Internship Report

(School of Information Technology Artificial Intelligence and Cyber Security, Rashtriya Raksha University India, https://rru.ac.in/)

Internship Role: Research Intern

(Human Centered Robotic Lab, IIT Gandhinagar, https://labs.iitgn.ac.in/hcr-lab/)

Candidate: Himanshu Prajapat (RSU1716012)

Mentor/Instructor: Dr. Vineet Vashista

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Duration: 17 Feb 2021 to 31 May 2021

Declaration

I am Himanshu Prajapat, a student of B.Tech in Computer Science Engineering at Rashtriya Raksha University. I declare that this report of internship at Human Centered Robotic Lab, IIT Gandhinagar has been authentically prepared by me. During the preparation of this internship report I had not ruptured any copyright act purposefully and I also further declare that I did not submit this report to any other institution for awarding any degree of certificate.

Himanshu Prajapat

Date: May 29, 2021

Remark

Acknowledgement

I would like to thank Ass. Prof. Dr. Vineet Vashista (Head of HCR Lab) who has provided me this opportunity with their valuable instructions and guidance during internship. I am thankful to the entire dynamic and innovative HCR Lab team members for being helpful and supportive in every little help I needed and for creating the opportunity for me to participate in their ongoing projects.

Also, I would like to thank Mr. Sagar Parek (Project Associate at HCR Lab) for providing me with every elaborate detail of the project and always guiding me through project tasks.

Finally, I would like to thank the Internship Department of RRU for supporting me during the internship process and also thankful to my friends who also supported me during this internship period.

Executive Summary

This is a detailed report of my internship at Human Centre Robotic Lab IIT Gandhinagar. During my internship I learned and explored about ongoing research projects at HCR Lab, intelligent robots, assistive robotic systems, human centered robotic systems, advanced real time physics simulation platforms, handling different sensor data, virtual reality platforms, 3D object modeling, sensors and actuators. I have learned to work on Unreal Engine (using C++) handling input data of Load Sensors and human gait analysis with camera sensor data using artificial intelligence algorithms. I have also work on literature review on 'Modeling of Kinetic and Kinematics Parameters of Human Walking using Artificial Intelligence' and 'Learning Human Control behavior to flying drone, based on collected real time quadcopter control data using Machine Learning methods' and shared with HCR Lab team. The career path I would be selecting for myself is influenced by my internship as I have had a great opportunity to practically work on human centered robotic systems and exploration of new ideas. I have also learned to prepare and present a good technical presentation. Working with the HCR Lab team gives a lot of other benefits like how to work in a team with innovative and productive outcomes also help me to improve my communication skills. I have tried my best to make it meaningful by reflecting my works and experiences at the Human Centered Robotic Lab, IIT Gandhinagar.

Table of Content

Motivation

Robots are entering every dimension of our social and working life, it makes robots work collaboratively with humans. Recent AI based upgrades in robotics are making robots intelligent and deployable in the real world.

Defense: Indian army deployed robotic arms to combat with stone platters. There are many types of ROV (Remotely Operated Vehicle) used by most of the world's defense forces for bomb disposal.

Medical: Surgical robots which help doctors to operate from anywhere in the world remotely. Assistive robotic systems are used in rehabilitation of patients. There are other service robots that also help nursing staff to take care of patients.

Space: Mars Rover and drones are used by NASA. Robotics arms at the International Space Station.

Agriculture: Monitoring large field areas by drones.

Industrial sector: For increasing production speed semi-conder industries are using robotic arms (KUKA) in their assembly line. Large automobile industries are also deploying specific task-oriented robots in their assembly line to make fast production.

Transportation: Self driving trucks used by the USA. Self-driving cars will be available to the public within the next few years.

Human Centered Robotics ensures reliability of robotic systems and increases productivity at the workplace.

I choose this field because I have been committed to develop intelligent robots for our human society.

Introduction

Robotics is the study of robots. Robots are machines that can be used to do jobs. Some robots can do work by themselves. Other robots must always have a person telling them what to do. (NASA)

When humans should be required in the loop, then the above will be called human centered robotics.

Robotic Arm is a type of mechanical arm, usually programmable, with similar functions to a human arm. For example, SCARA, Kuka arm, Canadarm, etc.

Mobile robots have the capability to move around in their environment and are not fixed to one physical location. And they can do this autonomously. For example, Shakey, BigDog, etc.

During Internship I have learned about some of the different kinds of ways where humans can interact with robots and both can collaboratively complete a single task with reliability. For example-

- Humans can collaboratively work with drones for carrying loads.
- Intelligent Robotic assistive systems can help in human gait rehabilitation.
- Humans can control robots with a virtual reality environment.

Also, a robotic system which is working with humans collaboratively, reduces hardware load carried by robots and power consumption which make it more suitable for real world implementation.

Overview of Organization

Human-Centered Robotic (HCR) Lab is established at Indian Institute Technology Gandhinagar.

The research work at the Human-Centered Robotics (HCR) Lab uses the principles of human motor and movement adaptation to develop novel human-centered robotic technologies to improve the quality of human life. The main focus has been on the integration of these understanding within the robot's design and control to enable a desired physical human-robot interaction. The HCR Lab includes researchers with engineering and cognitive science backgrounds and places a significant emphasis on human studies to evaluate the performance of proposed paradigms.

