Functional Movement (FMove) Tele-Screening Application

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Abstract

Recently, there has been renewed interest in fitness, especially with the rise in health conditions to lifestyle stress and pandemics. While the requirement of functional fitness has long been prevalent in sports, there is also a need for the same to maintain a healthy lifestyle with age and recover from various injuries. It is important to achieve functional fitness by spending long hours in the gym. Functional Movement Screen (FMS) is a screening test popularly used by physiotherapists to assess compensatory movement patterns that increase the chances of injury in sports. Popularly used in sports analytics and rehabilitation, the FMS is also used in movement correction for a fit lifestyle. In this work, we develop a mobile platform "FMove" for functional fitness evaluation using any mobile or embedded device with a camera. Our application uses real-time joint tracking from live videos to calculate the identified joint angles and distances for movement pattern monitoring and automated scoring of the movement form. A functionality score was automatically assigned based on the movement form, followed by a questionnaire for self-reporting of pain by the users. Our User Interface (UI) allows end users to automatically monitor their FMS scores.

Keywords: Biomedical Engineering, Healthcare Informatics, Mobile Application, Joint Tracking

Introduction

There has been a significant increase in the number of fitness applications that allow regular tracking of exercise routines and nutrition. With the recent success of AI and computer vision methods, applications to monitor exercise have been widely accepted. This application is further bolstered by the requirement for remote monitoring and assessment of functional fitness, which is of utmost importance in occupational therapy and in prevalent times of remote work. These applications can not only promote a healthier lifestyle but also aid healthcare professionals in alleviating their increased workload. Despite technological improvements, existing applications and systems do not focus on functional fitness movements. Over the last decade, the importance of functional fitness has gained momentum. Functional fitness leads to fewer Musculoskeletal Diseases (MSD), which are on the rise due to an unhealthy lifestyle and long work weeks with prevalent 1.71 billion cases worldwide [4] and are the primary source of disability [22]. A strong relationship has also been established between the workplace and MSD [5].

The Functional Movement Screen (FMS) is an application used to rate and rank movement patterns and functional mobility and is primarily targeted by physical therapists and fitness professionals. Experts have historically used the Functional Movement Screen (FMS) to assess the risk of sports injury [13]. Furthermore, [19] demonstrated the use of the FMS to identify the risk factors for MSD. The FMS is not meant to diagnose specific medical conditions but rather to identify movement dysfunctions and limitations to help prevent injuries and improve physical performance. It is commonly used in sports, physical therapy, and fitness settings. FMS consists of seven fundamental movements [2]:

* Deep Squat: Evaluates flexibility, mobility, and stability in the hips, knees, and ankles.
* Hurdle Step: Assesses stability and mobility in the hips and pelvis.
* Inline Lunge: Focuses on hip mobility and balance.
* Shoulder Mobility: Checks the flexibility and range of motion in the shoulders and thoracic spine.
* Active Straight Leg Raise: Evaluates hamstring and lower back flexibility.
* Trunk Stability Push-Up: Measures core and upper body strength and stability.
* Rotary Stability: Tests core strength and stability during rotational movements.

Each of these movements was scored based on specific criteria and rated on a scale of 0 to 3 where 3,2,1 represent perfect completion, compensated completion, and inability to complete the pattern, respectively. A score of 0 indicated the inability to complete the movement due to pain. The scores were summed over the seven movements with an expectancy of a minimum of 14, which signifies an increased risk of injury from physical activity. Once an individual's movement patterns are assessed using the FMS, appropriate corrective exercises can be prescribed to address identified issues. These corrective exercises are designed to improve movement quality and reduce the risk of injury. The FMS is commonly used by coaches, trainers, physical therapists, and other healthcare professionals working with athletes and individuals seeking to improve their physical fitness and wellbeing.

To make healthcare accessible to the general public at a low cost, we propose the development of a mobile FMS test to automatically score recommended movements. Our proposed application is not a medical diagnostic tool but is meant to aid the general population in understanding their standardized functional fitness score to seek medical help as and when required. The main contributions of this study are as follows:

* A novel application, FMove, was designed for automated Functional Movement Screen monitoring to assess compensatory movement patterns for early assessment of injury risk using a mobile device camera.
* Identification of joints, joint angles, and distances for automated scoring of FMS movement patterns.
* A mobile application was developed for facilitating tele-assessment and early risk identification using a mobile device.

Related works

1. *Automated Exercise Tracking*

Exercise Tracking has been extensively investigated with varied intellectual merits. The literature can be specialized in end-to-end applications using deep learning, which are black-box models, and find limited use in risk assessment owing to its limitation in understanding their reasoning. We discuss some popular relevant systems non-exhaustively. Exercise Tracking involves three major steps: 1) Joint Recognition, 2) Joint Angle Calculation, and 3) Angle Tracking. Joint Recognition is a more computationally challenging task with popular approaches using RGB images, RGB-D depth images, and 3D skeleton information. Advanced camera devices such as Microsoft Kinect and Azure Kinect have in-built joint tracking, but such devices are not readily accessible to the public and are expensive [23]. SMPL [17], Mediapipe [18] are popular open-source real-time joint tracking systems with 2D RGB images.

