Tecnológico de Monterrey
Escuela de Ingeniería y Ciencias

Biomechanics for the Digital Twin of Performance

Study Cases

Building Reliable Advances and BRAIN Innovations in Neurotechnology

iTY

Abstract

- This project focuses on movement tracking through video analysis to estimate acting forces on the body, with the aim of detecting risk of fracture for each joint in the human body.

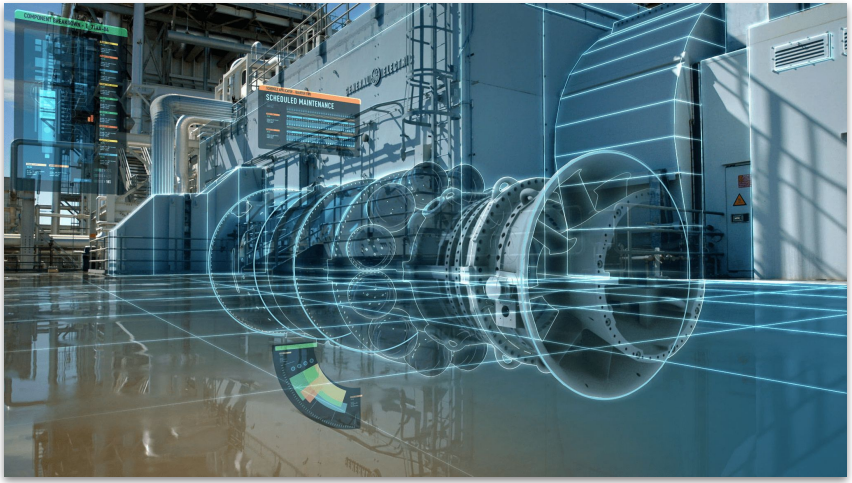
- The automatic digitization of humans' joints as key points via CV algorithms, together with biomechanical-related biometrics given by wearables, is capable of creating a markerless DT for biomechanical assessment.

Biomechanics

- It is the scientific study of the physical movement and structure of living creatures (Oxford University Press, 2021), often in humans referred to as the study of how the skeletal and musculature systems work under different conditions (What is Biomechanics? - Definition & Applications, 2016)

Digital Twin

- A Digital Twin is a virtual model of physical assets, which continually learn and provide data insights.
- Unlike traditional simulation models, Digital Twins benefit from real-time data, which is fed into its virtual environment.



Introduction

- Biomechanic analysis has been used for distinct applications, such as gait analysis regarding certain illnesses compared to a normal gait
- Recently, its application to sports has been on the rise, used to design and develop safety gear in sports, improvement for techniques and also minimize risk of fracture in specific movements.
- In high-intensity sports, fatigue injuries compose 20% of the total injuries (Fredericson et al., 2006).

Current problem

- Most of the current analysis on biomechanics are being done by consensus of multiple experts.
- Technology in this field is mainly composed of laboratory biometrics with markers attached.

Digital Twin in healthcare

- A Healthcare Digital Twin (HDT) would need to collect data such as age, weight, height, ECG, blood pressure, diet, mood etc. by numerous Internet of Things (IoT) devices (Shengli, 2021).
- Currently, some of the main approaches have been its use in modeling and simulation of different situations, such as medical surgery training simulation and medical equipment design (Y. Liu et al., 2019)

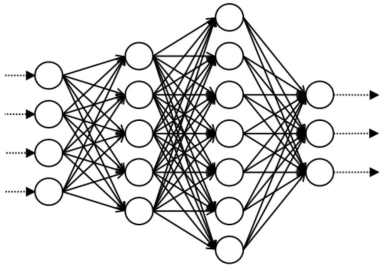
Proposal

Input:

- XYZ acceleration of a person given by the wearables employed
- XY joint's positions given by a markerless CV model.
- Persons' metadata (Kg, Age)

Output:

- Biomechanical features (force, torque, angle, power) by each joint
- Risk of fracture coefficient



