A Project Report on

Recommender System for Running Technique using Machine Learning and Computer Vision

Submitted in partial fulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY

in

Computer Science and Engineering

by

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April-2019

Faculty of Engineering

Department of Computer Science and Engineering

CERTIFICATE

This is to certify that **Ashish John Stanley** has successfully completed the project work entitled "**Recommender System for Running Technique using Machine Learning and Computer Vision** " in partial fulfillment for the award of **Bachelor of Technology** in **Computer Science and Engineering** during the year **2018-2019**.

Dr. K. Balachandran
Head of the Department

Dr. K. Balachandran	**Dr. Iven Jose**
Head of the Department	Dean

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BONAFIDE CERTIFICATE

It is to certify that this project titled ”Recommender System for Running Technique using Machine Learning and Computer Vision ” is the bonafide work of

Name	Register Number
Ashish John Stanley	1560313

Examiners [Name and Signature]
1.
2.

Name of the Candidate :
Register Number :
Date of Examination :

Acknowledgement

I would like to thank CHRIST (Deemed to be University)Vice Chancellor, **Dr. Rev. Fr. Abraham V M**, Pro Vice Chancellor,**Dr. Rev. Fr. Abraham**, Director of Faculty of Engineering, **Fr. Benny Thomas** and the Dean **Dr. Iven Jose** for their kind patronage.

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Declaration

I, Hereby declare that the Project titled "**Recommender System for Running Technique using Machine Learning and Computer Vision** " is a record of original project work undertaken by me for the award of the degree of **Bachelor of Technology** in **Computer Science and Engineering**. I have completed this study under the supervision of **Dr. K. Balachandran**, Computer Science and Engineering.

I also declare that this project report has not been submitted for the award of any degree, diploma, associate ship, fellowship or other title anywhere else. It has not been sent for any publication or presentation purpose.

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Date:

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Abstract

Most professional athletes are monitored by a physical coach who ensures the athlete is learning and developing in the right direction without having many setbacks. Such is not the case for most recreational runners, who are often found learning from their mistakes. One such area where recreational runners tend to make mistakes is running technique.

Current systems which help analyse running technique are not developed for a recreational runner as an end user. They are more focused on aiding a physical coach who monitors and guides a professional athlete. A recommender system to analyse running technique would help recreational runners to avoid injuries and bad performance due to wrong running technique. Analysis of running technique is done by a human pose estimation deep learning model which eliminates the requirement of markers to identify the pose of the athlete.

The recommender system is made to analyse lower limb angles during block clearance of a 100m sprint. A good block clearance will enable the athlete to get maximum horizontal velocity while moving into the acceleration phase.

Keywords: Human Pose Estimation , Recommender System , Running Technique.

Contents

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

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Item	Description
PA	**P**ush-off **A**ngle
BCH	**B**lock **C**learence **H**eight of the Centre of Mass
SPH	**S**et **P**osition **H**eight
FSL	**F**irst **S**tride **L**ength
SSL	**S**econd **S**tride **L**ength
SAI	**S**ports **A**uthority of **I**ndia

Chapter 1

INTRODUCTION

In today's digital era, the sports technology industry is booming, with a value north of $700 million dollars. This fuels elite and aspiring athletes to reach their best potential and break human performance barriers. A brilliant example is Eliud Kipchoge, a Nike athlete making the full marathon world record his own with a timing of 2 hours 1 Minute 39 seconds. Eliud Kipchoge was also part of 3 member Nike team that trained with high-performance equipment and targeted to break the 2-hour barrier mark.

Along with this huge contingent of athletes, fans are not left out by this lucrative industry. Fans are given heart throbbing, up close personal experiences with their favourite sports and athletes. From buying merchandise to getting live updates and getting unimaginable viewing experience of live sporting events, the sports tech industry has made it easily accessible to the fan community. Technology has given so much to sports that their amalgamation has brought domain specific advancements under the umbrella of "Sports Engineering". New technologies have found unique and empowering applications in the field of sports. Latest camera technology and live streaming ability have brought a drastic increase in viewership of sporting events. E-Sports has picked up a large community and it is making a statement in the sporting industry. Teams and Coaches are leaning towards digital applications to manage and lead teams. Smart wearable technology and sensors have made tracking athlete and team performance more analytical helping athletes improve on finer elements of training.

This industry is not only helping professional and aspiring athletes making a career out of sports but also others from different walks of life to enjoy their fair share of fitness and good health. Digital applications allow an individual to carry out monitored and personalized training plans to achieve personal fitness goals. Individuals are highly motivated to keep up with a strong functional physique by sheer exposure to the athletes they look up to.

1.1 Problem Formulation:

Softwares to help analyse running form requires pre-requisite knowledge of running form. This makes such software hard to use for recreational runners. One would need to know what parameters are taken into consideration for analysing running form. Without this knowledge using such software would not provide much value to a recreational runner. Other systems that automatically analyse running require the athlete to wear markers to identify the key points of the athlete.

Introduction of a deep learning model that can perform human pose estimation will minimise the pre-requisite knowledge required to analyse running. The model will take an input frame and provide pose estimation and feature extraction to provide feedback on the running form.

1.2 Problem Identification:

1.2.1 The Elite and The Recreational Runner:

The elite athlete competing at a competitive level has access to advance methods of training and equipment. Behind each elite athlete is a large team of coaches and staff working to make training routines, diet charts, recovery sessions etc. These supporting teams have expanded their functionalities to even handling social media, event appearances, promotions, sponsorships and financial management of the athlete so that the athlete is able to prioritise and work on performance enhancement.

State of the art material science and technology research pour into designing high end training equipment and gear for athletes. These advanced studies makes sure athletes don't miss out on smaller yet finer elements of performance. Athletes are showered with such products and tools with the help of big sponsorships. The elite are continuously monitored by expert coaches to assure they make no wrong moves in their pursuit to be the best.

The recreational runner is one who cannot divert complete efforts into being the best athlete since they have other priorities namely their main career. Most recreational runners are pursuing sport as means to keep good health and fitness although they do take part in the occasional competitive events at a local level. With this approach towards sport it makes it hard for recreational runners to keep up with latest training equipment and techniques due to factors such as finance and exposure. This lack of access to the latest tech makes recreational runners miss out on the best the industry have to offer. This can lead to recreational runners using equipment and techniques that make them prone to injury. Trying to follow a technique and performing it wrong and not having a monitoring and correcting mechanism can cause long term injuries. Such injuries can be severe, and without access to the latest sports medicine it can even be fatal.

1.2.2 Importance of Technique:

Every physical sport involves certain actions performed by the athlete to achieve the end goal of the sport. All these activities have a form which makes the athlete ensure the physical actions are done with no injury and maximum gain.

Learning or correcting an existing technique requires monitoring and an expert eye to overlook the form to avoid injury. Injury is the biggest worry for anyone involved in physical activity. An injury can end a person's physical activity if very severe. Hence every technique aims at eradicating injuries while ensuring the best performance.

A large number of people run for a sake of general fitness. The common misconception is running form is something we all naturally know.

1.3 Problem Statement and Objectives:

A lot of recreational runners lack knowledge of the right lower limb angles and the tools to visually calculate them and attain feedback. To tackle this problem a recommender tool for recreational runners involved in sprint running is made. The tool would help identify key lower limb angles from the selected frame at block clearance. The push-off angle at block clearance will be calculated from a video input of the starting phase of a sprint.

The overall objective of the project is to understand the running technique in terms of the lower limb angles and then provide a feedback in the form of a recommendation to the athlete about a correction in the technique if required. The objectives of the project are enlisted below:

1. With the help of literature survey understand the constraints of the lower limb angles during the start phase of a sprint.
2. From video input of starting phase identify athlete and joints of the athlete to create basic structure.
3. Extract lower limb angles (Push of angle and rear knee angle) and provide a recommendation based on the value of angle calculated.

