**Title:** Motion: A Mobile Application for Yoga Pose Accuracy and Consistency Evaluation

**I. Abstract**

Inadequate feedback on yoga poses could lead to severe injuries. However, receiving feedback from professional yoga instructors is costly and inconvenient. Therefore, existing studies aim to create software applications that identify and correct improper yoga pose execution. These studies, however, do not provide a criteria-based evaluation which is crucial for progress tracking and determining areas for improvement. To address this issue, this study aims to create a mobile application that evaluates a yoga practitioner’s pose accuracy and consistency in real-time. The application will utilize MediaPipe Pose and ML Kit to perform human pose estimation (HPE) and machine learning (ML) to identify and track the practitioner's pose execution. To evaluate the practitioner's pose accuracy and consistency, the system will store angle data for each frame of the practitioner's yoga pose execution during a 15-second window. The angle data will be compared against ideal angles to calculate accuracy and will be used to measure if the practitioner is able to maintain the pose to calculate consistency. To ensure the reliability of the application’s evaluations, a two-sample t-test will be used to determine if there is a significant difference between the application and a professional yoga instructor’s evaluations. It is expected that there will be no significant difference between the evaluations of the application and those from an instructor.

**II. Motivation and Discussion of Related Technology**

*A. IMPORTANCE*

Yoga has grown in popularity over the last two decades, especially in academic and medical settings [[1]](https://www.zotero.org/google-docs/?q8DAFa). This growth is largely due to the health benefits of yoga, such as treating stress, anxiety, and post-traumatic stress disorder (PTSD) [[2]](https://www.zotero.org/google-docs/?4Aju41). Due to the COVID-19 pandemic and resulting lockdowns, online yoga classes have become more prevalent, providing people with the opportunity to practice from the comfort of their own homes [[3]](https://www.zotero.org/google-docs/?WF9x8b). However, the lack of face-to-face interaction presents challenges for yoga instructors in evaluating students’ performance and correcting errors [[4]](https://www.zotero.org/google-docs/?AZwgFJ). In circumstances where access to certified yoga instructors is limited due to their scarcity and high cost [[5]](https://www.zotero.org/google-docs/?lwOtK7), novice yogis are limited to self-study in which they are unable to accurately assess the proper form of their poses [[6]](https://www.zotero.org/google-docs/?5uHM6x). Both situations lead to a rise in improper yoga postures and just like any other exercises, these can have far-reaching negative implications [[5]](https://www.zotero.org/google-docs/?BAhNsW) and cannot fully maximize yoga’s benefits [[7]](https://www.zotero.org/google-docs/?MCERDR).

*B. UNIQUENESS AND ADVANTAGES*

The current disadvantages of practicing yoga online instigated more research on computer-assisted self-training systems that propose to assist in correcting improper postures to prevent damage. Most of these studies utilize human posture estimation (HPE) and categorization [[8]](https://www.zotero.org/google-docs/?ep2AO8). Currently available systems, however, concentrate more on spotting positions and providing feedback to fix the stance. They lack the function to asses and grade the practitioner’s yoga form [[9]](https://www.zotero.org/google-docs/?tGPulG). Grading enables the user to experience the benefits of a pose (such as utilizing yoga blocks to support oneself) while making the pose accessible and safe for them. Fixing the stance can occasionally be made simpler or harder based on the individual's balance and stability needs (such as starting in a wider stance to increase stability).  Grading the practitioner’s yoga form can improve safety since it is found that a gradual increase in physical activity and duration can help reduce the risk of injury [[10]](https://www.zotero.org/google-docs/?nxraVp). Aside from that it can also allow each practitioner to progress at their own pace, addressing their individual needs and goals [[11]](https://www.zotero.org/google-docs/?l1DoMl).

The use of this system would benefit both certified and non-certified yoga practitioners. Non-certified yoga practitioners can safely practice without the need for physical supervision, saving time and money. On the other hand, certified instructors can enhance their students’ learning experience by being able to personalize their instruction based on individual needs and evaluations.

