Interim Report

PostureFit
An Intelligent Fitness Trainer Application

COMP4081 - Final Year Project

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Abstract

Overexertion and incorrect exercise technique are two main causes of injuries during exercise, mainly squats and deadlifts. However, existing solutions are expensive or inadequate in providing sufficient real-time feedback. PostureFit aims to assist in counting the repetition to reduce overexertion, and use Computer Vision and Machine Learning (ML) models to provide real-time analysis of the user’s execution technique. PostureFit would be developed as an application to reduce the user’s hardware cost. This report describes how our team will tackle the issues mentioned by developing a body form/posture analyzer, with novices lacking such movement experience as our main target user group. The development of this body form/posture analyzer application based on the Apple iOS ecosystem involves tasks comprised of stages of the Data Analysis process, in order to then be able to synthesize a well-defined ML model for analysis and detection. A full-scale application development process for its implementation will follow afterwards. The wireframes have been drawn, a batch of dataset collected and a Computer Vision model (MoveNet) has been tested to work on Apple iOS.
Acknowledgments

We would like to express my gratitude to Dr. Dirk Schnieders, our final year project advisor and a current lecturer in the University of Hong Kong, for his patience and effortful contributions in assisting us with this project’s development process. Without his guidance, we would not be at this stage in terms of progress and have confidence in its success.

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Table 4.1 Project schedule and milestones _________________________________ 11
1. Background

Physical activity is an essential part of maintaining a healthy body. According to the Centers for Disease Control and Prevention (CDC), physical activity contributes to the health of the nervous system, controls body weight, reduces the risk of diseases, and strengthens bones and muscles [1]. One of the most popular ways of achieving these goals is by exercising at fitness centers. A poll found that around 20 percent of adult Americans have gym memberships [2]. However, one of the major risks to health in gym exercise is injury, in which research has shown that the main cause of fitness-related injuries is due to overexertion or unnatural movement. Performing repetitive improper movements is unfortunately, the most common issue leading to acute injuries [3] which may even turn chronic, if not corrected early. For example, overexertion and unnatural movement cause around half of all free weight exercise and 80% of all squat, lunge, or deadlift movement injuries [4]. It is therefore important to have correct form during exercise.

Currently, most people lack adequate resources to maintain good form while performing exercise. As the problem is typically only able to be identified by a 3rd party [5], people are usually recommended to have a personal trainer to help correct exercise movements. However, this is often an expensive option in Hong Kong at an average of 650 Hong Kong Dollars per hour [6]. Another option is to perform exercises at home and using internet resources such as online videos and text for reference. This method has become more prevalent because of the COVID-19 pandemic [7]. However, this option often lacks adequate feedback and may cause injuries as the performer may not be aware of the ramification of their incorrect technique (body posture/form). We believe PostureFit can help solve a range of problems in strength training by providing a low-cost alternative with feedback via a mobile application.

This report outlines the project aims and objectives in section 2. It then reports on the methodology of designing the User Interface (UI) and an overview of future tasks in section 3. Afterwards, the discussion of the current project timetable in section 4. Lastly, the conclusion summarizes the report in section 5.
2. Objectives

PostureFit will be implemented and deployed on the Apple-based ecosystem on iOS with a Graphical User Interface (GUI) - the “screen” where users would look into to interact with the application. With our current plan, PostureFit shall cover two of the most popular and complex movements to perform, i.e., squats [8] and deadlifts [9] (see Appendix A). There may be additional movements if time allows. With the development of the project, PostureFit shall solve and aid in the following:

2.1. Intuitive fitness application

There hardly exist mobile-based fitness applications that guide users towards their exercise goals, without requiring them to guess whether the form/stance is proper for the particular movement they are performing. Such applications are generally one-way and do not offer distinct and clear instructions. Although similar systems exist in the market, they usually require additional hardware and are expensive.

2.2. Cheaper alternative

Hiring a personal trainer has been the norm for most people looking to improve their fitness journey. This is usually impractical for most people due to the costs associated with subscribing to a personal training plan. We aim to reduce costs by developing an iOS application running on Apple iOS devices. Most people already have a smartphone, with 93% of people older than 10 years old owning some smartphone in 2021 in Hong Kong [10]. This means that this proposed solution can be adopted with zero additional hardware cost for most. We agree that similar solutions exist in the market, such as Alfa AI [11], however most are notorious with their pricing scheme, in that they do not offer flexibility to users’ needs - they charge users for functions they may never use or simply do not want. Another example is IncludeHealth, which works by observing movements of body parts with a repetition counter as guidance during training [12]. This, however, does not provide feedback concerning the user’s execution technique correctness, whereas PostureFit would observe, assess, and correct the user’s form, alongside other potential features. IncludeHealth is also yet to be available to the public, meaning that it is not possible to compare the efficacy
between the two. We thus aim to create a competition that would include features we believe are most beneficial for the user.