1.4 Limitations:

The limitation of this project is that the user will have to manually select the right frame for analysis. If a wrong frame is chosen from the video input it will lead to erroneous analysis. Also, the system does not provide a predictive result of overall running performance but just a recommendation on certain aspects of running form. A analysis of a combination of frames from the video input along with time parameters such as reaction time will help provide a more comprehensive analysis and performance prediction potential.

Chapter 2

LITERATURE SURVEY AND REVIEW

Through the literature survey an understanding of how the lower limb angles affect the running performance had to be achieved. Acceptable and preferred lower limb angles that an athlete should have had to be identified. The lower limb angles had to be specific to a sprint during the starting phase from the set position to the block clearance. On understanding the lower limb angles a survey had to be done to understand the best way to extract features from the video input of the athlete running. Being able to identify the joints and connect them accurately to be able to extract the lower limb angles was crucial.

2.1 Literature Collection and Segregation:

2.1.1 Literature about running technique:

Morgan , et al.[1] in their paper discuss in elaborate all the factors that affect running performance and give relations between these factors and running performance.

Running Performance: The running technique is designed for an athlete to get maximum gain with minimum injury. A common term associated with running performance is “Running Economy”. Running economy is subdivided in 5 main verticals as mentioned below:

1. The training the athlete has been involved in
2. Physiological build of the athlete ,
3. The environment of an athlete’s training
4. Biomechanics or running kinematics of the athlete and
5. Anthropometry of the athlete.

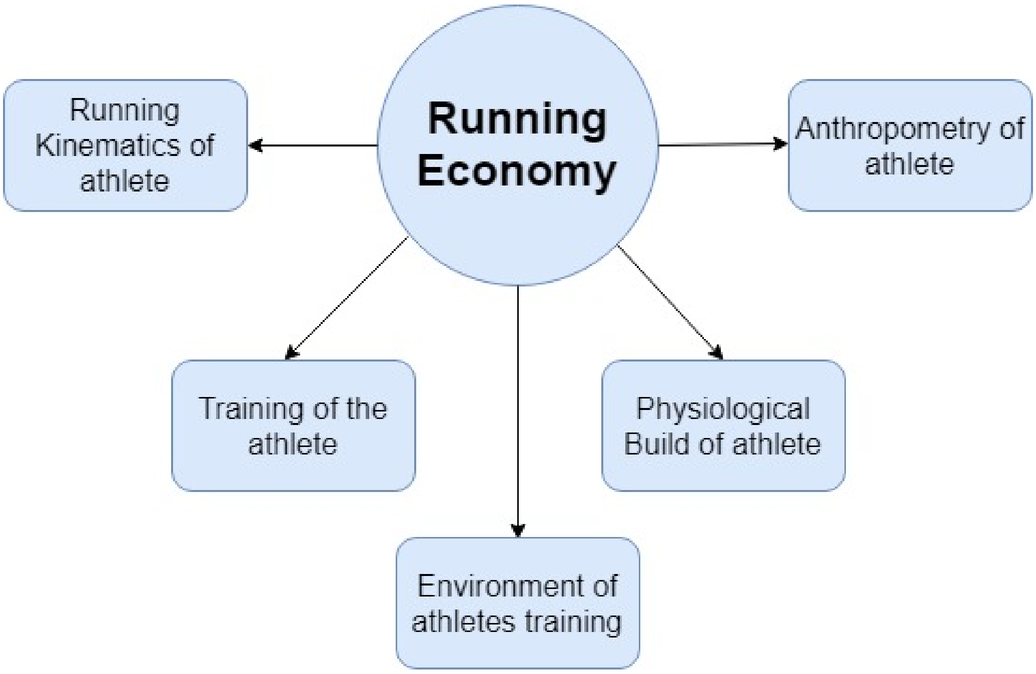

FIGURE 2.1: 5 Verticals of running economy

Each of these factors contribute to the performance of an athlete’s running performance. In this project we discuss only how Running Kinematics of a running athlete can be supervised by an expert system to identify and correct faulty posture.

2.1.2 Running Kinematics:

Running kinematics can be further branched out in detail under five different points:

1. Stride Parameters
2. Lower limb angles during different phases of running
3. Vertical displacement of the body (Vertical Oscillation)
4. Changes in horizontal velocity during ground contact
5. Trunk and pelvis orientation.

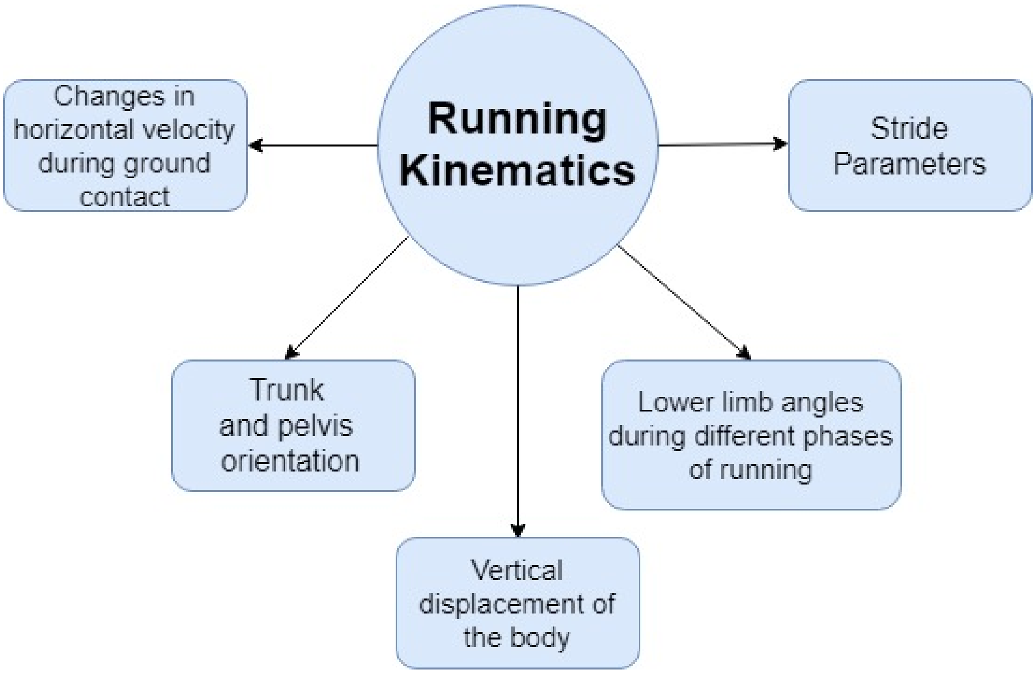

FIGURE 2.2: 5 Verticals of running kinematics

In this project the lower limb angles during the starting phase of a sprint will be extracted to provide a visual feedback to the runner.

Running can be divided into long distance endurance running and short distance running called sprints. Both the above mentioned running types have a running form specific to them. Sprint or short distance running has different phases and the running kinematics parameters vary in different phases of the sprint.

In a sprint there are multiple phases. This project deals with the starting phase of a sprint. The starting phase id the part of the race where the athlete is in contact with the blocks. In the start phase there is the set position and block clearance position.