Research project at HCR Lab - (https://labs.iitgn.ac.in/hcr-lab/research/)

Wearable Robotics:

- Stiffness modulation of a cable-driven leg exoskeleton (CDLE) for effective human–robot interaction[1]. In this work, multi-joint stiffness performance of CDLE is formulated to systematically analyze human–CDLE interaction. Further, potential alterations in CDLE architecture are presented to tune human–CDLE interaction that favors the desired human leg movement during a gait rehabilitation paradigm.

Motor Adaptation: Task execution in Virtual Reality Environment

- Lower-Limb Strategy Assessment during a Virtual Reality based Dual-Motor-Task[2]. In this study, a dual-task paradigm in a virtual environment is designed where both tasks demand motor skills. This study provides a new and

[1] Sanjeevi, N. S. S., & Vashista, V., (2020). Stiffness Modulation of a Cable-Driven Leg Exoskeleton for Effective Human-Robot Interaction. Cambridge Robotica. DOI: https://doi.org/10.1017/S0263574721000242

[2] Singh, Y., Rodrigues, V., Prado, A., Agrawal, S. K., & Vashista, V. (2020, September). Lower-limb strategy assessment during a virtual reality based dual-motor-task. In 2020 8th IEEE RAS/EMBS International Conference for Biomedical Robotics and Biomechatronics (BioRob) (pp. 252-257). IEEE. DOI: 10.1109/BioRob49111.2020.9224418

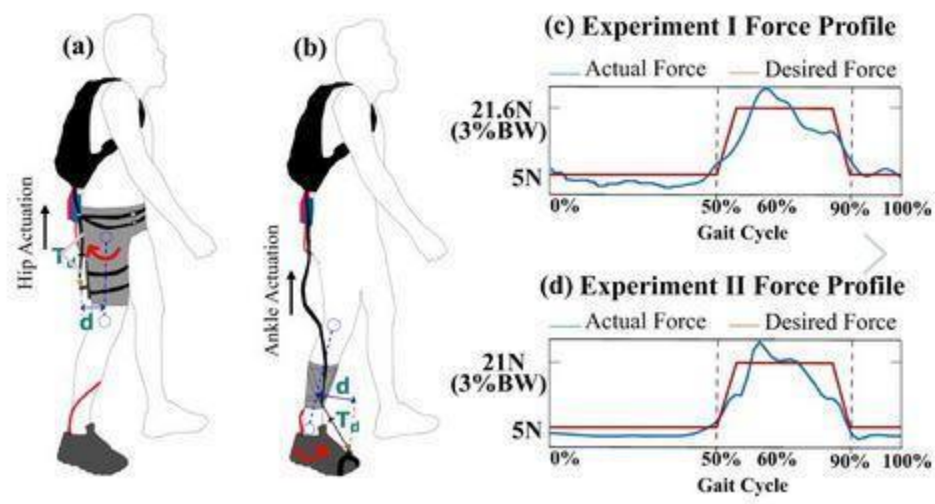
engaging paradigm to analyze dual-motor-task in a virtual reality environment.

Human-Quadcopter Interaction:

- On the Human Control of a Multiple Quadcopters with a Cable-suspended Payload System[3]. Experiments, where a human operator flew a two quadcopters system to transport a cable-suspended payload, were conducted to study the performance of the proposed controller. The results demonstrated successful implementation of human control in these systems.

I have included only a few details of most recent research that has been done at HCR Lab. There are many research projects in active modes which are available in detail at HCR Lab website.

WeARS: Wearable Adaptive Rehabilitation Suit[4]



Wearable Adaptive Rehabilitation Suit (WeARS) for lower extremity that uses externally actuated cables to resemble the role of agonist and antagonist muscles as

[3] Prajapati, P., Parekh, S., & Vashista, V. (2020, June). On the Human Control of a Multiple Quadcopters with a Cable-suspended Payload System. In 2020 IEEE International Conference on Robotics and Automation (ICRA). IEEE. DOI: 10.1109/ICRA40945.2020.9197279

[4] Iyer, S. S., Joseph, J. V., Sanjeevi, N. S. S., Singh, Y., & Vashista, V. (2019, October). Development and Applicability of a Cable-driven Wearable Adaptive Rehabilitation Suit (WeARS). In 2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN) (pp. 1-6). IEEE. Best Research Award (Finalist) Award. DOI: 10.1109/RO-MAN46459.2019.8956397

in a biological system. WeARS also uses a subject-specific control strategy that is adaptive to the subject's gait.

Implemented Methodology

I have been working on real time sensor data.

My task is to deploy a real time physics-based system in a virtual simulation platform.

Sensor data connectivity establishment with simulation platform by using plug-ins and customizing programming code with C++, accordingly HCR Lab system requirement.

Implementation of Kinect and Kinematics properties using C++ programming. And creating a C + + class to handle connectivity of continuous input sensor data with simulation platforms.

Using Machine Learning finding patterns b/w human control commands and quadcopter real time execution of those commands, based on collected real time quadcopter control data.

Deploying an AI and computer vision based system to predict human walking pose and extract out different Kinect and kinematics features related to human walk based on real time humans walking video data.