2.3. Exercise status tracker
The application will assist with counting the number of repetitions performed. This function would improve convenience for the user and by counting the amount of repetition performed, it can reduce overexertion and mental stress by the user in keeping track of the his/her current working set.

2.4. Body form analyzer
We are striving to create a particularly intuitive and effective body form analyzer that would allow users to exercise wherever they wish to - from the comfort of their home to fitness environments. This will be implemented onto the convenience of a mobile-based application developed on the Apple iOS ecosystem, paving way to user adoption with ease and simplicity due to their significant market share worldwide.

3. Methodology
The development process of PostureFit can be divided into five main tasks: incrementally developing the application in parallel with other tasks, testing the Computer Vision model (i.e., MoveNet), data collection, processing data (i.e., data wrangling and exploratory data analysis (EDA)), and creating Machine Learning (ML) models. This interim report offers a detailed description for the first task as well as an overview of goals and brief discussions of how the stated goals can be achieved.

3.1. Mobile application development
We are developing a mobile application on Apple’s iOS ecosystem with GUI for users to interact with and utilize the functions of this project, in parallel with other aspects of the project. This mobile-based application is being developed on Apple’s Integrated Development Environment (IDE) known as Xcode. The application does not require a server as data and functions are processed locally. The application would function as follows:

1. The camera would live-feed a series of frames of the user’s movements.
2. The live-fed frames would then be transformed into data points using the computer vision model outlined in section 3.2.

3. The application shall display key points and green lines connecting them for user reference.

4. The data points would be fed into the model synthesized in section 3.5, which would assist the user while performing exercise.

5. After multiple frames, the model should detect the type of movement performed and begins counting the repetition.

6. When the user starts from the first key points (i.e., a specific stance) detected and has movement per the model, the application would display an overlay of proper form/posture, i.e., colors and lines.

7. If the user’s dynamics does not follow the movement predicted by the model, the guidance line for the respective body part would turn red; a red arrow suggesting improvement would also be shown.

The application is tested on iPhone 12. The application is tested on (1) its performance using the frame rate, (2) accuracy, and (3) user satisfaction with the application.

The wireframe, the first step in the design of a GUI and a rough design of an application or website [13], has been drawn to include the desired functionalities. The application design contains the following elements:

a. repetition and set counter;
b. an outline of the user body to show how the computer vision algorithm would function;
c. signs and arrow signals of how to improve the execution technique for instantaneous feedback.
The GUI design is divided into two sections, the home screen and the main screen:

### 3.1.1. Home screen

This will be the first screen with action buttons where the user would begin interacting with the software (Fig. 3.1). With our current blueprint, it will display the two selected movements, i.e., the squat and deadlift, for the user to select which he/she wishes to perform and be guided through. It is also possible that we implement an automatic detection tool, where the application would be able to analyze and identify

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**Fig 3.1 Home Screen; 1) Action button w/squat graphic, 2) Action button w/deadlift graphic, 3) Action button for automatic detection**

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**Fig. 3.2 Main Screens; 1) User’s real time stance w/color-coded guidelines, 2) Dynamically adjusting bottom menu (collapse and expand up to dotted line) w/ pause and stop buttons, 3) Drop-down menu for exercise selection, 4) Repetition counter for the current working set. Selecting 3) to change between movements, e.g. deadlift to squat would bring screen A to D.**
the type of movement the user is performing. This would be the result of the implementation of classification models, if successfully implemented in section 3.5.

3.1.2. Main screen

Upon selection/identification of the movement, the screen will display a repetition counter on the top right of the screen, if again, the classification model (section 3.5) is successfully implemented.

The application will utilize the device’s front-facing camera while it is running. It will live-feed a sequence of frames of the user’s movements for transformation into key-points by computer vision model outline in section 3.2 and then processed by the models synthesized in section 3.5 with possible additional self-coded algorithms. Color-coded guide lines and key-points will be included and aligned onto the user’s body for user feedback and reference. This is the main function of the application and the project as a whole. This resembles to that of a systematic stick figure graphical representation as shown in Fig. 3.2 in the previous page - red-colored lines indicate that the particular limb/body part requires correction towards the direction of the arrow, whereas green-colored lines indicate that it is within acceptable limits (i.e., proper form/stance).