FIGURE 2.3: The phases in a sprint

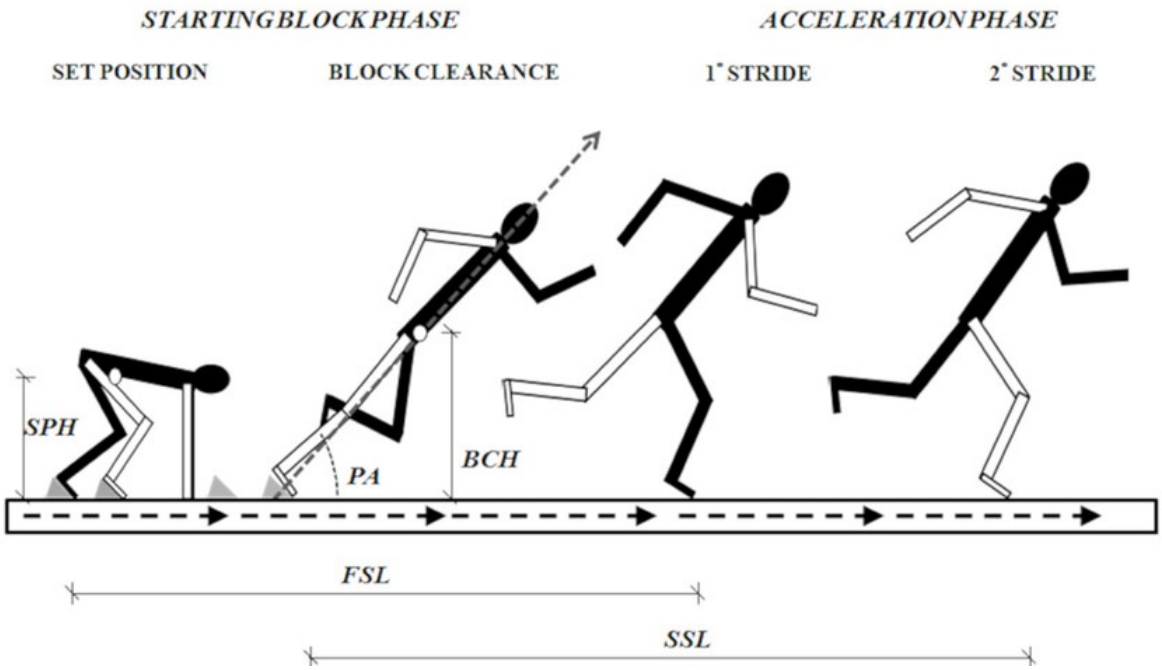

FIGURE 2.4: Start and acelleration phase in a sprint

- The set position height (SPH)
- the block clearance height of Centre Of Mass (BCH)
- push-off angle (PA)
- first (FSL) and the second (SSL) stride length

Biomechanics of the sprint start [2]:

The paper after studies identifies that the rear knee angle in set position can be around 90degree or 130degrees. On block clearance the athlete must leave the block at a low angle. Leaving the block at such a low angle will ensure that the athlete in the first and second stride length will have the total centre of body will be before the contacting point of the foot and the ground. An ideal first stride and second stride will ensure there is minimum horizontal braking forces.

From block clearance to sprint running: Characteristics underlying an effective transition [3]:

The paper discusses in detail all the phases of a transition of a sprint from the start phase to the acceleration phase. The start phase technique and impact of the technique on the performance in the sprint is enlisted. A good set position would require the centre of gravity high and placed closely to the starting line. Such a position can be achieved by adjusting different lower limb angles which is the main region of interest in this project. Hence the lower angles that need to extracted are:

- Rear Knee angle at set position
- Push off angle at block clearance (PA)

The effects of three different knee angles on kinematics in the sprint start [3]:

Three rear knee angles at block clearance are studied and their relation with the push off angle. The push of angle is crucial to attain maximum horizontal velocity in a sprint. The three angles discussed are 90, 115 and 135 degrees. The study revealed that a smaller rear knee angle will provide higher acceleration in the start phase. Hence of the three angles studied the 90 degree rear knee angle is preferred. These three angle did not have a relation with the push off angle. The push off angle will fall in the range of 32degree to 42degree for an ideal sprint start.

2.1.3 Literature for Feedback Systems and their effects on running performance:

Weakley, Jonathon JS, et al.[5] Demonstrated about the enhanced results in sports performance with the help of visual feedback in weight lifting. Athletes involved in weight lifting had a impact on the mood and competitiveness. The visual feedback to the weightlifters ensured increase in their performance.
A general study performed by Wilson, Kyle M., et al.[6] also depicts a drastic improvement in the mood , competitiveness and learning ability of an athlete with the help of visual feedback. Correcting technique is a critical learning component for an athlete

and providing visual feedback has shown increase in the learning ability of the athlete in the above mentioned paper.
Rowing technique correction has been made possible by real time visual feedback as depicted in the work of Fothergill, Simon [7]. The rowers were exposed to real time feedback of their technique and a visible improvement in their rowing technique has been confirmed. Similar result would be seen when visual feedback id provided for different sports techniques.

2.1.4 Literature on Methods of identifying Human Joints and Structure:

The book written by Moeslund, Thomas B., et al. [8] talks about the computer vision techniques of identifying humans and their activities. It speaks in detail about how to recognize parts of the body such as face of a human, and joints. For the project being identifying joints is vital to be able to extract features. The computer vision study which deals with visual analysis of human comes under "Human pose Estimation". Human pose estimation uses deep learning models to learn the features that define the pose of a human and identify it. These human pose estimation systems can be used to identify the various joints for the project.

The work by Balan, Alexandru O., et al.[9] discusses a method to extract 3D models of human shape and structure from an image. This ensure that human pose estimation is a good technique to rely on to create accurate representations of the human body. Hence Human pose estimation will help identify and create a simple structure of the athlete's body at different phases of the race.

Work by Cao, Zhe et al.[10] explain human pose estimation based on part affinity field approach. They train a deep neural network that is capable of taking an input image and providing an output of key points of the human pose. They have a 3 phase architecture that helps achieve this.
Phase 1: The initial 10 layers of the network work on developing feature maps for the given input.
Phase 2: Based on the concept of part affinity a mutli-stage branched CNN to predict the 2D coordinates of the key points and the 2D vector fields that defines the affinity between key points.

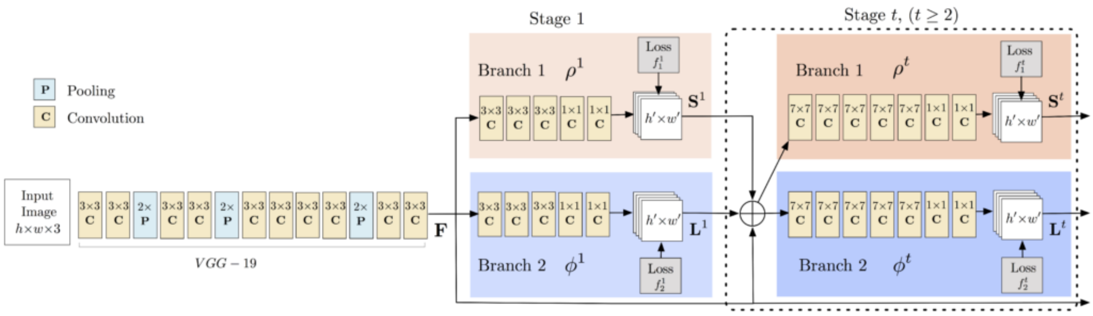

FIGURE 2.5: Multi-Person Pose Estimation model architecture

FIGURE 2.6: Showing confidence maps for Left Shoulder for the given image

Phase 2: The final output is achieved by using a greedy inference technique on the confidence and affinity maps.

FIGURE 2.7: Showing Part Affinity maps for Neck – Left Shoulder pair for the given image

2.2 Critical Review of Literture:

From the literature studied an understanding has been achieved of the factors that affect running technique. For the implementation of this project the lower limb angle, the push-off angle will be extracted. From literature, the accepted range for PA is between 32 and 42 degrees. The PA angle within this range at block clearance will provide a good transition into the acceleration phase.

To be able to define the structure of the athlete we will use the deep learning model developed over the part affinity field approach. This human pose estimation model will provide better results since it will take into consideration an affinity map of the affinity between the ankle and knee.