I had done literature review on 'human gait analysis using AI based methods with video data of walking' and concluded, OpenPose[5] has been used in a wide range of recent research projects to extract out skeleton models from video data.

I found most influencing research peppers was –

1. In 'Two-dimensional video-based analysis of human gait using pose estimation[6]', They compared a large set of spatiotemporal and sagittal kinematic gait parameters as measured by OpenPose (a freely available algorithm for video-based human pose estimation) and three-dimensional motion capture from trials where healthy adults walked overground. They

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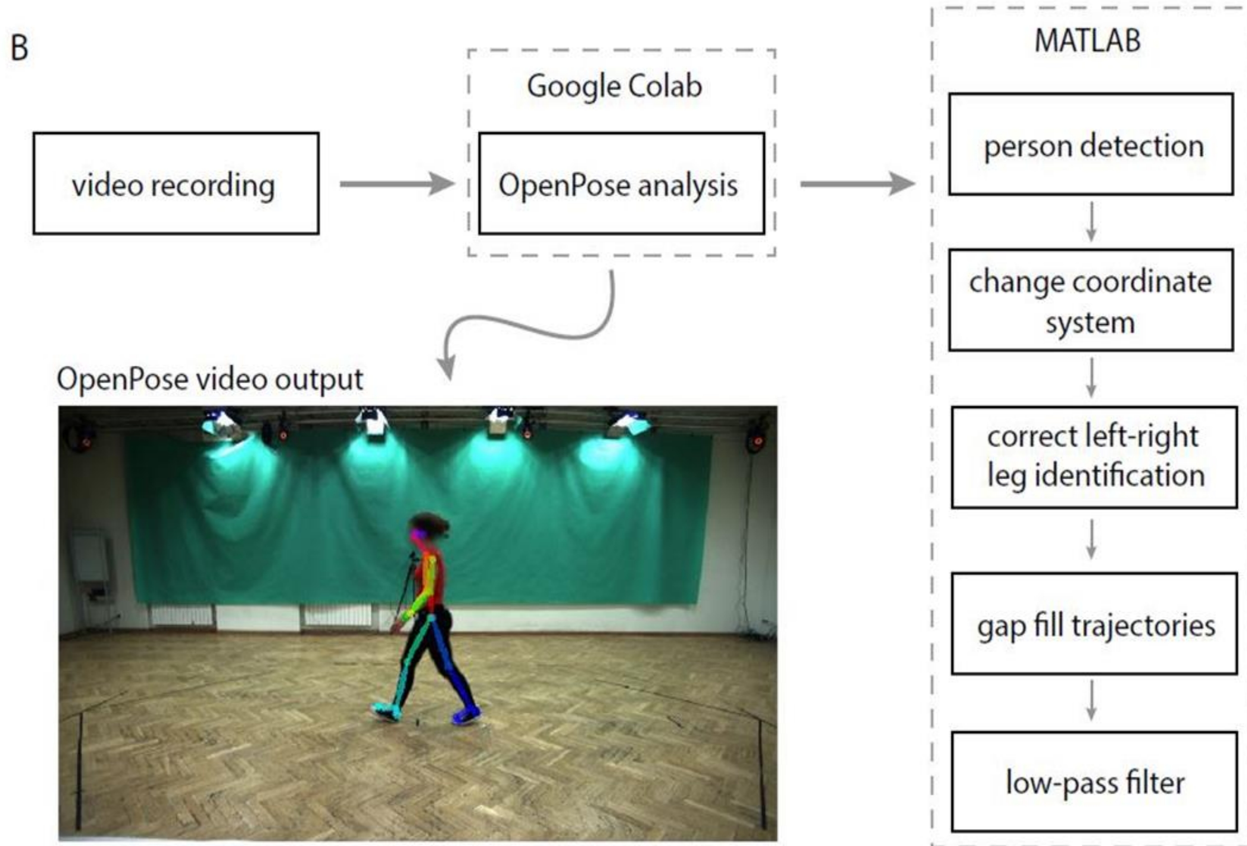
[5] Zhe Cao, Gines Hidalgo, Tomas Simon, Shih-En Wei, Yaser Sheikh. OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields. Published in: IEEE Transactions on Pattern Analysis and Machine Intelligence (Volume: 43, Issue: 1, Jan. 1 2021). DOI: 10.1109/TPAMI.2019.2929257.

[6] Jan Stenum, Cristina Rossi, Ryan T. Roemmich. Two-dimensional video-based analysis of human gait using pose estimation. Published: April 23, 2021. https://doi.org/10.1371/journal.pcbi.1008935.

