Aayam Regmi

Aayam Regmi(77466864) - Initial Project Plan + Risk Register

Component 1: Project Specification (Initial Project Plan + Risk Register)

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Level 6 Production Project

Project Initiation

Name: Aayam Regmi	**Student I.D.: 77466864**
Course: BSc (Hons) Computing	Supervisor's Name:

Final Project Individual Aim & Objectives

Title of my Project: Comparative Evaluation of Vision-Based Finger Tracking for Piano Interaction

Aim of my Project: To evaluate robustness, accuracy and real-time performance of two or more open-source vision-based finger tracking systems during interaction with a real piano acting as a ground truth. Considering lighting conditions, finger and hand occlusion challenges, and user diversity (hand size and skin tone) the aim is to determine whether these variables affect the consistency, performance and accuracy across different pretrained models.

Objectives of my Project:

- To develop a fundamental understanding of vision-based hand and finger tracking algorithm techniques including temporal tracking, landmark detection and handing occlusions between overlapping hands and fingers.
- To analyze existing computer vision finger tracking approaches in real-time.
- To design a system with a camera programmed to work with finger tracking and a real electronic piano for ground truth interaction.
- To establish a camera-to-keyboard calibration system that maps pixel coordinates to physical key positions.
- To compare multiple pretrained finger-tracking models (MediaPipe Hands, OpenPose, MoveNet) under same experimental conditions and evaluate the result.
- To define and implement quantitative performance metrics for finger tracking evaluation.
- To analyze different lighting situations and its effect on tracking accuracy and stability.
- To consider tracking performance across users with different hand sizes.
- To assess performance bias when using tests with broad skin tone categories.
- To investigate the impact of finger and hand occlusion on tracking accuracy and recovery behavior.

- To evaluate trade-offs between accuracy and real-time performance between different pretrained models and tabulate the results.
- To identify current limitations of approaches in vision tracking models in piano interaction contexts and recommend targeted improvements.
- To establish a reproducible experimental protocol for evaluating hand-tracking systems in the context of music and instruments.

Specification of my Product:

Functional Requirements

#	Functional Requirement	Description / Scope	MoSCoW
1	Finger landmark tracking using vision models	Using preexisting finger tracking models with a fixed camera above a real piano	Must
2	MIDI ground truth capture	Establish ground truth with digital MIDI output of Casio CTK-2400	Must
3	Temporal synchronization & comparison	Tabulate comparison between different models, fingertip position and keypress times	Must
4	Support multiple open-source models	Integrate & compare at least MediaPipe Hands, OpenPose, MoveNet (Thunder)	Must
5	Camera-to-keyboard spatial calibration	Map pixels to physical piano or establish virtual landmarks	Must
6	Data logging system	Store x,y coordinates, video frames and timestamps provided by MIDI	Must
7	Keypress event analysis	Calculate MIDI keypress and fingertip Euclidean distance, marking active finger or failure	Must
8	Quantitative performance metrics calculation	Calculate primary metric MPJPE and secondary metrics like loss rate, temporal jitter, occlusion recovery time, FPS latency	Must
9	Controlled variation of experimental conditions	Test different scenarios like hand size, skin tones and occlusion	Must
10	Statistical comparison of models	Perform statistical tests (e.g. t-test) to compare models across conditions	Must
11	Model selection justification	For piano interaction provide scientific reasoning and recommendations for the best suitable model	Must
12	Reproducible experimental protocol	Record a detailed protocol for future enhancements and recreations	Should

13	Evaluation under additional models	Include one or more extra models beyond the main three (e.g. BlazePose, HRNet, custom fine-tuned, etc.)	Could
14	Real-time visualization	Add detection landmark and active finger indicator live overlay interface during data collection	Should
15	Automatic detection & annotation of occlusion events	For severe occlusion cases automatically classify and log frames	Could
16	3D hand pose estimation	Use models that output 3D coordinates with multi camera system	Won't
17	Mobile / embedded deployment	Deploy the final comparison system on mobile devices or edge hardware	Won't
18	Multi-camera / multi-view tracking	Use more than one camera for improved accuracy	Won't
19	Real-time audio feedback during playing	Generate sound or visual feedback based (gamification)	Won't

