features[ball]["shape_features"]["non_compactness"] for ball in balls
    }
    solidity = {ball: features[ball]["shape_features"]["solidity"] for ball in balls}
    circularity = {
        ball: features[ball]["shape_features"]["circularity"] for ball in balls
    }
```

```python
eccentricity = {
    ball: features[ball]["shape_features"]["eccentricity"] for ball in
balls
}

get_histogram(non_compactness, "Non-Compactness")
get_histogram(solidity, "Soliditiy")
get_histogram(circularity, "Circularity")
get_histogram(eccentricity, "Eccentricity")

channel_colours = ["red", "green", "blue"]

def get_ch_features(feature_name):
    return {
        colour: {
            ball: features[ball]["texture_features"][colour][feature_name]
            for ball in balls
        }
        for colour in channel_colours
    }

def get_ch_stats(feature_data, colours=channel_colours):
    return [[feature_data[colour][ball] for ball in balls] for colour in
colours]

asm_avg = get_ch_features("asm_avg")
contrast_avg = get_ch_features("contrast_avg")
correlation_avg = get_ch_features("correlation_avg")
asm_range = get_ch_features("asm_range")

asm_data = get_ch_stats(asm_avg)
contrast_data = get_ch_stats(contrast_avg)
correlation_data = get_ch_stats(correlation_avg)
asm_range_data = get_ch_stats(asm_range)

asm_title = "ASM Avg"
contrast_title = "Contrast Avg"
correlation_title = "Correlation Avg"
asm_range_title = "ASM Range Avg"

plt_colours = ["yellow", "white", "orange"]
channels = ["Red Channel", "Green Channel", "Blue Channel"]

plt.figure()

def get_boxplot(data, title, colours=plt_colours, rows=3, columns=3,
offset=0):
    channels = ["Red Channel", "Green Channel", "Blue Channel"]

    fig = plt.figure(figsize=(8,3))  # Get the Figure object
    fig.suptitle(title)  # Set the overall title
```

```python
        for i, d in enumerate(data):
            ax = plt.subplot(rows, columns, i + offset + 1)
            ax.set_facecolor(channel_colours[i])
            ax.patch.set_alpha(0.5)
            violins = plt.violinplot(
                d, showmeans=True, showmedians=False, showextrema=False
            )
            for j, pc in enumerate(violins["bodies"]):
                pc.set_facecolor(colours[j])
                pc.set_edgecolor("black")
                pc.set_alpha(0.2)
            plt.xticks([1, 2, 3], balls, rotation=45)
            plt.title(channels[i])

    def get_boxplot_specific(data, title, i, colours=plt_colours):

        plt.figure(figsize=(2.5,6))
        d = data[i]
        violins = plt.violinplot(
            d, showmeans=True, showmedians=False, showextrema=False
        )
        for j, pc in enumerate(violins["bodies"]):
            pc.set_facecolor(colours[j])
            pc.set_edgecolor("black")
            pc.set_alpha(0.5)
        plt.xticks([1, 2, 3], balls, rotation=45)
        plt.title(title + '\n' + channels[i])
        ax = plt.gca()  # Get the current Axes instance
        ax.set_facecolor(channel_colours[i])  # Set the background color
        ax.patch.set_alpha(0.1)  # Set the alpha value

    columns = 3
    rows = 1

    get_boxplot_specific(asm_data, asm_title, 2)
    plt.tight_layout()
    plt.savefig("Report/assets/features/asm_data_blue_channel")
    plt.close()

    get_boxplot_specific(asm_range_data, asm_range_title, 2)
    plt.tight_layout()
    plt.savefig("Report/assets/features/asm_range_data_blue_channel")
    plt.close()

    get_boxplot_specific(contrast_data, contrast_title, 0)
    plt.tight_layout()
    plt.savefig("Report/assets/features/contrast_data_red_channel")
    plt.close()

    get_boxplot_specific(correlation_data, correlation_title, 1)
    plt.tight_layout()
    plt.savefig("Report/assets/features/correlation_green_channel")
    plt.close()
```

Problem 1: Tracking

```python
from matplotlib import pyplot as plt
import numpy as np


def kalman_predict(x, P, F, Q):
    xp = F * x
    Pp = F * P * F.T + Q
    return xp, Pp


def kalman_update(x, P, H, R, z):
    S = H * P * H.T + R
    K = P * H.T * np.linalg.inv(S)
    zp = H * x

    xe = x + K * (z - zp)
    Pe = P - K * H * P
    return xe, Pe


def kalman_tracking(
    z,
    x01=0.0,
    x02=0.0,
    x03=0.0,
    x04=0.0,
    dt=0.5,
    nx=16,
    ny=0.36,
    nvx=0.16,
    nvy=0.36,
    nu=0.25,
    nv=0.25,
):
    # Constant Velocity
    F = np.matrix([[1, dt, 0, 0], [0, 1, 0, 0], [0, 0, 1, dt], [0, 0, 0, 1]])