Chapter 3

DESIGN

The project was divided into three sections:

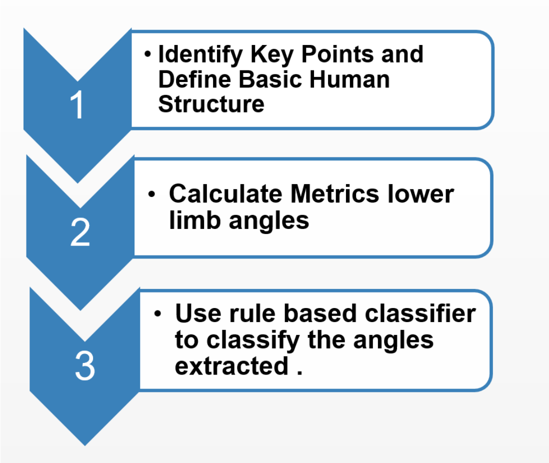

FIGURE 3.1: Sections of the project

The athlete must be identified and then joints of the athlete must be identified. These operations can be done using human pose estimation. On identifying the key points of the athlete we can use it to define the structure of the pose. This structure will be a basic skeletal representation of the athlete.
With the skeletal structure and reference to the X-Y axis we calculate the lower limb angles. The lower limb angles will be calculated using the geometric operations on the lines and co-ordinates of the joints.

FIGURE 3.2: Basic Pipeline

3.1 Pre-processing

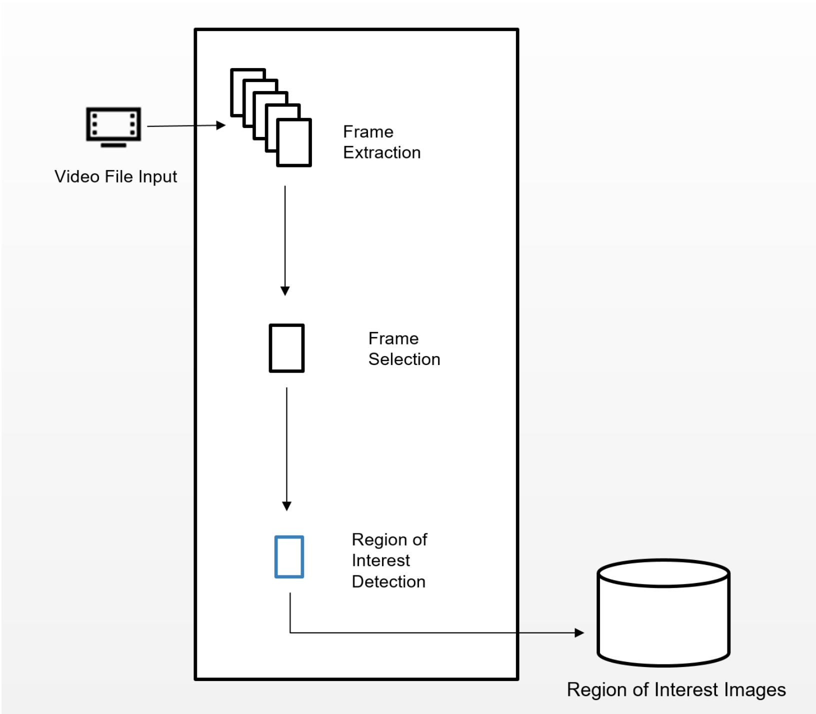

FIGURE 3.3: Pre-processing

In the pre-processing stage the video input is extracted into individual frames. From these frames the relevant block clearence frame is identified and selected. From the selected frame the athlete alone is identified to remove all other unnecessary parts of the image. Thus with the help of the pre-processing stage we have only the region of interest.

3.2 Keypoint identification:

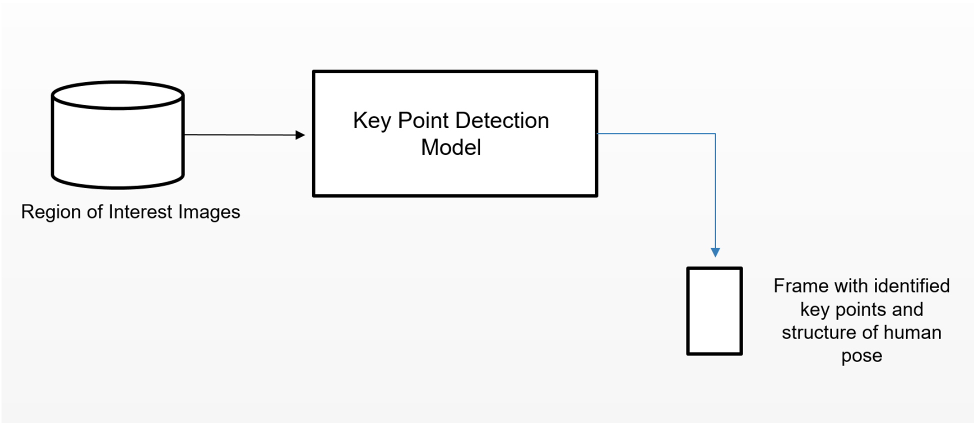

FIGURE 3.4: Pre-processing

Keypoint identification will help identify all the joints that are required to create a basic skeletal structure of the athlete in the block clearence frame.

3.3 Feature Extraction and Classification:

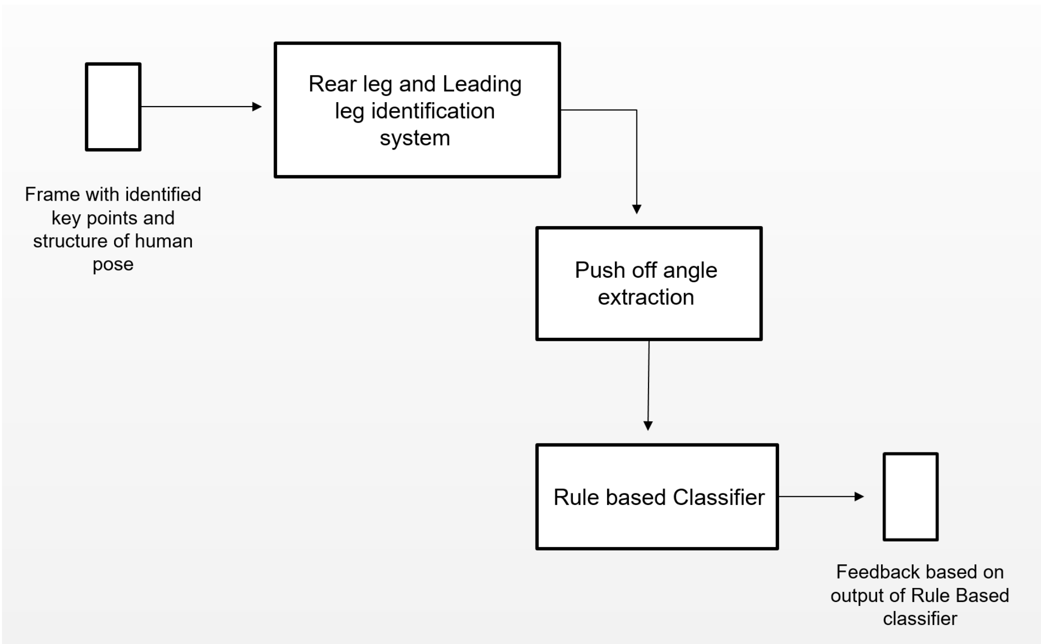

FIGURE 3.5: Feature Extraction

Athletes will have different leading and rear legs at block clearence. Since pose estimation identifies right leg and left leg differently it is necessary to pin point as to which leg is the rear leg. This is essential because at block clearence the push of angle is between the extended rear leg and the x-axis.
Once the rear leg is identiied the angle can be extracted. Push off angle will be the angle between the x-axias and the line joining the rear legs knee and ankle.
A rule based classifier will check if the angle is in the correct range specified (32-42degrees). Smaller the angle greater will be the forward thrust in the acceleration phase.