This technology has the potential to be utilized by yoga instructors in yoga competitions to objectively evaluate and score contestants. Additionally, its capabilities can be extended beyond just yoga, to include stretching exercises and other forms of physical activity such as Pilates, providing a comprehensive grading system for a variety of physical practices.

*C. RELATED TECHNOLOGIES*

1. Human Pose Estimation

Human Pose Estimation (HPE) is used to describe a process in computer vision concerned with pinpointing the location of a person's body inside a scene. Most methods for HPE involve taking a picture with the use of an optical sensor in RGB so that body parts and the user's location can be determined.  A person's fingers, toes, and even face might serve as landmarks for this method. A 2D or 3D model of the human body can then be constructed using this data. These depictions, also known as key points or landmarks, are essentially a map of the articulations we perceive in the moving body. It is typically employed in conjunction with other computer vision technologies for usage in such fields as surveillance, augmented reality, and fitness and rehabilitation [[12]](https://www.zotero.org/google-docs/?fjCW95).

2. k-Nearest Neighbors (k-NN)

k-Nearest Neighbors is an ML algorithm that employs feature similarity to forecast the values of any new or missing data. It is a non-parametric, supervised learning method [[13]](https://www.zotero.org/google-docs/?HIFn9g). It is used in ML Kit and MediaPipe Pose for classification and regression and is a simple yet effective machine-learning algorithm for small datasets. Since it is simple, it requires a little training and is computationally inexpensive, making it well-suited for real-time applications.

3. MediaPipe Pose

A ML pipeline called MediaPipe is capable of managing a library of audio, video, and other media assets. This framework is compatible with a broad range of hardware, including servers, desktop computers, and iOS and Android-powered mobile devices. In a user’s photo or video, the MediaPipe Pose high-fidelity body posture tracking tool can locate 33 3D landmarks. The model's output coordinates will include width, height, and depth measurements and information on how clearly the detected posture can be seen in the original image or frame [[14]](https://www.zotero.org/google-docs/?Z9al0w). The study chose MediaPipe Pose to process the datasets (testing and training) because of its easy integration with other tools, especially with TensorFlow and ML Kit.

4. ML Kit

The ML Kit framework was created to let mobile apps incorporate ML. It offers pre-trained models and APIs for several use cases, such as pose detection, image labeling, and more. Thanks to its features for model customization and on-device model training, developers can alter their machine-learning models to meet their unique demands. It focuses on both ML on-device and in the cloud, making it suitable for a variety of applications, from straightforward prototypes to intricate, large-scale production systems [[15]](https://www.zotero.org/google-docs/?mS947d). In this study, the pose of the user's body is determined in real-time from a continuous video source or a static image using ML Kit’s Pose Detection API.

**III. Work Design Concept**

MediaPipe Pose and ML Kit are utilized for human pose estimation (HPE) and a pose classifier is employed, trained using pose landmarks extracted from a yoga pose dataset. The application first classifies the practitioner's pose in real-time and then grades its accuracy and consistency. To assess the accuracy and consistency, the system is designed to record the practitioner's performance within a 15-second timeframe, capturing necessary data for each frame. The calculation of performance metrics in a person's yoga pose involves defining the pose in numerical terms. This is accomplished by determining the angles between specific body parts, which provide information about the pose.

For each angle in a pose, there is a specified “ideal angle”. These ideal angles are used to create the "ideal pose," which serves as a benchmark for the evaluation of the practitioner's performance. The system determines the accuracy of the practitioner's performance by comparing their pose to the ideal pose and the ideal angles. Moreover, the consistency of the practitioner's performance is evaluated by measuring their ability to maintain the pose within the defined 15-second window, regardless of any deviations from the ideal angles.