Automatic exercise monitoring has been used on mobile apps [6], wearable sensor devices such as RecoFit [20], and smartwatches [1, 3] with integrated sensors. Weight tracking for fitness was proposed by incorporating accelerometers [8] and RFID [11]. Our system is a mobile application that does not require any additional sensors and is geared more specifically towards FMS assessment. Furthermore, these existing apps mostly track exercise repetitions and sets and do not always require real-time body joint tracking and processing to ensure correct movement form.

1. *Mobile Fitness Applications*

Various exercise-based games have been developed for mobile and Virtual Reality (VR) targeted to different medical conditions and for general fitness. Many exercise-based apps are modelled as exergames to motivate users to participate, such as Mr. Mapp [7] focuses on Phantom Pain, mobile based Fitness Tour [9] towards obesity, while others focus on a wide range of fitness applications such as Vertipex [15] in VR, Fitness Companion [21], Bunny Bolt [14], and FitCoach [12].

1. *Mobile Functional Movement Screen*

In our search, we found two mobile applications, namely FMS Pro and Symmio, which discuss mobile FMS and are developed by the same team. However, FMS Pro is a paid service and Symmio is by invitation only, which hinders the comparison or testing of the same. These applications have not reported discussions on the use of any automated movement form tracking or automated scoring. Symmio is backed by research [19], where authors conduct a user study on the validity of the application but does not discuss how the application works or FMS scores are calculated making it a black-box for social use.

FMove Design

1. *Application Components*

Our proposed application has 5 major modules namely 1) Joint Selection 2) Joint Tracking, 3) Movement Tracking, 4) Automated Scoring, and 5) Pain Questionnaire as illustrated in Figure 1. Module Joint Selection: The first component of joint selection allows end-users to perform general FMS where the required joints are preset and through expert-in-the-loop allows experts to monitor selected joints for improvement. We performed tests to establish the baseline joints to be tracked for appropriate FMS movement monitoring.

**Module Joint Tracking:** Following Joint selection, the joints are tracked in real-time through the mobile device camera using open-source Mediapipe [18] which is an open-source framework providing real-time, cross-platform computer vision applications using the BlazePose [24] deep learning model. We used Mediapipe's pose tracker, which identifies 33 joint landmarks and provides their three-dimensional (3D) coordinates. Based on the information from the earlier module, we filter the necessary joints to speed up mobile device computation.

**Module Movement Tracking:** Our third module tracks the movement while being performed for a single repetition, which is the standard procedure according to the official FMS guidelines. Each movement was initiated using a demonstration video of the movement to be performed. The user is prompted to enter a preset pose specific to the movement, and the application automatically verifies the pose using joint orientations. Once the pose is verified, the user can activate the sequence for the movement and perform the movement using trigger actions such as palm closing. If the movement is not ended manually within 60 seconds using a palm-closure gesture, our application automatically assumes completion of the movement, assuming that the movement cannot be completed by the user. In Figure 2, we present the User Interface of our application.

**Module FMS Score:** For movements tracked, deviations from the FMS official movement checks are used to compute the FMS score in real-time which is displayed to the end-user. Furthermore, an FMS score of zero was automatically allocated for non-completion of the movement. For computation of the FMS score, we used the official guidelines for each movement and passed the information on joints selected by the in-loop expert user during the session.

A diagram of a work flow

Description automatically generated

*Figure 1: Automatic FMS Monitoring and Scoring Pipeline*

**Module Pain Questionnaire:** In this application component, we ask user for self-reporting their pain experience on a scale of ten following the Numerical Rating Scale (NPRS-11) [10]. Traditionally, the FMS score asks for user pain only when the user obtains a score of 0, but we extend the same to collect pain scores irrespective of the FMS Score, as users with higher pain thresholds may complete the movement while experiencing pain.

Our third, fourth, and fifth modules were intertwined, tracking all seven movements, calculating their FMS scores, and collecting the pain questionnaire one after the other. The FMS scores for all seven movements were summed for a comprehensive FMS score and pain score, which were provided to the user and experts if involved in joint selection.

1. *Automated FMS Scoring*

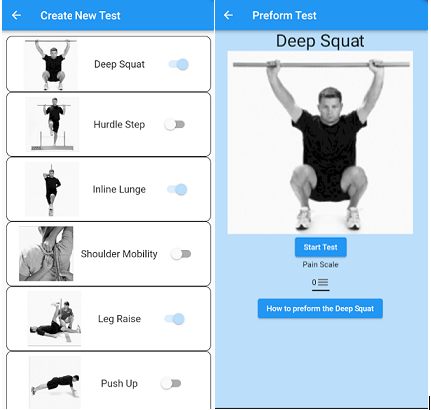
Our application automatically scores based on the FMS criteria, which vary for each movement [2]. The recorded video for each exercise was transferred to a backend Python server for scoring purposes. We tracked different joints and calculated the appropriate angles and distances between them to enable automated movement pattern tracking and scoring, as listed in Table 1. We showed a live display of the angles and distances on a screen to aid users in understanding their movement patterns.