Methodology - Manual digitization

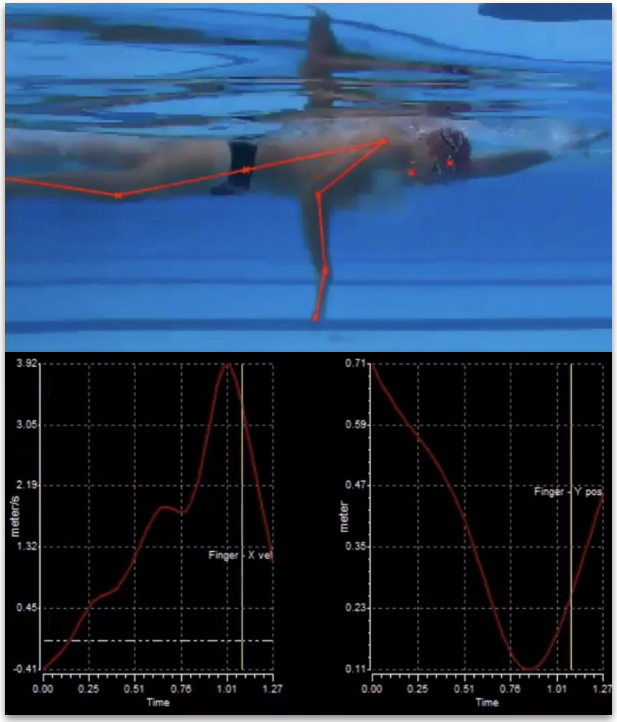
- Video selection

Skillspector

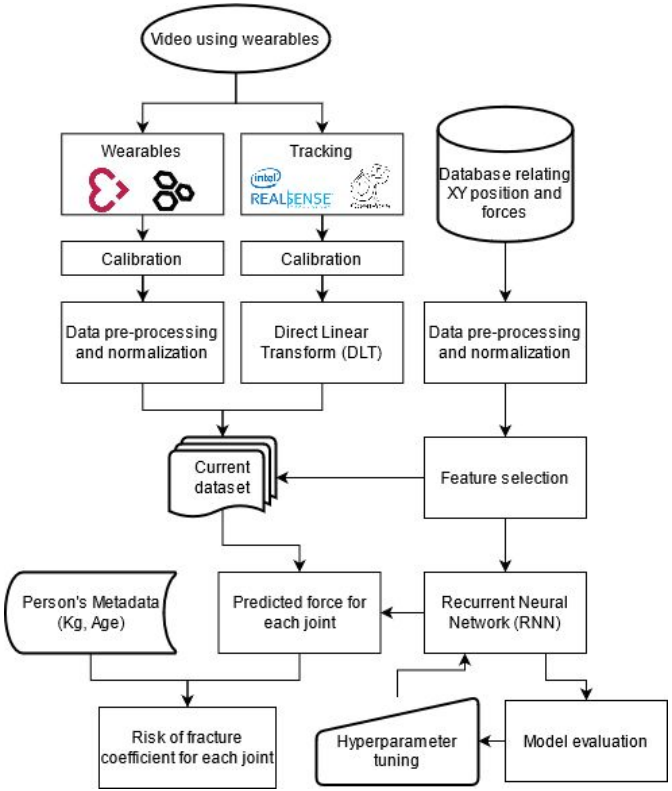
- Calibration of body position (for mapping video image coordinates to world space coordinates)
  - -Profile selection
  - -Height of person
- Manual digitization of body movement (tracking)
  - -Profile selection (previously created small database)
  - -Points to be digitized
- Graphs of dynamical elements in specific points e.g. velocity and acceleration on x and y axis

Calculations

- Estimation of forces depending on sport e.g. force analysis of foot in high kick for taekwondo