Non-Functional Requirements

#	Non-Functional Requirement	Description / Expectation	MoSCoW
1	Research-focused with functional prototype	Deliver meaningful research insights supported by a working prototype system	Must
2	Fair & controlled comparison conditions	models evaluated under identical hardware, lighting, camera position & setup	Must
3	Development using Python & established open-source libraries	Use Python + OpenCV, MediaPipe, MIDI libraries, stats & plotting as primary tools	Must
4	Ethical compliance & participant protection	Follow university ethics guidelines, obtain approval, informed consent, anonymized & secure data storage	Must
5	Reasonable real-time performance	Achieve at least 15–20 FPS on the development machine during data recording	Should
6	Good code quality, documentation & reproducibility	Clean code structure and comprehensive README	Should
7	Basic robustness & graceful error handling	System logs errors and continues operation (no full crash)	Could

Research:

Finger tracking systems are used in many fields today, including human-computer interaction (HCI), virtual and augmented reality, and medical assessments [1]. In modern frameworks for finger tracking, accuracy is the deciding factor for usability, and often research done under such libraries have controlled datasets that might not account for multiple real-world interaction challenges [2]. From lighting variations to finger occlusion and user diversity, a piano has many of these challenges that can test these frameworks' accuracy [3].

Due to vision-based tracking systems relying on RGB image information, skin tone is included in this project as an evaluation factor [4]. Multi-range RGB values introduce different contrasts and reflections under different lighting conditions, which can influence landmark detection evaluation [5]. Studies conducted under vision systems can exhibit disparities in performance across demographic groups [6]. Multiple pretrained models might be trained under biased RGB values with limited demographic diversity [7]. With broad skin tone assessments, this study will be able to assess potential bias in the system, determining potential dataset improvements for vision tracking models [4][7].

Hand size is also considered, as differences in finger length and joint spacing may affect landmark localization accuracy [2]. Piano interaction presents unique challenges, including rapid finger movements, frequent hand occlusion, and proximity of fingers, making it an ideal testbed for tracking system robustness [3][8]. Additionally, multi-model tests can determine if certain behaviors are model-specific or a generalized problem in terms of finger tracking systems [2][9].

Evaluation:

The average Euclidean distance between predicted fingertip locations by the open-source models and the corresponding pressed key location is the Mean Per-Joint Position Error (MPJPE) [10]. MPJPE will be the primary performance metric for this research. If MPJPE is a negligible value like <10mm, the tracking will be considered accurate [10][11].

Secondary metrics:

- Loss rate (percentage of frames where hands are not detected)
- Temporal jitter (standard deviation of joint positions across continuous frames)
- Occlusion recovery time (frames required to re-establish tracking)
- Latency (FPS) [2][9][12]

The dataset and results will be categorized by the following standards:

1. Lighting categorization:

- standard indoor 400-500 lux
- bright 800-1000 lux
- dim 150-200 lux [2]

2. Hand size categorization: Small · Medium · Large [2]

3. Skin tone category method: Fitzpatrick Scale [4][13]

Statistical analysis will be paired with a t-test ($p<0.05$) to compare model performance [2][9].

Validation of ground truth generation will be done by annotating 10% frames [11].