1. *User Interface*

Our prototype application user interface focuses on ease of use. Our application home screen shows images of the seven FMS movements that, when clicked on, opens a new page with the option of viewing a movement demonstration video and button to initiate a test for the movement that initiates the mobile camera. Once a movement is completed, the toggle for movement on the home screen is switched to show the same. Once a movement is completed, the mandatory pain scale is automatically prompted and assigned a value. The FMS score was automatically populated from the back end. Once all movements were completed, the cumulative FMS score was obtained.

*Table 1: Movement Types monitored in our FMS application, Joints Tracked, Angles Measured and Distanced Measured for monitoring movement form and automated scoring.*

|  |  |  |  |
| --- | --- | --- | --- |
| **Movement Type** | **Joints Tracked** | **Angles Tracked** | **Distances Tracked** |
| Deep Squat | Ankle, Knee, Hip, Shoulder | Hip,Knee | - |
| Hurdle Step | Hips, Knee, Ankle, Wrist, Shoulder | Hips and Shoulder for lumbar spine | - |
| In-Line Lunge | Shoulder, Wrist, Feet, Knee | Shoulder | Left to Right Feet |
| Shoulder Mobility | - | Wrist | Left to Right Wrist |
| Active Straight Leg Raise | Hip, Ankle, Shoulder | Hip | - |
| Trunk Stability | Elbow, Thumbs, Eye, Mouth, Shoulders, Hips | Elbow, Spine | Thumb to Shoulder |
| Rotary Stability | Elbow, knee | \_- | Elbow to Knee |



*Figure 2: User Interface*

FMove application Evaluation

The accuracy of movement pattern detection is largely dependent on the environment and Mediapipe, which calculates the joint locations in the backend. The Mediapipe has already been assessed to be efficient, reliable, and valid for use in tele-rehabilitation by Latreche et. al [16] against Goniometer and Angle ruler. Furthermore, the underlying BlazePose model outperformed the comparative approaches, with a minimal lag of 20ms on Pixel 3 and 25ms on Macbook Pro. [18]. We evaluated our application using a Pixel 5 phone Android emulator with a screen resolution of 1080 × 2340 as the target environment. We tested our application in indoor and outdoor lighting environments up to a realistic distance of 6 ft from the camera to work seamlessly.

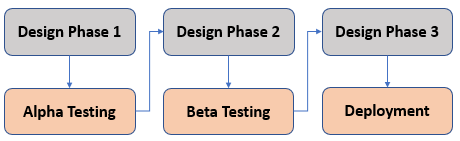
Discussions and Future Work

1. *Security and Privacy*

For our prototype application, we deleted the recorded videos to ensure that sensitive user data were not collected. In design phase II, we will attempt to process the FMS score frame-by-frame, making it real-time and alleviating the need to store videos for FMS score calculation. In the future, we plan to test our application involving experts such as coaches, trainers, and physical therapists, and implement the necessary databases and privacy for data storage and transmission.

1. *Future Work*

We identified four phases of development for all deployable applications, as shown in Figure 3. In this paper, we presented a prototype for the proposed mobile functional movement screening in Design Phase 1. In Design Phase 2, we will involve appropriate expert users for alpha testing of the application, understanding, and developing secure data collection based on expert requirements. We will conduct trials in Beta Testing and finalize our design in Phase 3. Furthermore, we will develop a deep learning algorithm to automatically score the movements through the Institutional Review Board-approved data collection and expert annotation of data in Design Phases 2 and 3.



*Figure 3: FMove Design and Testing Phases*

CONCLUSION

In this paper, we present a novel prototype application for a Functional Movement Screen (FMS). Our FMS application automatically scores the user's movement pattern using the prescribed FMS criteria on a scale of 0 to 3, along with a pain questionnaire on a prescribed scale of 1-10 for each of the seven movements. Our application uses open-source deep-learning packages to identify joint positions in 2D mobile device cameras. We identified and selected the correct joints required for each movement from tracking and allowed an in-loop expert to select monitoring joints and observe score improvement or degradation in physiotherapy programs. Our final application will be developed in three design phases intertwined with the testing phases. In the next phase, as future work, we will work with fitness and rehabilitation experts to extend functionality to accommodate expert-in-the-loop improvements in functional fitness and movement. The successful deployment of our application will be a step towards raising awareness of functional fitness in public and making health services accessible by leveraging advancements in technology.

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