Should the user wish to pause/change/end the current exercise, he/she can manually do so by tapping on a specific button situated at the bottom menu of the screen. This bottom menu also includes a drop-down menu, in which the bottom menu will dynamically adjust after it is triggered, consisting of the other type(s) of movement(s), with squat/deadlift as the only two options in the meantime (depicted in Fig. 3.2, 3).

The application may also be able to detect if the user does not exhibit any form of exercise motion, automatically pausing the session.

3.2. Computer vision model testing

This project uses a computer vision model that allows computers to extract information from images and videos [14]. We are utilizing an open-source pose detection model called MoveNet [15], developed by Google and readily available on the TensorFlow library. This model is specifically developed for pose detection and
Human Pose Estimation (HPE) i.e., the general problem in Computer Vision and ML with the goal to observe, analyze and identify the position and orientation of a person in the open environment through a camera [16]. We have selected Google’s MoveNet model instead of other major HPE models such as OpenPose and PoseNet, as it has the fastest processing speed in comparison to the other two, despite scoring the lowest in terms of accuracy [17]. We are mainly looking for faster performance with an acceptable limit to accuracy, since the users will be moving while such processing is performed within the mobile device itself - a more complex model will expend a longer processing time and require more power. Hence, the other two is not desirable for a mobile device. MoveNet also offers two variants of the model, namely: Lightning and Thunder. Lightning has been developed for latency-critical applications, whereas Thunder has been developed for high-accuracy applications. Nonetheless, it is claimed that both variants run faster than real-time applications (i.e., at 30+ FPS). MoveNet offers 17 key points for developers to work on. These points can then be used to construct a representation of the human body by adjoining lines between the points. An example of MoveNet implementation is shown in Figure 3.3 below, in which data extracted using the model are overlaid over the extracted image.

![Sample implementation of the MoveNet computer vision model.](image)

Fig. 3.3 Sample implementation of the MoveNet computer vision model. 3 sample images are overlaid with key data points extracted using the model identified by pink dots. Lines connect key body parts where orange, blue, and white lines represent left side of the body, right side of the body and connection between the two, respectively [11].
To test the functionality of the computer vision model, MoveNet, the model is being incorporated into a prototype. MoveNet is selected because the model has been specifically trained using images of physical activity stances [18]. This should improve detection accuracy as the model’s training set fits the project’s intended use case. The prototype would be able to receive live photo fed from the device’s camera and display them on screen. Furthermore, it would display the coordinates of key data points outputted from the MoveNet model. The model has been tested for its performance which can be inferred to having between 43 to 51 frames per second on an iPhone 12 [18]. We, therefore, are aiming to create a prototype that can process at least 30 frames per second - rate at which the live video feeds.

3.3. Data collection

Data best suited for analysis is in the form of graphics, i.e., still images and videos (image sequence) of different body stances associated with the squat and deadlift. We have collected such data from:

a) Online sources/databases (e.g. YouTube, Google Images, etc.)

b) Recording videos/images of ourselves or participating subjects performing the selected movements

c) Asking participants to submit recordings of themselves performing the selected movements

We have classified the imagery in each movement to be either acceptable or unacceptable with the guidance of a physical instructor of experience for further processing in later stages of Data Analysis (DA). This classification should not be confused with data cleaning (i.e., the process of removing anomalous data from the dataset), as we should process data from both categories (i.e., acceptable or unacceptable). This is crucial as we utilize the datasets for supervised learning (SL) - an ML technique of processing from available data, in which each data point is labelled and contains features, in order to distinctly classify objects afterwards.
3.4. Data wrangling, cleaning and EDA

This is the part of DA where MoveNet has also brought about its functionality. With its utilization, data points have been pin-pointed and extracted upon detection by the model. As expected, we have extracted all the 17 key points detected by MoveNet from most of the graphics and stored such data in the comma-separated values (CSV) file format, i.e., a popular data storage format where each value is stored as text, separated by commas [19]. This format is chosen because of its compatibility with multiple programming languages as well as supported by many programming libraries, and packages of developed code which can be reused [20]. We have opted for the Thunder variant of the model as it offers more accuracy than Lightning. Accuracy is paramount while processing data for analysis - it is crucial for us to detect anomalous data and remove them if necessary, otherwise it will severely impact the accuracy of the models to be synthesized in later stages. We are currently in this subprocess of identifying and removing anomalous or missing data in a process called data cleaning. Notwithstanding, missing data points collected from image sequences may be calculated using the average of adjacent timeframes (e.g., if data points are missing in frame 7, such data points can be calculated from frames 6 and 8). The ‘cleaned’ data will be transformed and be better shaped for data modeling. This process is called data transformation.