To evaluate the accuracy and consistency of a practitioner's yoga pose, MediaPipe Pose and ML Kit will be utilized for human pose estimation (HPE) and a pose classifier will be employed, trained using pose landmarks extracted from a yoga pose dataset. It will first classify the user's pose in real-time and then grade its accuracy and consistency. To assess the accuracy and consistency, the system will be designed to record the user's performance within a 15-second timeframe, capturing necessary data for each frame. The calculation of performance metrics in a person's yoga pose involves defining the pose in numerical terms. This will be accomplished by determining the angles between specific body parts, which provide information about the pose.

Figure 1. System ArchitectureDiagram

Description automatically generated

In a yoga pose, the angles between specific body parts, such as the elbows, shoulders, hips, and knees, are crucial in determining the proper alignment and posture of the pose [[5]](https://www.zotero.org/google-docs/?bsprdp). These angles play a significant role in the effectiveness and safety of the pose, as well as the level of difficulty of the pose. Maintaining proper angle relationships allows for optimal stretching and strengthening of the muscles, reduces the risk of injury, and ensures that the practitioner is getting the maximum benefits of the pose. Thus, accurately measuring and tracking these angles is essential for a successful and safe yoga practice [[7]](https://www.zotero.org/google-docs/?OnuMgl).

For each angle in a pose, there is a specified “ideal angle”. These ideal angles will be used to create the "ideal pose," which will serve as a benchmark for the evaluation of the user's performance. The system will determine the accuracy of the user's performance by comparing their pose to the ideal pose and the ideal angles. Moreover, the consistency of the user's performance will be evaluated by measuring their ability to maintain the pose within the defined 15-second window, regardless of any deviations from the ideal angles.

**Data Collection,  and Preprocessing and Ideal Angles Calculation**

The process of collecting the dataset for this study will involve gathering images of three yoga poses: tree, warrior 2, and goddess pose. A minimum of 250 images per pose will be collected. To ensure that the dataset is homogeneous, the asymmetrical poses of tree and warrior 2 will be standardized by aligning all instances in a consistent direction. To further mitigate the potential impact of the varying pose directions on the pose classifier’s accuracy, a separate set of these poses will be generated by mirroring the original set of images.

MediaPipe Pose will be used to extract the pose landmarks of the yoga pose dataset. The landmark information will be stored in a CSV file which will be split into a 80% training set, and 20% testing set. Furthermore, these landmarks will serve as inputs for the calculation of the ideal angles.

Diagram

Description automatically generated

Figure 2. Data Collection and Preprocessing Process Flow Diagram

To determine the ideal angles in the dataset, the arctan2 function will be utilized to calculate the angles between pairs of points. The formula is as follows:

joint angle =( arctan2 (Cy-By , Cx - Bx ) - arctan2(Ay-By ,  Ax -Bx  ) ) \* 100

Where

A= first landmark

B= second landmark

C = third landmark

landmarkx= x-axis of the landmark

landmarky= y-axis of the landmark

This methodology will enable the calculation of the angles between the three points and will be used to determine the optimal angle for each pose in the dataset. To do this, the system will calculate the angles between the elbows, shoulders, hips, and knees for each and every image. These angle calculations will then be averaged across the individual sets to obtain a representation of the ideal angles.

**Pose Classifier Training**

The pose classification in this study will make use of the k-Nearest Neighbor (k-NN) algorithm provided by ML Kit. To classify poses, the algorithm requires a representation of each pose as a feature vector and a metric to compute the distance between these vectors.