Methodology - Automatic digitization

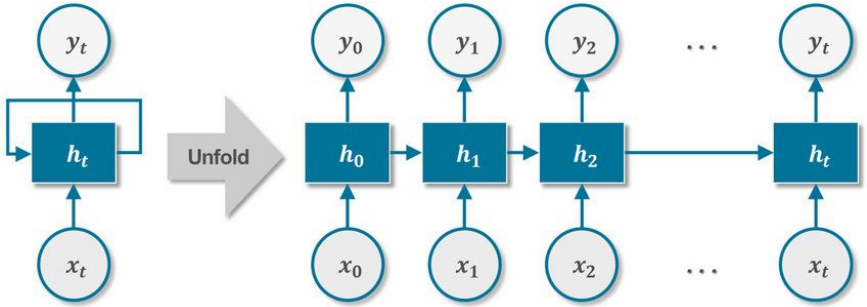


OpenPose

- A real-time multi-person system that detects up to 135 human keypoints (body, hand, facial and foot) on images and video.
- It is based on a Convolutional Neural Network (CNN) algorithm which does not require markers to track the movement of the human body.

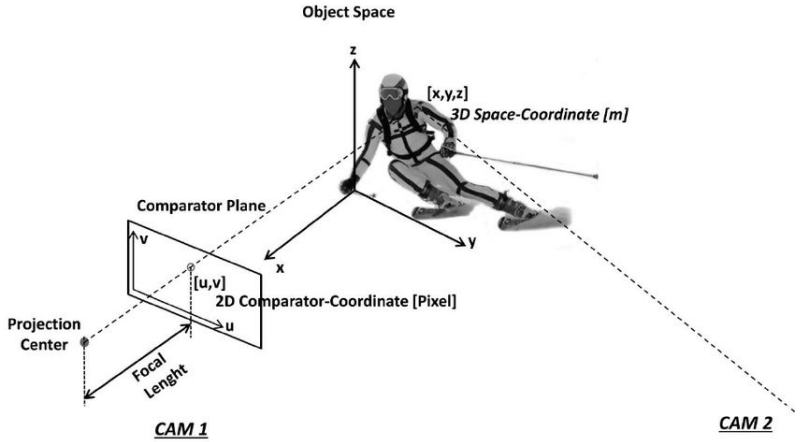
Recurrent Neural Network

- A type of Artificial Neural Network (ANN) which uses sequential data.
- Unlike others ANNs, these have memory and so past inputs influence new inputs and outputs.
- Their applications are mainly Natural Language Processing (NLP) and time-series forecasting.



Direct linear transform

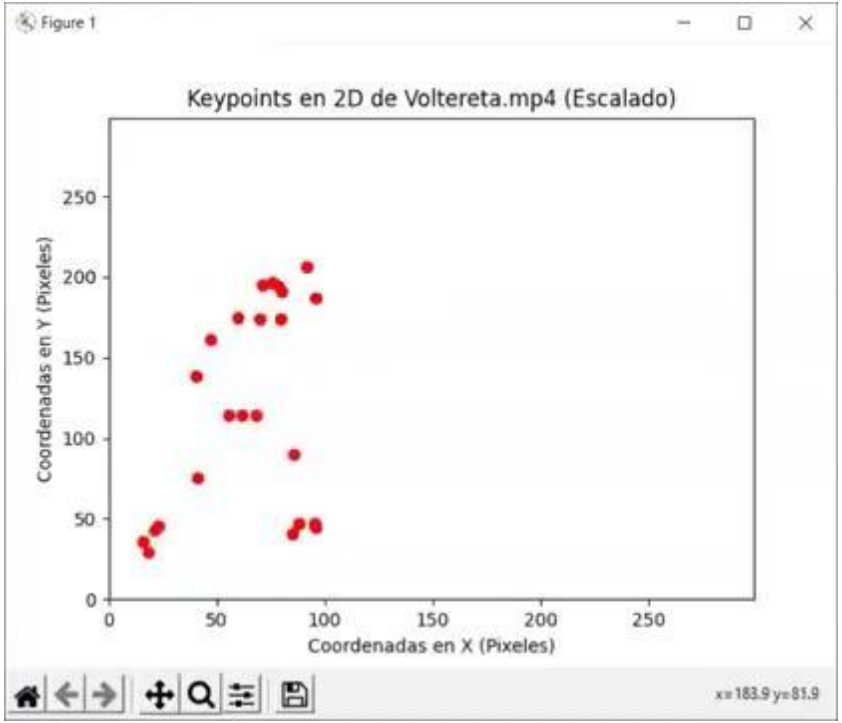
- Using a set of control points already known, it can determine the 3D location of an object.
- Compute a fundamental matrix, used:
  - Projective transformation
  - Image rectificacion
  - Projective invariants
  - Outlier detection
  - Stereo matching