In EDA, we will perform further exploration in terms of the datasets acquired from earlier data collection. EDA is the investigation and analysis of the collected data to help extract new information [21]. Here, we aim to gain a better understanding of the data and interactions between variables. We plan to utilize descriptive statistics and visualization (i.e., charts). Descriptive statistics summarizes the collected data and presents its features into quantitative information. We are adopting this statistical model due to the information it yields, i.e., information about variables in a dataset and it highlight potential relationships between variables. We expect to realize the relationship between data and variables that may not be noticed in previous stages. Data anomalies not detected previously may also be encountered in this stage, thus possibly requiring us to return to the data cleaning process.
3.5. Model synthesis and in-depth analysis

We will explore multiple SL algorithms to detect the type and key moments of the two chosen movements (i.e., squat and deadlift). We will employ SL using processed images’ datapoints of key moments as training data. The goal of this model is to use the moments to distinguish between the varying nature of movement technique/posture. Additionally, as repetitions are a series of key moments, by detecting these moments, for example the upper position and lower position, we can then use it as checkpoints to count the number of repetitions performed. The algorithm which has the highest accuracy for each case will be chosen. We will perform hyper-parameter tuning as well as other ML improvement techniques such as dimensionality reduction, ensemble learning, etc. The accuracy, as a standard for SL, will be computed by comparing the predicted classification of test data with the data’s label.

We will explore multiple regression models to find the variables needed to create a function that can determine the correct location of the key points as a function of time. We opted for the regression model because there exists a range of values that can be considered as proper form/execution technique; additionally, we are yet to know the function of the range. As a result, we shall employ ML to help determine these values. With the function determined, the application can then compare the supposed location of each body points with the user’s position to suggest improvements. As with SL, the algorithm which provides the highest accuracy will be selected. The accuracy will be computed by comparing the algorithm results with the classification performed in section 3.3.
4. Project schedule and milestones

The development process has brought about unexpected delays to our initial schedule. Due to personal work and the difficulty encountered, there was a need to push data wrangling, EDA and synthesis of ML models down the timeline.

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<th>Date</th>
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<th>Status</th>
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<td>15 October 2022</td>
<td>- Created wireframes for GUI</td>
<td>Completed</td>
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<tr>
<td></td>
<td>- Explored HPE libraries for further processing of raw data</td>
<td></td>
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<tr>
<td>22 November 2022</td>
<td>- Finalized data collection</td>
<td>Completed</td>
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<tr>
<td>3 January 2023</td>
<td>- Developed iOS-based <strong>prototype</strong> running MoveNet on iPhone</td>
<td>Completed</td>
</tr>
<tr>
<td>26 January 2023</td>
<td>- Complete data wrangling and cleaning of current batch of data</td>
<td>In progress</td>
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<tr>
<td></td>
<td>- Complete EDA with current batch of data</td>
<td></td>
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<tr>
<td>9 February 2023</td>
<td>- Complete synthesis of the ML model for repetition counter</td>
<td>Planned</td>
</tr>
<tr>
<td>16 February 2023</td>
<td>- Incorporate repetition counter ML model into the iOS application</td>
<td>Planned</td>
</tr>
<tr>
<td>9 March 2023</td>
<td>- Complete development of a posture correction algorithm or ML model</td>
<td>Planned</td>
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<tr>
<td>23 March 2023</td>
<td>- Deploy selected algorithm and ML models onto finalized mobile application</td>
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<tr>
<td>30 March 2023</td>
<td>- Test application for real-world usage</td>
<td>Planned</td>
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<tr>
<td>6 April 2023</td>
<td>- Finalize mobile application deployment on iOS</td>
<td>Planned</td>
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Table 4.1 Project schedule and milestones
4.1. What has been accomplished

4.1.1. Wireframe and GUI prototype
Currently, we have completed aspects of Graphical User Interface (GUI) design, further to the wireframe (i.e., the skeleton of an application’s ‘screen’) - the prototype version of a working mobile application and later, for testing purposes such as implementing the MoveNet model and for other Machine Learning (ML) models that will be synthesized in later stages of the process.