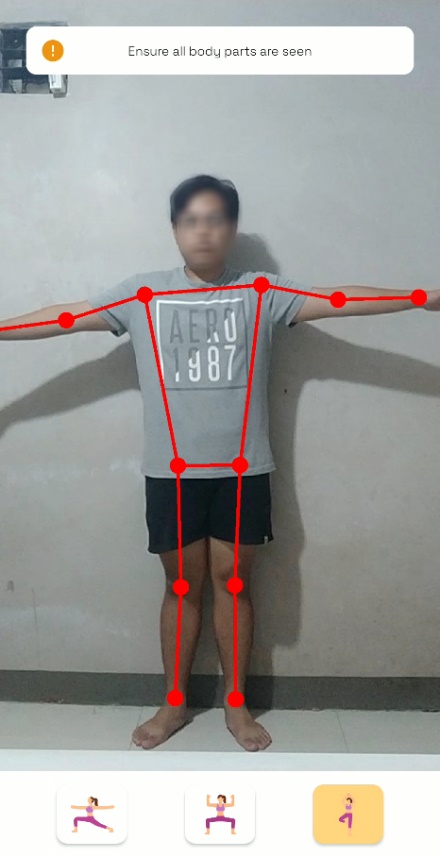
To create these feature vectors, pairwise distances between selected joints in the poses (such as the wrist and shoulder, ankle and hip, and both wrists) will be calculated and used. To ensure consistency in the analysis, all poses are standardized to have the same torso size and vertical orientation before creating the feature vectors.

To improve the accuracy of the classification, the k-NN search is performed twice using different distance metrics. Firstly, the minimum per-coordinate distance is used to eliminate poses that were similar to the target pose but had slight differences in their feature vectors, indicating a different pose. Then, the average per-coordinate distance is used to identify the closest pose cluster from the results of the first search.

Finally, exponential moving average (EMA) smoothing is then applied to reduce any noise in pose prediction or classification. In addition to looking for the closest pose cluster, a probability for each one is computed and will be used to smooth out the data over time [[14]](https://www.zotero.org/google-docs/?W5xeNW).

**Computer Vision and HPE**

AndriodX will be utilized to access the device’s camera and ML Kit’s pose detector will be employed to detect and track the pose of the most prominent person in the frame. The pose detector operates in a latency-reduced and smooth manner by avoiding the person-detection step in subsequent frames as long as the person remains visible and is detected with high confidence. The pose detector returns a Pose object that contains 33 pose landmarks [[16]](https://www.zotero.org/google-docs/?ALHZ5E), which will be used to create a visual representation of the pose skeleton and to calculate the joint angles of the detected pose. This pose skeleton will aid the user in making sure that all body landmarks are visible with a white skeleton indicating that all essential body parts are detected and a red skeleton indicating otherwise.

A picture containing text

Description automatically generated

Figure 3. Complete Landmark Detection       Figure 4. Incomplete Landmark Detection

**Performance Evaluation**

Accuracy and consistency are critical components in grading a yoga pose because it gives a clear indication of the level of control and mastery the user has over their body movements. An accurate pose is important because it helps prevent potential injuries that can result from incorrect alignment of body parts. On the other hand, consistency is important because it shows the user's ability to maintain the pose for an extended period, demonstrating their strength and stability. The ability to accurately and consistently perform a pose is a crucial aspect of successful yoga practice, and ML Kit's Pose Estimation feature provides the necessary data for pose evaluation through its PoseLandmark information.

*Accuracy*

To quantify the error, the "ideal pose" with “ideal angles” will be used as a reference to compare with the user’s pose. Both the "ideal" pose and the user’s pose are will be represented as arrays of angles and will be used to determine the accuracy of the user’s performance. The calculation of accuracy by deviation will be used to determine the extent to which a series of joint angles deviates from the “ideal angles”. By finding the difference between the mean or average joint angle and the ideal angle, and dividing it by the ideal angle, the system will able to determine the deviation and assess the accuracy of an individual joint angle.

Di=xi - m(X)

Where Di= absolute deviation

  xi= joint angle

m(X)= mean

The total accuracy is then obtained by averaging the accuracy of each of the eight different joint angles.

*Consistency*

The calculation of consistency for yoga poses involved determining the dispersion of the user's joint angles relative to the mean. The use of standard deviation allowed for the assessment of the consistency of the user's pose, regardless of its accuracy.