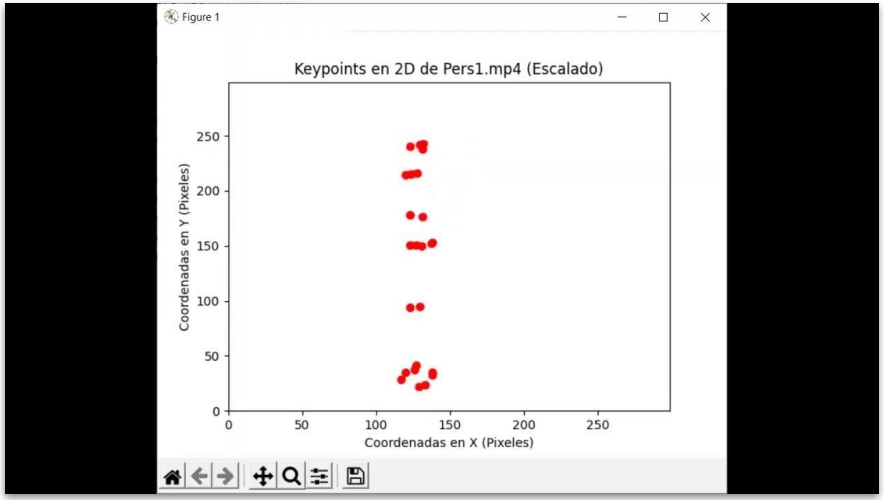
Manual digitization using web videos
Swimming

Manual digitization using web videos
Taekwondo

Automatic digitization using web videos



Automatic digitization using our own videos



Next steps

- Recurrent Neural Network (RNN) training using a database
- Automation of OpenPose/Intel analysis using its API for Python
- The use of Direct Linear Transformation (DLT) to calibrate
- Risk of fracture and biomechanical fractures prediction based on the RNN and person's metadata

Conclusions

- Past investigations, which involve laboratory devices using markers, revealed that biomechanical features such as force, angles and torque could be extracted for each joint.

- Markerless tracking using software such as OpenPose and Intel® RealSense™ have shown promising results on estimating and predicting the position of humans' joints.

- Artificial intelligence and Machine Learning approaches, using wearables such as Hexiwear and Empatica E4, could only require calibration steps in order to predict the force, angles and torque, without the need of a laboratory device using attached markers.

Bibliographic references

- CMU-Perceptual-Computing-Lab (2021). OpenPose [Repository]. GitHub.
- What is Biomechanics? - Definition & Applications. (2016, September 26). Retrieved from https://study.com/academy/lesson/what-is-biomechanics-definition-applications.html
- Oxford University Press (2021) In Oxford Advanced American Dictionary, 2021
- Wei Shengli (2021). Is Human Digital Twin possible?. *Computer Methods and Programs in Biomedicine Update, 1, 100014.*
- Liu, Y.,, Zhang, L., Yang, Y., Zhou, L., Ren, L., Fei, W., Liu, R., Zhibo, P., Jamal, M.(2019) A Novel Cloud-Based Framework for the Elderly Healthcare Services Using Digital Twin. Retrieved from: https://ieeexplore.ieee.org/abstract/document/8686260