4.1.2. Data collected and wrangled
We have collected video data from various sources as mentioned in the methodology section, mainly from self-recording, requesting past recordings from friends and downloading videos available from YouTube, all of the two movements. Subsequently, we have also extracted singular frames from each video into the JPEG image format for further analysis in key point extraction for ML model synthesis in later stages of the process.

Fig. 4.1 Depicted key points identified on extracted frame

Fig. 4.2 Collection of video data
4.1.3. Test MoveNet deployment

The MoveNet HPE model has been tested on iOS on iPhone 12 to be running smoothly as expected with the utilization of TensorFlow Lite (i.e., a toned-down version of TensorFlow made available for mobile devices).

4.2. What will be done

As noted in the project timeline, the second semester will focus on the creation of ML models which can help accomplish our project objectives, namely repetition counter and posture correction algorithm. The tasks we wish to accomplish are as follows:

A) Synthesis and incorporation of a repetition counter ML model
B) Decision on the utilization of an algorithm or ML model for execution technique correction
C) Finalization and testing of the project goal

5. Conclusion

PostureFit is a versatile and intuitive mobile application, designed to be readily available to the general population. It assists users in the types of exercise movements (i.e., squat and deadlift for now) they wish to perform with proper form. We have completed the first few milestones of the project, along with exploration of open-source pose estimation models available for use, namely: OpenPose, PoseNet and MoveNet. The decision to adopt MoveNet was due to its appropriate performance in speed and accuracy - 30+ frames per second analysis rate on a moving subject, with an average accuracy rate of 80.6% (Thunder variant).

We are also aiming to be as energy-efficient as possible with the adoption of MoveNet.
without sacrificing a great amount of accuracy. Following the adoption of a pose estimation model, we were able to lay out a plan for DA - the most crucial phase in the project in order to be able to yield a useful and precise ML model.

The project can be divided into five tasks. First, the design of the application was done. Second, we are testing the implementation of the computer vision model, MoveNet, for our prototype. We aim to achieve at least 30 frames per second to ensure fluid user experience. Third, we collect data by taking videos, requesting for videos, and collecting from online resources. Fourth, the data is being cleaned to improve ML accuracy. Fifth, the data will then be used to develop a ML model which would distinguish key moments and provide prediction for body parts’ location of correct form. Sequence of key moments will be used to count repetitions while prediction will be used to provide feedback of the user’s form.

We acknowledge that limitations exist, of which a major one is the positioning of the camera (device) from the user. We understand that it is of natural preference that users would like their mobile device to be placed right in-front of them, without the need to glance to their side, straining their neck. We will soon explore the possibility of placing the device diagonally from the user, in an attempt to reduce strain and discomfort (refer to fig. 5). However, it is still uncertain of its possibility to function. Overall, although with minor delays and difficulties that we have encountered along the way, we believe that PostureFit is well underway towards success.

![Fig. 5 Possibility of device placement from user (top view); 1) User, 2) Mobile device](image)
References


Interim Report


Appendix

Squats and deadlifts as depicted in Fig. A.1 and Fig. A.2 respectively, are very complex movements to perform, requiring gross motor skills (large muscle involvement) and a great amount of concentration, due to which inexperienced individuals performing either movements have a high chance of executing it improperly, if not guided by a professional. This is the main reason why we have chosen them as the first two types of exercise movements that PostureFit shall aid with.

The squat mainly targets the gluteus Maximus, minimus and medius (buttocks), quadriceps (front of the thigh) and hamstrings (back of the thigh) - a good number of large muscle groups to explain the reason behind the need of experience and good coordination in order to perform either movements properly. If a squat is done improperly, for example by leaning too much forward during execution, it will cause stress on the lower back instead of the target areas as mentioned before. This may also lead to lower back pain, knee pain and possibly herniated discs if done heavily and for a period of time.

The deadlift on the other hand, targets hamstrings, glutes, hip flexors, quads, core muscles, upper back muscles and lower back muscles - an even more complicated exercise movement in comparison to the squat. With similar reasons behind the need of experience and good coordination for proper execution, it is worth to reiterate that PostureFit is being developed to help beginners execute the movements properly and to prevent the aforementioned problems that might be encountered if done improperly.