B= (xi - m )2N

Where B= user angle consistency deviation

xi= joint angle

m =mean of the joint angles

To obtain the overall consistency, the standard deviation of the consistency values for all 8 joints is calculated and used as the measure of the user’s total consistency.

Total Consistency (%)=( (Bi - )2N) \* 100

Where Bi= each deviation from the joint angle consistency

=mean of the joint angles consistency deviation

N = total number of angles

*Simple Moving Average Filter*

The detection of yoga poses involves stability challenges due to small movements of landmarks can cause fluctuations in the calculated angles. To mitigate these fluctuations and produce more accurate results, a simple moving average filter was applied to the angle data. This filter works by computing the average of a specified number of the most recent data points, effectively eliminating noise and providing a more stable and representative estimate of the data.

SMAk= Pn-k+1 +Pn-k+2 + ... + Pn k

         = 1ki = n-k+1nPi

Where SMAk= mean over the last k data-points Pi= each deviation from the joint angle

n =mean of the user angles

k =mean of the user angles

**IV. Feasibility Analysis**

The objective of this study is to create a yoga pose performance metric evaluation system for both beginner and professional yoga practitioners. The goal is to provide a mobile application that evaluates a yoga practitioner's pose accuracy and consistency in real-time, utilizing the MediaPipe Pose and ML Kit to create a yoga pose classifier trained on a dataset of yoga pose landmarks. This information will enable practitioners to identify areas for improvement in their yoga poses and focus on those areas in their practice. A two-sample t-test will be used to statistically analyze the data and validate the system's output with a professional yoga instructor's evaluation.

The study will be implemented in three phases: data gathering and preprocessing android development, and testing. The estimated timeline for the completion of this project is three months, with a focus on delivering a functional and effective tool for yoga practitioners. The results of this study will provide insight into the potential for utilizing technology to improve one's yoga practice and contribute to the field of health and fitness through the use of mobile technology.

**V. Expected Results**

The main objective of this study is to develop an objective and accurate evaluation system for yoga practitioners that is expected to have no significant difference in evaluating an individual’s pose performance compared to a professional yoga instructor. The system will employ MediaPipe Pose and ML Kit and should classify a user's yoga pose and evaluate accuracy and consistency in real-time. The expected outcome of this project is to be able to provide a valuable tool for yoga practitioners to enhance their practice by  allowing tracking of progress and safe practice without supervision.

**VI. Conclusion**

In conclusion, the mobile application "Motion" offers a unique solution to evaluate the accuracy and consistency of a user's yoga pose performance. The system aims to quantify the user's performance by calculating the deviation from the "ideal angle" to measure accuracy and using standard deviation to measure consistency. The use of this system will provide an objective way for individuals to track their progress and focus on areas for improvement in their yoga practice. Furthermore, this study highlights the potential for utilizing technology to improve health and fitness and contribute to the field through the innovative application of mobile technology in the practice of yoga.

**VII. References**

[[1] L. Douglass, “How Did We Get Here?A History of Yoga in America, 1800-1970,” *Int. J. Yoga Ther.*, vol. 17, no. 1, pp. 35–42, Jan. 2007, doi: 10.17761/ijyt.17.1.180p845622653856.](https://www.zotero.org/google-docs/?VWWQuJ)

[[2] A. Büssing, A. Michalsen, S. B. S. Khalsa, S. Telles, and K. J. Sherman, “Effects of yoga on mental and physical health: a short summary of reviews,” *Evid.-Based Complement. Altern. Med. ECAM*, vol. 2012, p. 165410, 2012, doi: 10.1155/2012/165410.](https://www.zotero.org/google-docs/?VWWQuJ)

[[3] J. Hart, “Core Wellness Practices to Recommend in Times of Crisis,” *Altern. Complement. Ther.*, vol. 26, no. 4, pp. 155–157, Aug. 2020, doi: 10.1089/act.2020.29280.jha.](https://www.zotero.org/google-docs/?VWWQuJ)