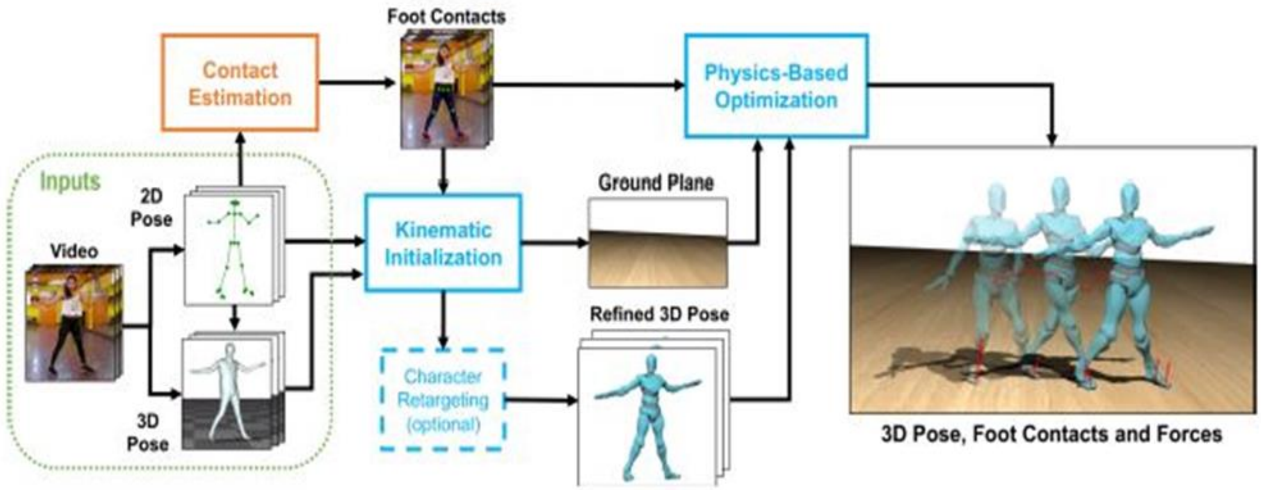
found that OpenPose performed well in estimating many gait parameters (e.g., step time, step length, sagittal hip and knee angles) while some (e.g., double support time, sagittal ankle angles) were less accurate. This method helps us to extract out Kinematic features from 2D skeleton videos.
Method overview –



2. In 'Contact and Human Dynamics from Monocular Video[7]', they used a physics based method for inferring 3D human motion from video sequences that takes initial 2D and 3D pose estimates as input. First estimate ground contact timings with a novel prediction network which is trained without hand-labeled data. They also demonstrate their method on character animation and pose estimation tasks on dynamic motions of dancing and sports with complex contact patterns. For getting 2D skeleton video output they also used

[7] Davis Rempe, Leonidas J. Guibas, Aaron Hertzmann, Bryan Russell, Ruben Villegas, Jimei Yang. Contact and Human Dynamics from Monocular Video. Stanford University and Adobe Research. In European Conference on Computer Vision (ECCV) 2020. https://geometry.stanford.edu/projects/human-dynamics-eccv-2020/

OpenPose and also, they used ground contact timing which is motivational for our future research direction.
Method overview -



Given an input video, their method starts with initial estimates from existing 2D and 3D pose methods. The lower-body 2D joints are used to infer foot contacts (orange box). Their optimization framework contains two parts (blue boxes). Inferred contacts and initial poses are used in a kinematic optimization that refines the 3D full-body motion and fits the ground. These are given to a reduced dimensional physics-based trajectory optimization that applies dynamics.

Tools and technology used

For simulation and Virtual Reality, I have worked on Unreal Engine (UE4). This is a most open and advanced real-time 3D creation platform for photoreal visuals and immersive experiences. Development using UE4 requires visual studio C++.

Wii balance board (4 – Load sensors) provides data of fluctuating human body weight in standing position. It connects via Bluetooth to transfer data.

I have worked in a team and we use BalanceBoardPlugin[8] to access sensor input and implement sub stepping modules in C++ and blueprint class.

I have used Python language and online IDE Jupyter Notebook to preprocess quadcopter control data for deployment of machine learning methods.

For working with video data, I have been using the OpenPose platform which uses Deep Convolutional Neural Network models and OpenCV.

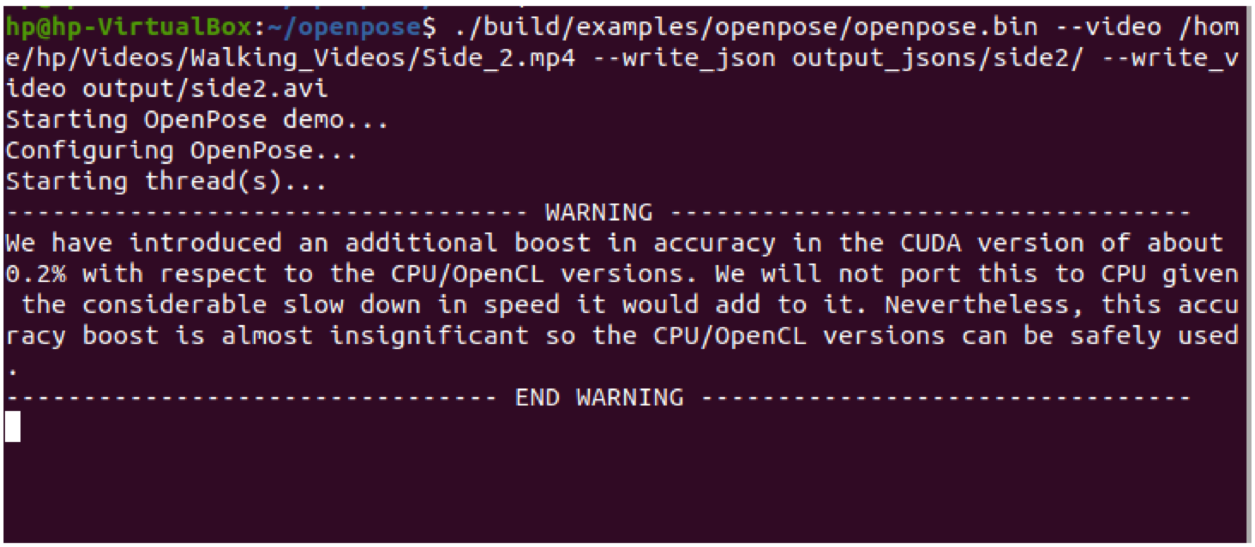
[8] Wii Balance Board UnrealEngine 4 Plugin. https://github.com/hiroog/BalanceBoardPlugin.