Chapter 4

ACTUAL WORK

To implement the project visual data of 18 athletes from Sports Authority of India running are recorded and analysed. The athletes were asked to run the first 45m of the 100m track and a camera was placed at the 10m marks to record their starting phase and the first few strides after block clearance.

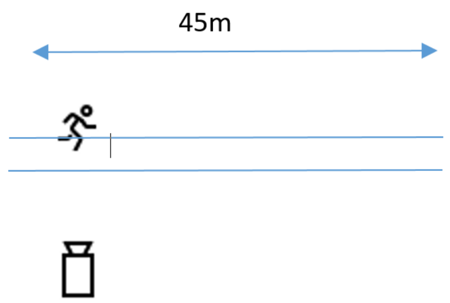

FIGURE 4.1: Camera position to record starting phase

4.1 Frame Selection:

Each athlete's video of the start phase was extracted into individual frames. From these individual frames the end user would have to select the frame that needs to be analysed.

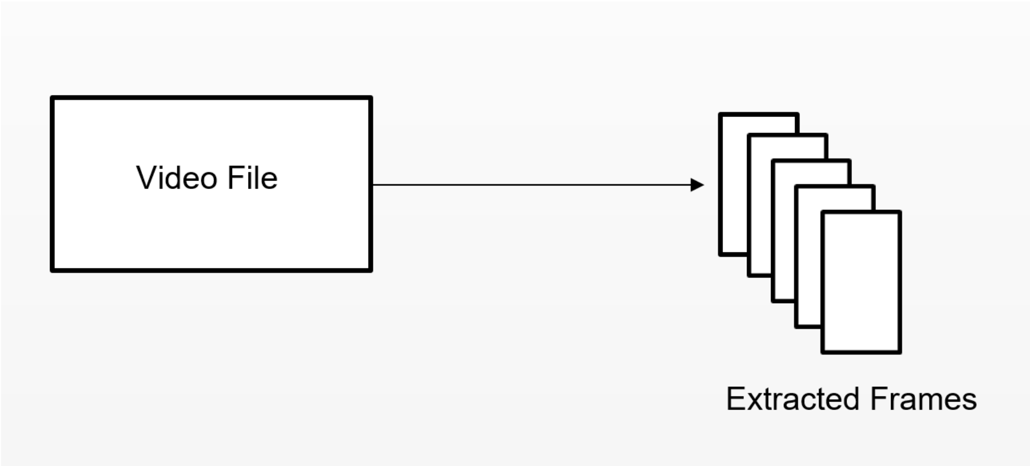

FIGURE 4.2: Frame Extraction

Once the frames have been extracted the athlete needs to be identify the frame to be analysed. The frame to be selected is the block clearance frame. The block clearance frame is the frame in which the rear leg is stretched out straight and is in contact with the block.

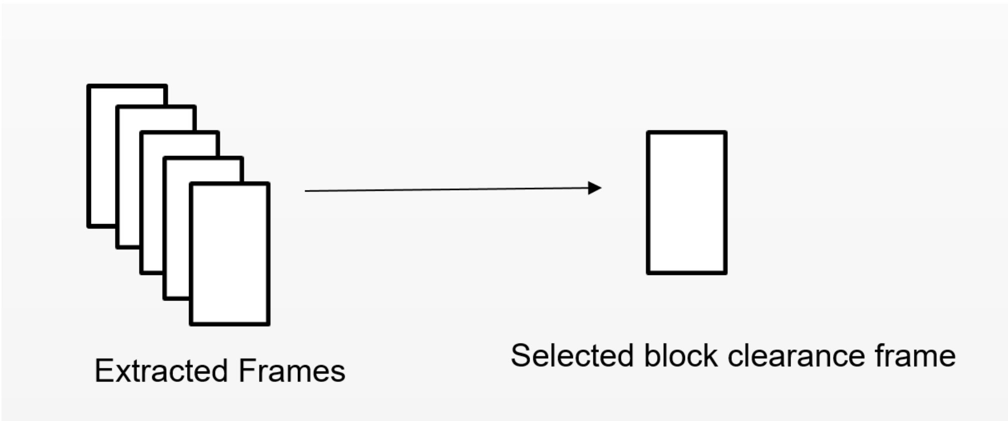

FIGURE 4.3: Frame Selection

4.2 Region of Interest Selection:

From the selected frame there will be a lot of noise in the form other humans and other objects that are not necessary for our analysis. Hence a hum detection model is used to detect the athlete in the frame that has to be analysed.

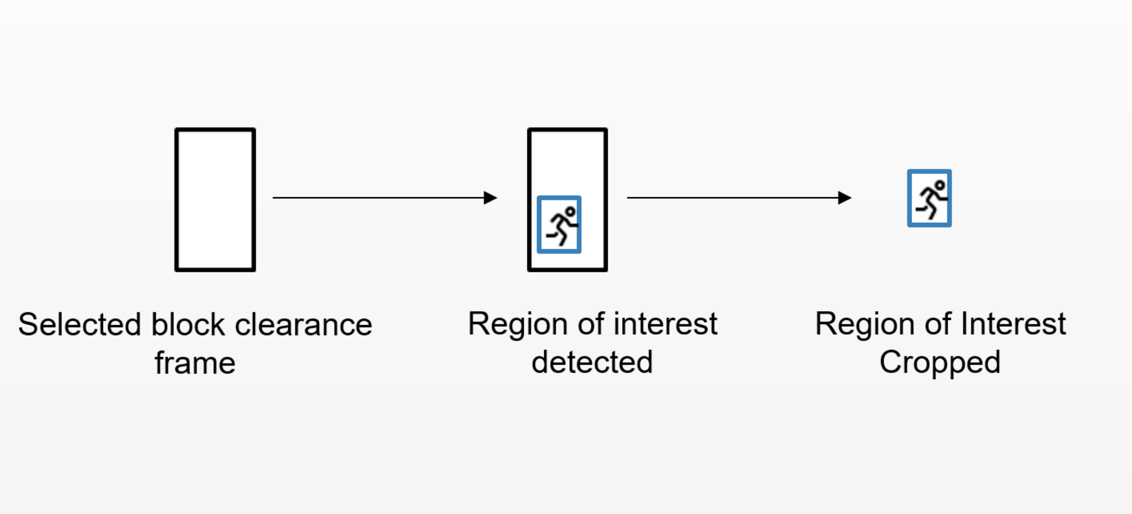

FIGURE 4.4: Region of Interest Selection

Identifying the athlete from the region when more than one human is detected: At times the frame can have multiple humans, and only the athlete of interest will have to be taken into consideration. For this we check for the closest human to the camera because the camera is positioned closest to the athlete. The below image has two human detected in the frame. But it can be seen that the athlete closest is our athlete of interest and the identification window's size of this athlete of interest has a greater area than the other human's identification window.