    # Cartesian observation model
    H = np.matrix([[1, 0, 0, 0], [0, 0, 1, 0]])

    # Motion Noise Model
    Q = np.matrix([[nx, 0, 0, 0], [0, nvx, 0, 0], [0, 0, ny, 0], [0, 0, 0, nvy]])

    # Measurement Noise Model
    R = np.matrix([[nu, 0], [0, nv]])

    x = np.matrix([x01, x02, x03, x04]).T
    P = Q

    N = len(z[0])
    s = np.zeros((4, N))
```

```python
    for i in range(N):
        xp, Pp = kalman_predict(x, P, F, Q)
        x, P = kalman_update(xp, Pp, H, R, z[:, i])
        val = np.array(x[:2, :2]).flatten()
        s[:, i] = val

    px = s[0, :]
    py = s[1, :]

    return px, py


def error(x, y, px, py):
    err = []
    for i in range(len(x)):
        err.append(np.sqrt((x[i] - px[i]) ** 2 + (y[i] - py[i]) ** 2))
    return err


def optimisation(trial, x, y, z, dt, nx, ny, nvx, nvy, nu, nv, x01, x02, x03, x04):
    # dt = trial.suggest_float("dt", 0.05, 1.0, step=0.05)

    # Q
    nx = trial.suggest_float("nx", -2.0, 2.0)
    ny = trial.suggest_float("ny", -2.0, 2.0)
    nvx = trial.suggest_float("nvx", -2.0, 2.0)
    nvy = trial.suggest_float("nvy", -2.0, 2.0)

    # R
    nu = trial.suggest_float("nu", -1.0, 1.0)
    nv = trial.suggest_float("nv", -1.0, 1.0)

    # init x
    x01 = z[0][0]
    x02 = z[1][0]

    px, py = kalman_tracking(z, x01, x02, x03, x04, dt, nx, ny, nvx, nvy, nu, nv)
    rms_val = rms(x, y, px, py)
    return rms_val


def rms(x, y, px, py):
    err = np.array(error(x, y, px, py))
    return np.sqrt(err.mean())


def optimize_rms(x, y, z):
    import optuna
    from tqdm import tqdm

    trials = 100000

    pbar = tqdm(total=trials, desc="Optimization Progress")
```

```
    def print_new_optimal(study, trial):
        # Check if the trial is better than the current best
        pbar.update(1)
        if trial.value == study.best_value:
            print(f"New Best RMS: {trial.value} (trial number {trial.number})")
            print("Best parameters:", study.best_params)

    optuna.logging.set_verbosity(optuna.logging.WARNING)

    study = optuna.create_study()
    dt = 0.5
    nx = 0.16
    ny = 0.36
    nvx = 0.16
    nvy = 0.36
    nu = 0.25
    nv = 0.25
    x01 = 0.0
    x02 = 0.0
    x03 = 0.0
    x04 = 0.0

    study.optimize(
        lambda trial: optimisation(
            trial, x, y, z, dt, nx, ny, nvx, nvy, nu, nv, x01, x02, x03, x04
        ),
        n_trials=trials,
        n_jobs=8,
        callbacks=[print_new_optimal],  # Add the callback here
    )

    return study.best_params


if __name__ == "__main__":

    x = np.genfromtxt("data/x.csv", delimiter=",")
    y = np.genfromtxt("data/y.csv", delimiter=",")
    na = np.genfromtxt("data/na.csv", delimiter=",")
    nb = np.genfromtxt("data/nb.csv", delimiter=",")
    z = np.stack((na, nb))

    dt = 0.5
    nx = 0.16
    ny = 0.36
    nvx = 0.16
    nvy = 0.36
    nu = 0.25
    nv = 0.25
    x01 = 0.0
    x02 = 0.0
    x03 = 0.0
    x04 = 0.0
```

```python
#optimize_rms(x, y, z)

px, py = kalman_tracking(
    nx=nx,
    ny=ny,
    nvx=nvx,
    nvy=nvy,
    nu=nu,
    nv=nv,
    x01=x01,
    x02=x02,
    x03=x03,
    x04=x04,
    z=z,
)
plt.figure(figsize=(12, 8))
plt.plot(x, y)
plt.plot(px, py)
plt.scatter(na, nb)
plt.title("Kalman Filter")
plt.savefig("Report/assets/tracking/kalman_filter.png")
plt.show()
```