OpenPose: It has represented the first real-time multi-person system to jointly detect human body, hand, facial, and foot keypoints (in total 135 keypoints) on single images.

- Input – Human walking video data (.mp4, .avi, etc.) Or Image data.
- Output – 2D video data (.mp4, .avi, etc.) in which a human character overlapped with his skeleton model or it also provides only a skeleton model without overlapping of real human character.

I have been working with both Ubuntu20.04 and Windows 10 platforms to deploy OpenPose. It requires a high performing computational system.

OpenPose Source Code[9] based installation and outcomes



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hp@hp-VirtualBox:~/openpose$ ./build/examples/openpose/openpose.bin --video /hom
e/hp/Videos/Walking_Videos/Side_2.mp4 --write_json output_jsons/side2/ --write_v
ideo output/side2.avi
Starting OpenPose demo...
Configuring OpenPose...
Starting thread(s)...
---------------------------------- WARNING ----------------------------------
We have introduced an additional boost in accuracy in the CUDA version of about
0.2% with respect to the CPU/OpenCL versions. We will not port this to CPU given
 the considerable slow down in speed it would add to it. Nevertheless, this accu
racy boost is almost insignificant so the CPU/OpenCL versions can be safely used
.
-------------------------------- END WARNING --------------------------------
```

Fig 1. Using OpenPose processing input video and extracting out 2D skeleton video and JSON data files.

[9] CMU-Perceptual-Computing-Lab /openpose. https://github.com/CMU-Perceptual-Computing-Lab/openpose.