[[4] “The pros and cons of teaching yoga online,” *Sequence Wiz*, Jan. 29, 2020. https://sequencewiz.org/2020/01/29/the-pros-and-cons-of-teaching-yoga-online/ (accessed Sep. 14, 2022).](https://www.zotero.org/google-docs/?VWWQuJ)

[[5] S. Goyal and A. Jain, “Yoga Pose Perfection using Deep Learning: An Algorithm to Estimate the Error in Yogic Poses,” *J. Stud. Res.*, vol. 10, no. 3, Nov. 2021, doi: 10.47611/jsrhs.v10i3.2140.](https://www.zotero.org/google-docs/?VWWQuJ)

[[6] N. Yu and Y.-T. Huang, “Important Factors Affecting User Experience Design and Satisfaction of a Mobile Health App—A Case Study of Daily Yoga App,” *Int. J. Environ. Res. Public. Health*, vol. 17, no. 19, p. 6967, Oct. 2020, doi: 10.3390/ijerph17196967.](https://www.zotero.org/google-docs/?VWWQuJ)

[[7] A. Anilkumar, A. K. T., S. Sajan, and S. K. A., “Pose Estimated Yoga Monitoring System.” Rochester, NY, Jul. 08, 2021. doi: 10.2139/ssrn.3882498.](https://www.zotero.org/google-docs/?VWWQuJ)

[[8] H.-T. Chen, Y.-Z. He, and C.-C. Hsu, “Computer-assisted yoga training system,” *Multimed. Tools Appl.*, vol. 77, no. 18, pp. 23969–23991, Sep. 2018, doi: 10.1007/s11042-018-5721-2.](https://www.zotero.org/google-docs/?VWWQuJ)

[[9] P. Parmar, A. Gharat, and H. Rhodin, “Domain Knowledge-Informed Self-Supervised Representations for Workout Form Assessment,” *ArXiv220214019 Cs*, Feb. 2022, Accessed: May 17, 2022. [Online]. Available: http://arxiv.org/abs/2202.14019](https://www.zotero.org/google-docs/?VWWQuJ)

[[10] I. of M. (US) C. on M. N. Research, *Exercise, Infection, and Immunity: Practical Applications*. National Academies Press (US), 1999. Accessed: Jan. 29, 2023. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK230961/](https://www.zotero.org/google-docs/?VWWQuJ)

[[11] “Physical exercise and fall prevention: A systematic review and meta-analysis of experimental studies included in Cochrane reviews - ScienceDirect.” https://www.sciencedirect.com/science/article/abs/pii/S0197457221002184 (accessed Jan. 29, 2023).](https://www.zotero.org/google-docs/?VWWQuJ)

[[12] L. Zatolokina, “Human Pose Estimation Technology 2022 Guide,” Apr. 21, 2022. https://mobidev.biz/blog/human-pose-estimation-technology-guide (accessed Sep. 13, 2022).](https://www.zotero.org/google-docs/?VWWQuJ)

[[13] L. Trivedi and R. Vij, “Performance of different machine learning methods on activity recognition and pose estimation datasets.” arXiv, Oct. 18, 2022. doi: 10.48550/arXiv.2210.10247.](https://www.zotero.org/google-docs/?VWWQuJ)

[[14] “Pose Classification,” *mediapipe*. https://google.github.io/mediapipe/solutions/pose\_classification.html (accessed Jun. 27, 2022).](https://www.zotero.org/google-docs/?VWWQuJ)

[[15] “ML Kit,” *Google Developers*. https://developers.google.com/ml-kit (accessed Jan. 31, 2023).](https://www.zotero.org/google-docs/?VWWQuJ)

[[16] “Detect poses with ML Kit on Android  |  Google Developers.” https://developers.google.com/ml-kit/vision/pose-detection/android (accessed Feb. 02, 2023).](https://www.zotero.org/google-docs/?VWWQuJ)