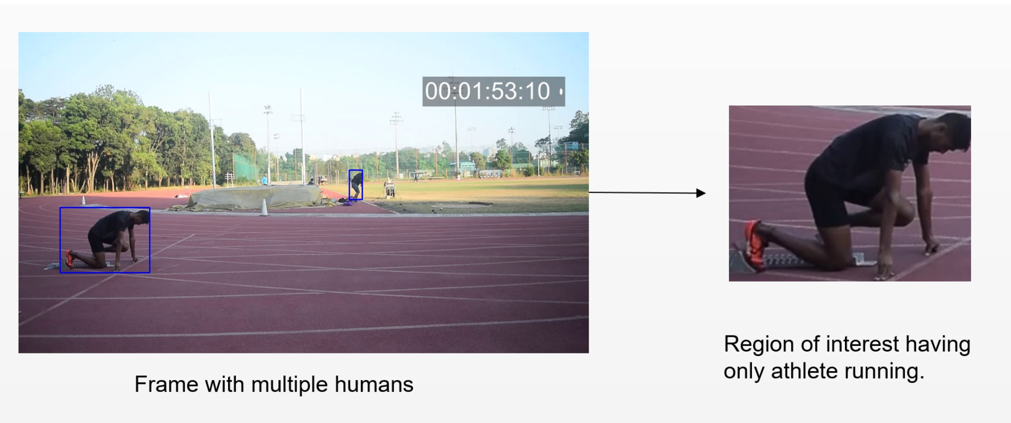

FIGURE 4.5: Sample of Region of Interest Extraction

4.3 Human Pose Estimation:

A deep learning model is used to identify the key point (joints) in the human body. Since the camera has a right side profile view of the athlete running hence the joints in view are:

- Right shoulder
- Right elbow
- Right wrist
- Left elbow
- Left wrist
- Right hip
- Right knee
- Right ankle
- Left Knee
- Left ankle

Due to occlusion we cannot view the left shoulder and left hip. The region of interest image is used as input for the key point detection model.

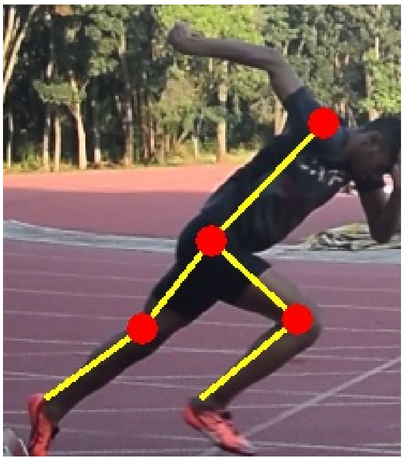

FIGURE 4.6: Sample of Pose Estimation

4.4 Feature Extraction:

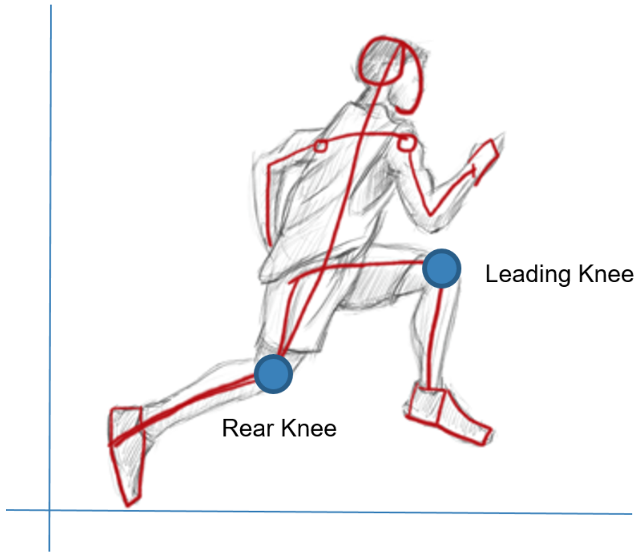

FIGURE 4.7: Identification of rear knee

The human pose estimation identifies dosent just identify the knee join or ankle joint , but identifues as a knee as the right knee or left knee and the same with the ankle ad joints on the hands. To calculate the PA it is essential to identiy which angle is the rear angle. PA is the angle formed between the rear leg and the x-axis at block clearence.

Algorithm 1 Identification of rear Knee

1: **Input:** rightKneeCoordinates ,leftKneeCoordinates
2: **Output:** rearLeg
3: Start:
4: **IF** rightKneeCoordinates[x] **is Less Than** leftKneeCoordinates[x] **THEN:**
5: rearLeg=rightLeg
6: **ELSE:**
7: raerLeg=leftLeg
8: **RETURN** rearLeg

Once the rear leg has been identfied the PA can be claculated between the rear leg and the X-axis. To calculate the angle we calculate the simple geometric calculations to calculate the angle between two lines. The two lines forming PA are the X-axis and the line joining the rear legs ankle and knee. Based on the PA value we do a rule based classification to determine if the value is within the accepted range.

Chapter 5

RESULTS, DISCUSSIONS AND CONCLUSIONS

5.1 Results & Analysis

The end result of the project is a tool that can identify key points of an athlete at block clearance and extract the push off angle which is important to or a goof acceleration phase. The tool is a recommender for recreational runners who don't have a coach to check if their PA falls within the effective range for a good transition into the acceleration phase. The tool does not require markers to be placed on the athlete to identify the key points. This makes the tool user-friendly for a recreational runner to use. Within the project the sections that were executed successfully are:

- Pre-processing to remove noise from the frame captured and have only the region of interest.
- Identifying the key points in the athlete without markers and making a basic structure.
- Calculate the Push-off and provide a recommendation The feedback states if PA is within the efficient range or not.

Sample Output of Test Data 1:

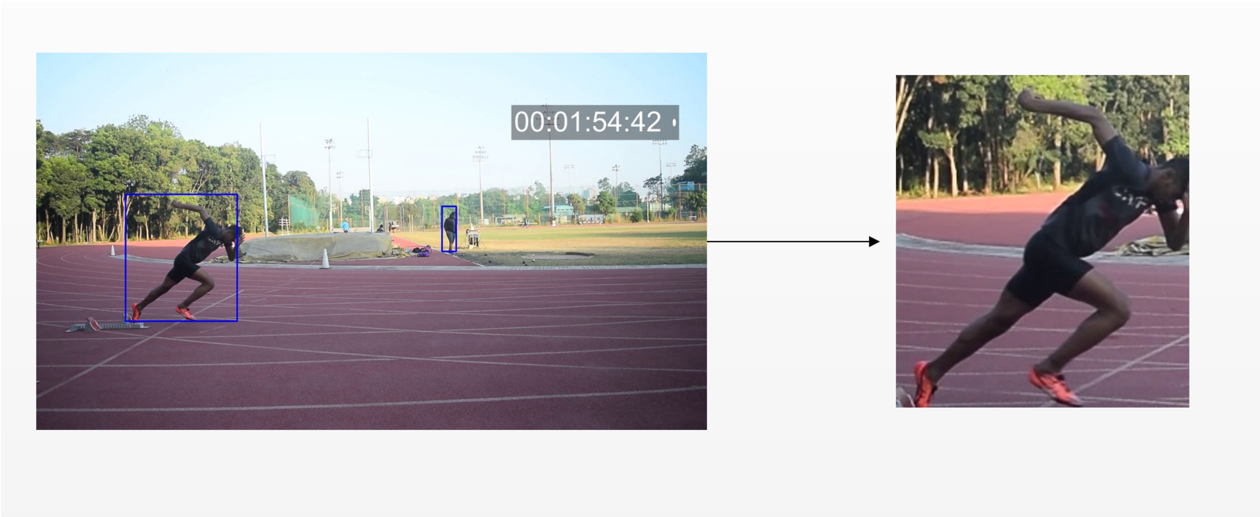

FIGURE 5.1: Test Data 1:Region of Interest Extraction

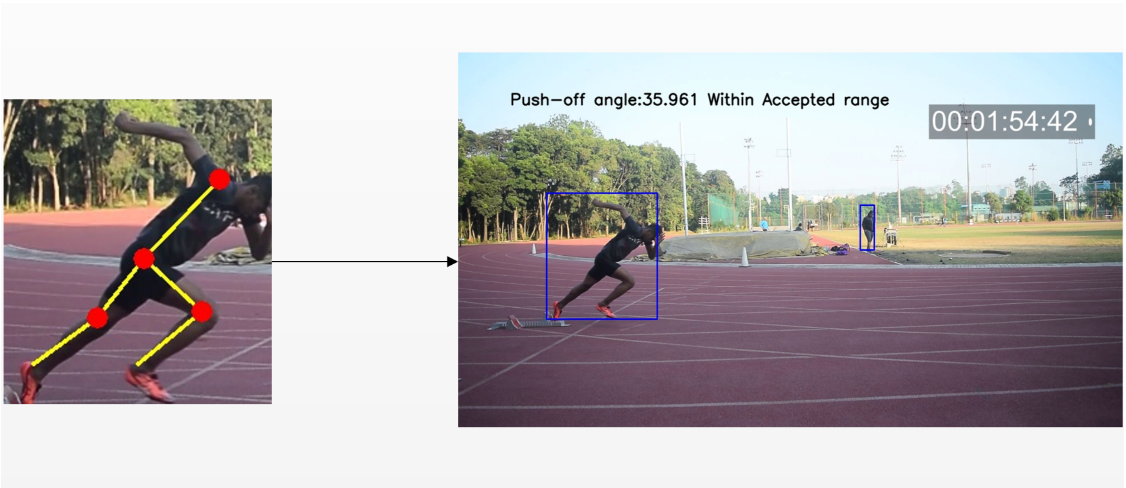

FIGURE 5.2: Test Data 1: Final Feedback

Sample Output of Test Data 2:

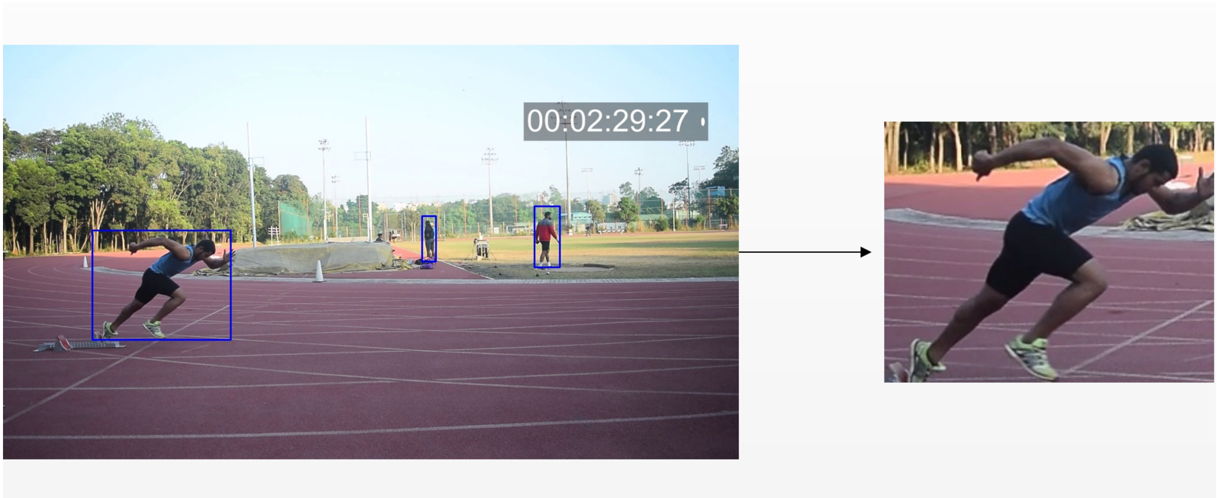

FIGURE 5.3: Test Data 2: Region of Interest Extraction

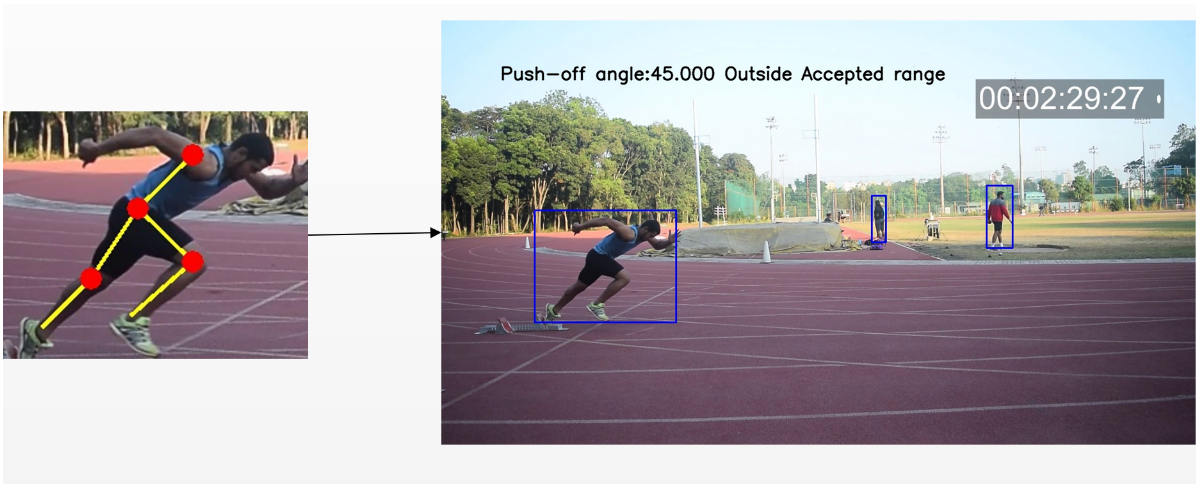

FIGURE 5.4: Test Data 2: Final Feedback

Sample Output of Test Data 3:

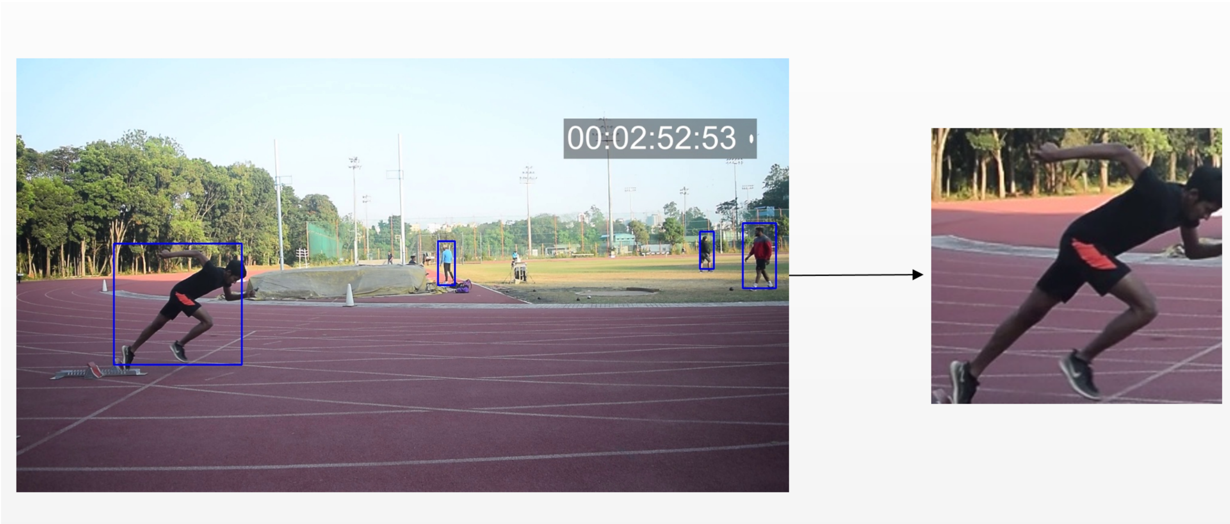

FIGURE 5.5: Test Data 3: Region of Interest Extraction

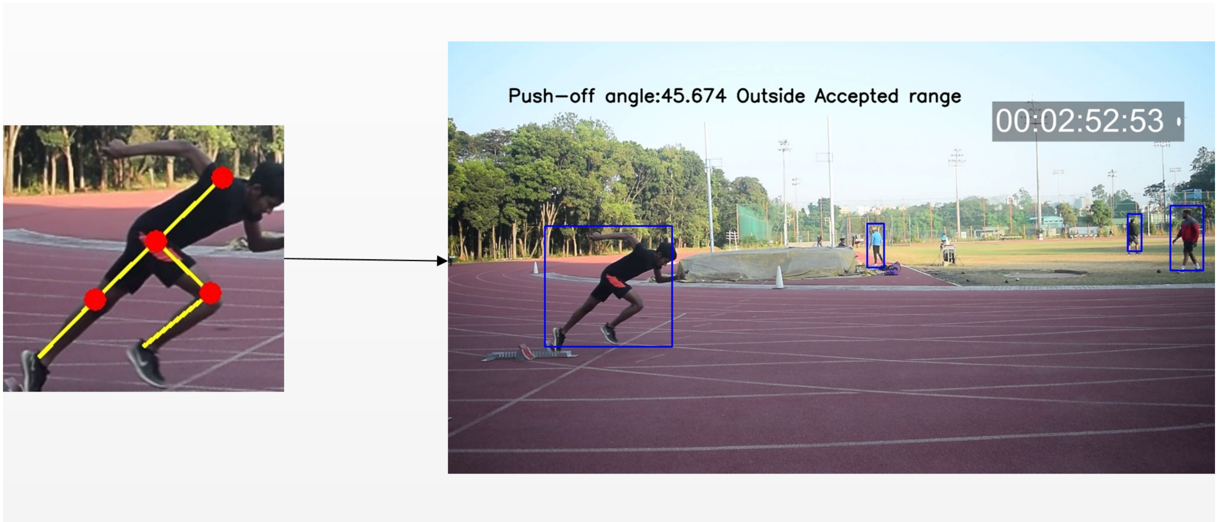

FIGURE 5.6: Test Data 3: Final Feedback

5.2 Comparative Study

The results of the push-off angle extracted is compared with results from Kinnovea, the existing software used by the Sports Authority of India (SAI). The below table shows all the push -off angle calculated by kinnovea in comparison to the angle calculated by the feature extraction script.

TABLE 5.1: Comparison of push-off angle calculated by Kinnovea and Feature Extraction Script

Serial Number	Kinnovea (In degrees)	Feature Extraction (In degrees)
1	42	42
2	39	40
3	45	45
4	41	41
5	46	45
6	42	42
7	42	41
8	42	42
9	38	39
10	41	41
11	45	45
12	46	46
13	49	49
14	42	41
15	46	46
16	42	42
17	41	41
18	41	41

From the above table we see that the feature extraction when compared with Kinnovea software used by SAI has a descent accuracy with error in calculation ranging between +1 or -1.

5.3 Cost Estimation Model

The resources for the implementation included computer processing resources, a video capturing camera and human effort. The project was completed within a period of 6 months. There was no additional cost for the resources. The complete project was executed by already owned devices and no new purchases had to be made exclusively for the completion of the project. The camera used was a GoPro Hero 6 and the laptop for processing and executing scripts was a Dell Inspiron 15 7000.

5.4 Conclusions

Taking into consideration the faulty running technique and providing a recommendation to correct the same was the prime motive of this project. This has been successfully realised through the completion of this project. Through this project, the push-off angle, a lower limb angle is identified from the block clearance frame of a sprint video analysis. The identification of the push-off angle is achieved with the help of human pose estimation. Once the angle is identified, a simple rule-based classifier is used to provide feedback.

Running for recreational runners has always been a means of keeping fit and a hobby for many. But with the lack of a physical coach monitoring running technique, injuries or bad performance is a possibility. This project can be used to bridge the gap between recreational athletes and their access to knowledge about the right running form.

5.5 Scope for Future Work

The project can be extended to perform complete video analysis of the entire 100m sprint. Under the following points there can be future development:

- In the current system, the frame selection of the block clearance frame is done manually by the user. A model that identifies the frame automatically can be made to avoid any erroneous selection of frame by the recreational runner.
- Currently only the block clearance of a sprint is being analysed. This analysis can be extended to frames of the first and second stride to be able to give more comprehensive feedback of the transition from the start phase to the acceleration phase.
- A data set that includes timing of the athlete will help provide better feedback and predictions of performance. The timing factors which can be included are reaction time at the start and personal best of the athlete.
- A graphics-based visual overlay for feedback would give better clarity to the recreational runner.

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Appendix A

Code Snippets

A.0.1 Region of Interest Extraction:

```
if __name__ == "__main__":
    model_path = 'G:/faster_rcnn_inception_v2_coco_2018_01_28/frozen_inference_graph.↩
    pb'
    odapi = DetectorAPI(path_to_ckpt=model_path)
    threshold = 0.7
    cap = cv2.VideoCapture('G:/Camera1/(4)Camera_Evangeline.mp4')
    count =0
    while True:
        count +=1
        r, img = cap.read()
        img = cv2.resize(img, (1280, 720))

        boxes, scores, classes, num = odapi.processFrame(img)

        # Visualization of the results of a detection.
        area=0; x1=0;x2=0;y1=0;y2=0
        maxArea =0
        for i in range(len(boxes)):
            # Class 1 represents human


            if classes[i] == 1 and scores[i] > threshold:
                box = boxes[i]
                height =abs (box[1]-box[3])
                width= abs(box[2]-box[0])
                area = height * width
                print (str(i) + ',' +str( area) + ','+ str(count))
                #Idetifying the athelete if multiple humans are detcted in the frame-
                #Assuming the athlete is closest to the frame, hence window on the ↩
    athlete will have largest ar
                if area>maxArea:
                    x1=box[1]
```

```
                    y1=box[0]
                    x2= box[3]
                    y2=box[2]
                    maxArea=area


        #Cropping the Region of interest from the frame.
        img=img[y1:y2, x1:x2]
        #Viewing the Region of Interest
        cv2.imshow("preview", img)
        #Saving the region of Interest
        cv2.imwrite("G:\\Images\\4\\frame%d.jpg" % count, img)
```

The region of interest detection will crop out and save on the athlete under analysis.

A.0.2 Human Pose Estimation and Feature Extraction:

```
#Angle calculation:
def calculate (pt1 , pt2):
    x1=pt1[0]
    y1=pt1[1]
    x2=pt2[0]
    y2=pt2[1]
    if x2-x1==0:
        return 90
    else:
        m=float((y2-y1)/(x2-x1))
        rad=math.atan(m)
        ang=(rad*180)/math.pi
        return ang
```

The above code snippet is the function used to calculate the angle between a given line and the X-axis. This is how Push-off angle is claculated.

```
for i in range(nPoints):
    # confidence map of corresponding body's part.
    probMap = output[0, i, :, :]

    # Find global maxima of the probMap.
    minVal, prob, minLoc, point = cv2.minMaxLoc(probMap)

    # Scale the point to fit on the original image
    x = (frameWidth * point[0]) / W
    y = (frameHeight * point[1]) / H

    if prob > threshold :
```

```
        cv2.circle(frameCopy, (int(x), int(y)), 8, (0, 255, 255), thickness=-1, ↩
    lineType=cv2.FILLED)
        cv2.putText(frameCopy, "{}".format(i), (int(x), int(y)), cv2.↩
    FONT_HERSHEY_SIMPLEX, 1, (0, 0, 255), 2, lineType=cv2.LINE_AA)

        # Add the point to the list if the probability is greater than the threshold
        points.append((int(x), int(y)))
    else :
        points.append(None)

# Draw Skeleton
for pair in POSE_PAIRS:
    partA = pair[0]
    partB = pair[1]

    if points[partA] and points[partB]:
        cv2.line(frame, points[partA], points[partB], (0, 255, 255), 2)
        cv2.circle(frame, points[partA], 8, (0, 0, 255), thickness=-1, lineType=cv2.↩
    FILLED)
```

The above code snippet is used foe definising the structure of the athlete from the human pose estimation model.