Live Cases

Case 1: Using wii balance board provides body weight fluctuation data during standing body movement, which we use to control 3D models in UE4.

I have been working in a team. We create a UE4 Blueprint project and then handle balance board input data using C++ class modules. Implemented a sub-stepping C++ module for deploying a more realistic and controlled simulation environment in UE4 Engine.

Without sub stepping Data access by simulation engine is discrete format which becomes cause of less realistic actuation of 3D objects. Sub stepping provides a highly realistic simulation environment by providing continuous minor fluctuations.

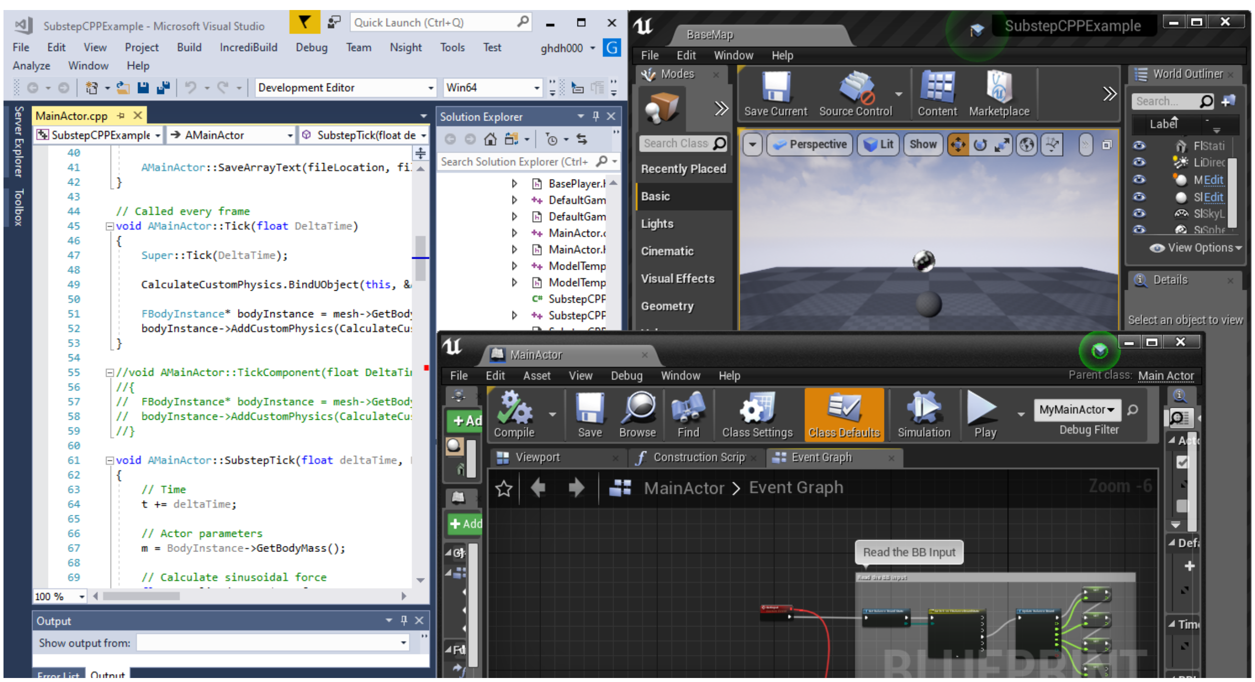


Fig. 2: Sub stepping class implementation in UE4 using C++ and accessing input with balance board plugin using blueprint class.

Case 2: In HCR-Lab there is Vicon motion capture system for validation and camera sensor to collect human walking video data. With the help of Deep Learning and computer vision systems extract out different kinematic features of human walk only based on video data. Which will reduce extra hardware weight from robotic assistive systems and increase smoothness of the overall system. For that we deploy OpenPose model to process lab video data and convert it into 2D skeleton video data. And then to extract kinematic features from 2D video data, we used a MATLAB based model (described in the literature review section). Which provides Step time, Stance time, Swing time, Double support time, Step length, Gait speed.

Fig. 3: Overlapped skeleton based OpenPose output video. Video source: HCR Lab, IIT-Gandhinagar.

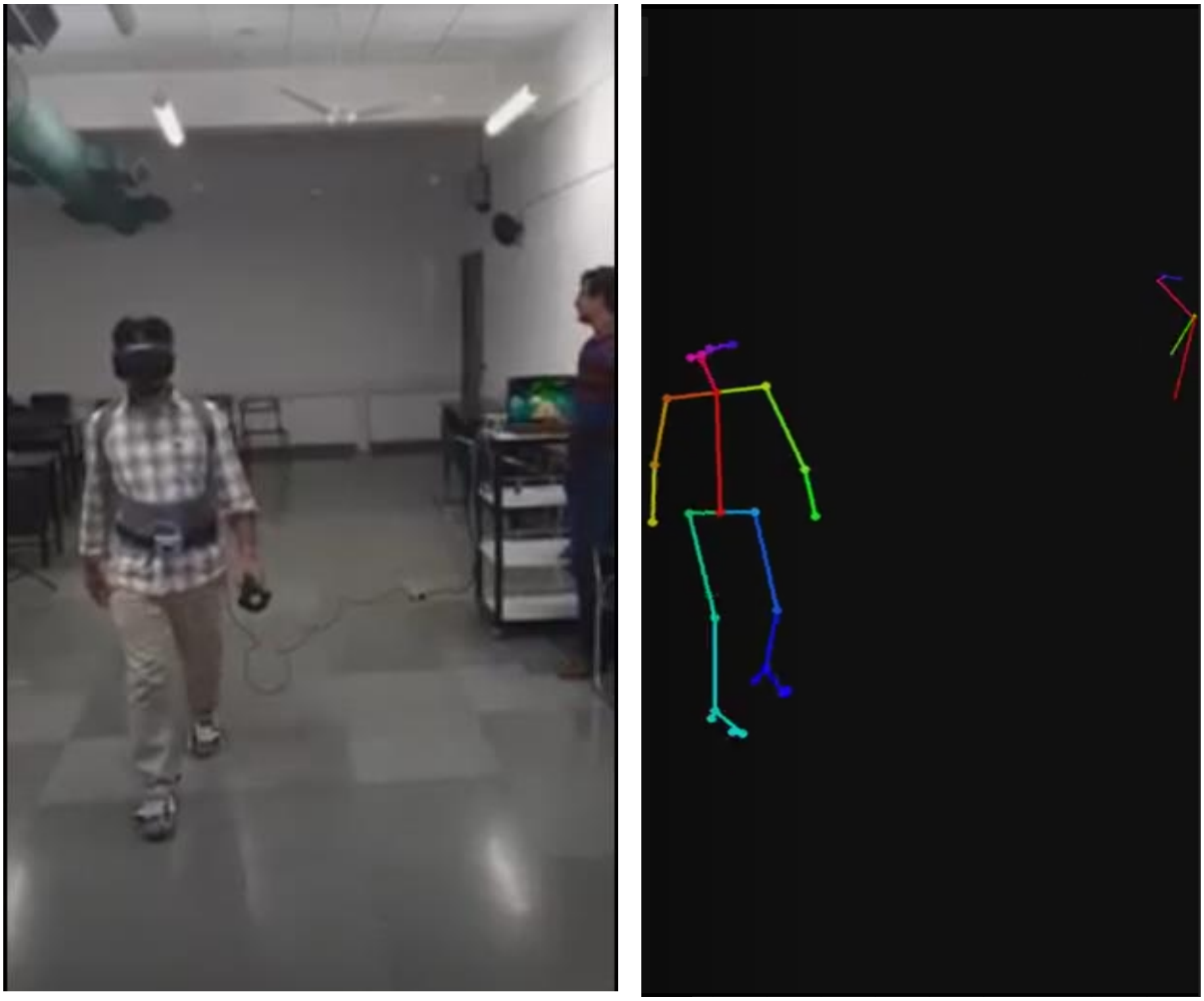


Fig. 4: Only skeleton based 2D output video. Video source: HCR Lab, IIT-Gandhinagar.

To extract out gait parameters from these 2D videos related JSON data files we used MATLAB based model[10].

[10] . Two-dimensional video-based analysis of human gait using pose estimation. Published: April 23, 2021. https://doi.org/10.1371/journal.pcbi.1008935. Method used in this research paper also. https://github.com/janstenum/GaitAnalysis-PoseEstimation.

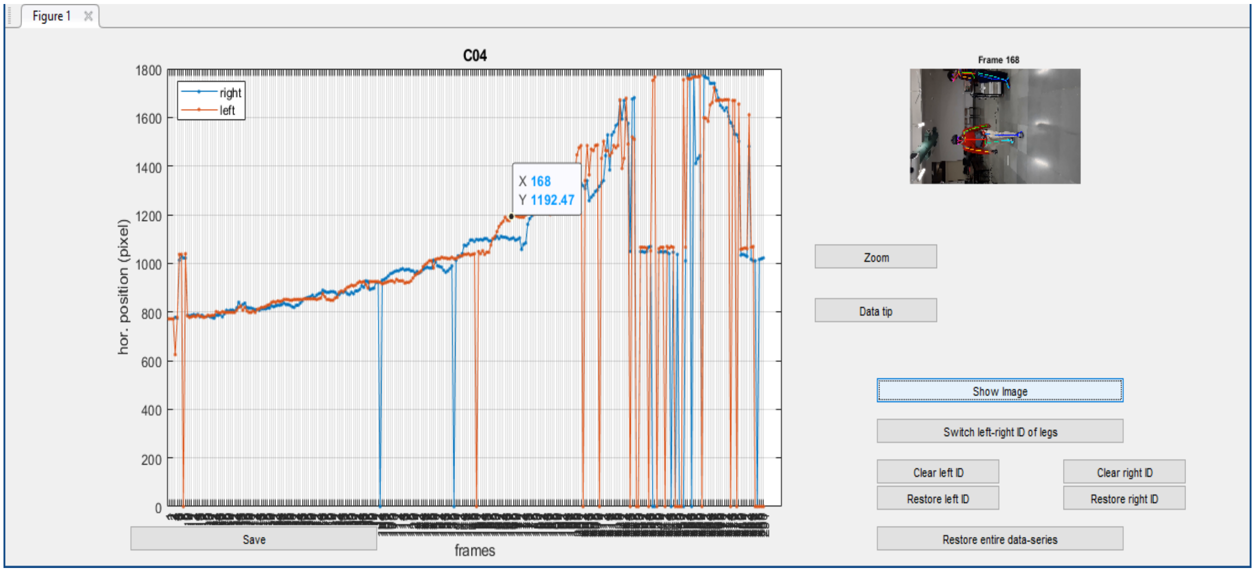


Fig. 5: Left and Right leg positions-based data plot, data frames of heel-strike and toe-off gait events. Data source: HCR Lab, IIT-Gandhinagar.

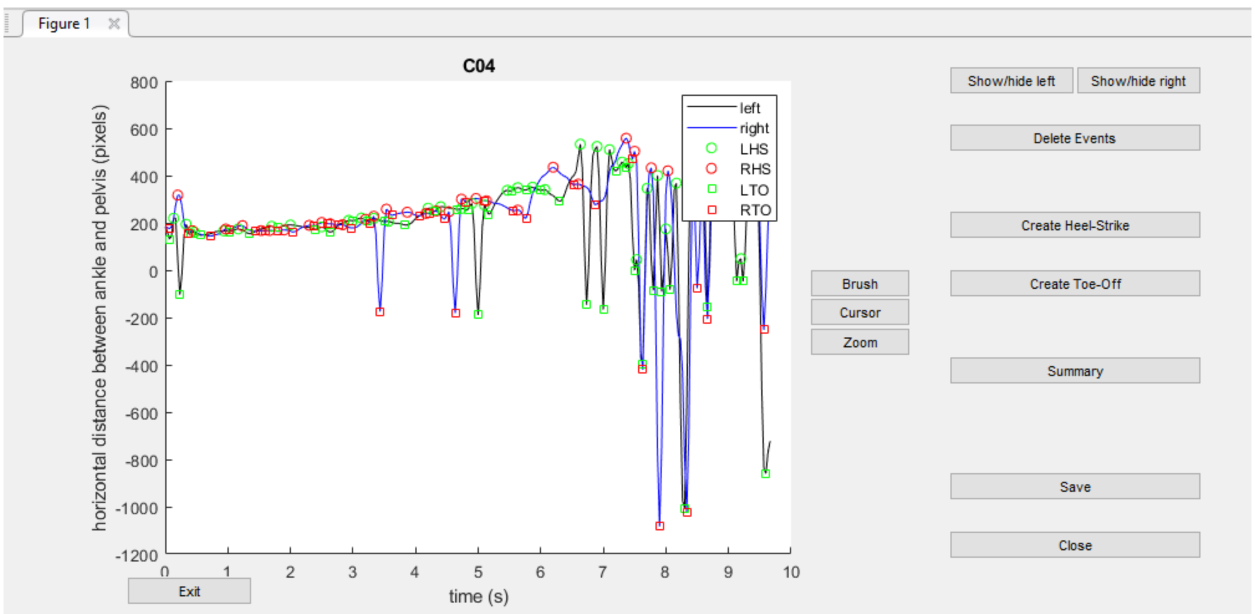
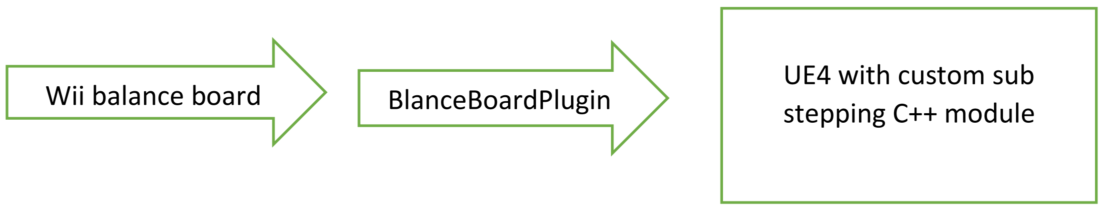


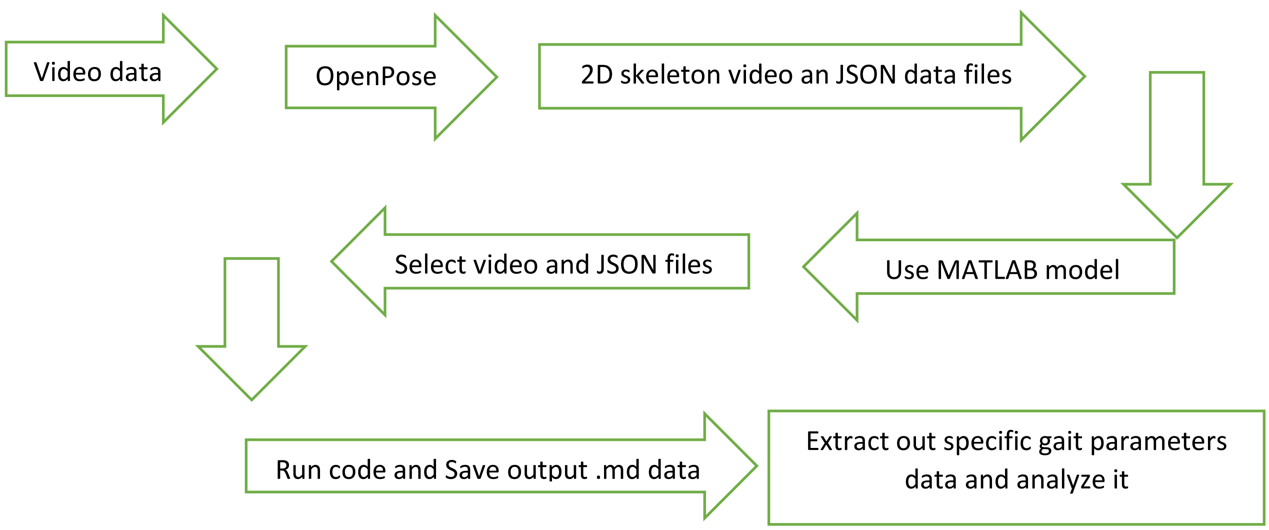
Fig. 6: Analysis of 2D video data with time, graph shows horizontal distance between ankle and pelvis (pixels) with respective of time. Data source: HCR Lab, IIT-Gandhinagar.

Work so far done

Sensor data connectivity with real world physics constraint enabled simulation engine. Controlling 3D models in UE4 engine with load sensor data.



In Human gait analysis, I had deployed OpenPose to preprocess video data and convert it into 2D skeleton model. And using a MATLAB based model to extract out features.



Conclusion

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This internship provides me with an actual realistic Human Robot Interaction work environment which helps me to understand various aspects of Human Centered Robotics like, WeARS system works collaboratively with humans as an assistive system to rehabilitate gait cycle deformation.

My project work is highly influenced by this internship and HCR Lab research work. Working within the innovative, dedicated and highly motivated team of HCR Lab helps me to understand various aspects and concepts of robotics and how to engage with the real world environment to develop new robots. I learned about IMU, different microcontrollers, motors, encoders and some of the other hardware aspects of robotic systems. I also got aware about designing parameters for different parts of robotic systems. Also, I explore research and innovation possibilities and requirements in robotics to make it highly trustworthy dominating future technology.

I also got hands-on experience with a Virtual Reality system which is very helpful to testify to human robot interaction.

Robots and humans can work together and collaboratively when robots have an efficient perception and recognition ability about human cognition.

Future Work

My future work in robotics will be highly motivated by the Human in the loop approach. From this internship getting a highly motivated beginning will definitely help me to pursue my career with focus and passion for innovation. I will continue to explore, research and develop robotics systems.

I will focus more on Artificial Intelligence (AI) enabled technologies for development of smart robotic systems.

There are many futuristic sub fields of robotics that are highly dominating because of enhanced implantability in the real world – I have been highly motivated to explore these fields.

- Soft Robotics
- Digital Twin
- Open-Source Robotics
- Cognitive Robotics
- Bio Mimic
- AR/VR