Project Planning & Methodology

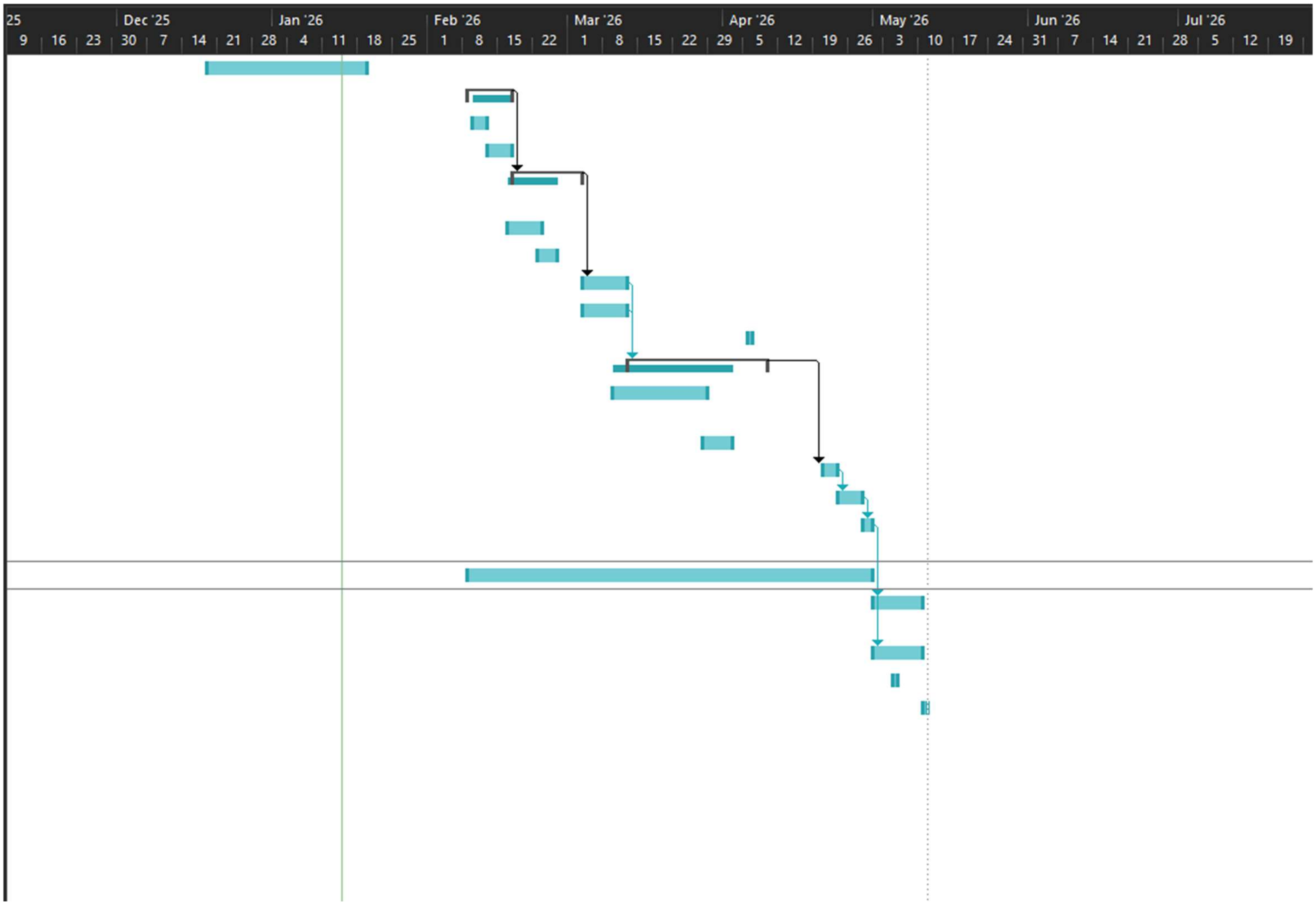
Project Planning:

Task Sheet

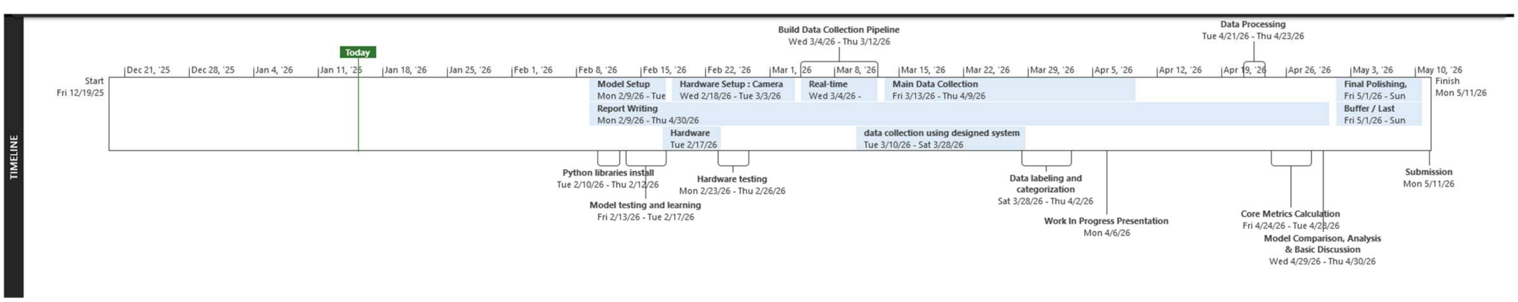
GANTT CHART

	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1		Project initiation + risk register	22 days	Fri 12/19/25	Mon 1/19/26		
2		**Model Setup and Testing**	**7 days**	**Mon 2/9/26**	**Tue 2/17/26**		
3		Python libraries install	3 days	Tue 2/10/26	Thu 2/12/26		
4		Model testing and learning	3 days	Fri 2/13/26	Tue 2/17/26		
5		**Hardware Setup : Camera and Piano Calibration**	**10 days**	**Wed 2/18/26**	**Tue 3/3/26**	**2**	
6		Hardware purchase	5 days	Tue 2/17/26	Mon 2/23/26		
7		Hardware testing	4 days	Mon 2/23/26	Thu 2/26/26		
8		Build Data Collection Pipeline	7 days	Wed 3/4/26	Thu 3/12/26	5	
9		Real-time Overlay System Creation	7 days	Wed 3/4/26	Thu 3/12/26		
10		Work In Progress Presentation	1 day	Mon 4/6/26	Mon 4/6/26		
11		**Main Data Collection**	**20 days**	**Fri 3/13/26**	**Thu 4/9/26**	**8,9**	
12		data collection using designed system	15 days	Tue 3/10/26	Sat 3/28/26		
13		Data labeling and categorization	5 days	Sat 3/28/26	Thu 4/2/26		
14		Data Processing	3 days	Tue 4/21/26	Thu 4/23/26	11	
15		Core Metrics Calculation	3 days	Fri 4/24/26	Tue 4/28/26	14	
16		Model Comparison, Analysis & Basic Discussion	2 days	Wed 4/29/26	Thu 4/30/26	15	
17		Report Writing	59 days	Mon 2/9/26	Thu 4/30/26		
18		Final Polishing, Proofreading, Formatting	7 days	Fri 5/1/26	Sun 5/10/26	16	
19		Buffer / Last-minute Fixes	7 days	Fri 5/1/26	Sun 5/10/26	16	
20		Research Presentation	1 day	Tue 5/5/26	Tue 5/5/26		
21		Submission	1 day	Mon 5/11/26	Mon 5/11/26		

Gantt chart



Project Timeline



Methodology:

This project adopts a Rapid Application Development (RAD) methodology because the data collection and processing will need higher priority and time after the system is developed.[14] Other methodologies such as waterfall emphasizes a straightforward development with no turnback's, while RAD prioritizes rapid development and iterations of a working prototype. For comparative research projects like this, RAD is appropriate as core functional testing platform is required rather than product ready application. RAD allows continuous feedback and changes from the supervisor's advice as well.

Resources

The software I require to complete my Project successfully:

Item	Source
Windows OS	Own
Python 3.8+	Own
MediaPipe	Open Source
OpenCV	Open Source
MIDI Interface Libraries (mido, python-rtmidi)	Open Source
Statistical Analysis Software (scipy, statsmodels)	Open Source
Data Visualization (Matplotlib, Seaborn)	Open Source
Version Control (Git, GitHub)	Open Source
Microsoft Word	Own
Microsoft Excel	Own
Microsoft PowerPoint	Own
Web browsers: Google Chrome	Own

The hardware I require to complete my Project successfully:

Item	Source
Laptop / PC (16GB RAM, i7-14th gen CPU, RTX 5070)	Own
USB Camera (30 FPS, 1080p resolution)	Own
Casio CTK-2400 Digital Piano	Own
USB A-to-B Cable (for MIDI connection)	Purchase
Camera Tripod or Mount	Purchase
Digital Lux Meter (for lighting measurement)	Purchase
Colored Calibration Markers	Purchase

Human Resource

I am working on my Project with the following people

Name: Aayam Regmi

Role:

Module Leader: Dr. Rohit Raj Pandey

Supervisor:

Initial Bibliography

1. Zhang, F., et al. (2020). MediaPipe Hands: On-device Real-time Hand Tracking. arXiv preprint arXiv:2006.10214.

2. Jo, H., & Kim, S. (2022). Comparative Analysis of OpenPose, PoseNet, and MoveNet Models for Pose Estimation in Mobile Devices. Traitement du Signal.

3. Liang, H., et al. (2016). Barehanded Music: Real-time Hand Interaction for Virtual Piano. ACM Symposium on Interactive 3D Graphics and Games.

4. Buolamwini, J., & Gebru, T. (2018). Gender Shades: Intersectional Accuracy Disparities in Commercial Gender Classification. Proceedings of Machine Learning Research.

5. Groh, M., et al. (2023). Robustness Evaluation in Hand Pose Estimation Models using Metamorphic Testing. arXiv preprint.

6. Mehrabi, N., et al. (2021). A Survey on Bias and Fairness in Machine Learning. ACM Computing Surveys.

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8. Hiranaka, A. (Year). AR Piano Playing Using Real-Time Hand Tracking.

9. Kim, et al. (2022). Comparative Analysis of Skeleton-Based Human Pose Estimation. MDPI Future Internet.

10. Mueller, F., et al. (2018). GANerated Hands for Real-Time 3D Hand Tracking from Monocular RGB. CVPR.

11. Salz, D., & Azam, F. (2019). Playing a Virtual Piano with Dynamics. Stanford University Report.

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13. Fitzpatrick, T.B. (1988). The Validity and Practicality of Sun-Reactive Skin Types I Through VI. Archives of Dermatology.

14. Martin, J. (1991). Rapid Application Development. Macmillan.

Risk Register

ID	Risk	Risk Description	Likelihood	Impact	Severity Level	Owner	Mitigation	Status
1	Inaccurate or unstable finger tracking due to occlusion	Frequent occlusion due to fast hand movements while playing the piano	Medium (4)	Medium (3)	(12) Medium	Aayam Regmi	Have datasets with controlled tempos and occlusion levels	Open
2	Poor model performance under varying lighting conditions	Inconsistency due to light level changes	Medium (3)	Medium (3)	(9) Medium	Aayam Regmi	Conduct all data collection under controlled lighting environment (dim/standard/bright)	Open
3	Bias or degraded performance across skin tones and hand sizes	Performance disparity in training data categorized by Fitzpatrick scale	Medium (3)	Medium (3)	(9) Medium	Aayam Regmi	Have diversity in participant recruiting in hand sizes and skin tones and perform statistical tests on Fitzpatrick scale groups	Open
4	Synchronization issues between video & MIDI ground truth	Unsynchronized comparison due to timestamp mismatch	Low (2)	High (5)	(10) Medium	Aayam Regmi	Use precision timestamps and validate test data using annotations	Open
5	Real-time performance below target (FPS < 15-20)	Low model performance on hardware	Low (2)	Low (2)	(4) Low	Aayam Regmi	Use lighter models and use NVIDIA CUDA acceleration supported models or just multi core CPU procession	Open
6	Ethical approval or participant consent delays	Delay in approval of research or issues with data consent and protection	Medium (3)	High (5)	(15) High	Aayam Regmi	Prepare ethical consent form and discuss with supervisor regularly	Open
7	Hardware failure, malfunction or unavailability	Hardware failure due to various reasons like static charge, water damage or unavailability	Low (2)	High (5)	(10) Medium	Aayam Regmi	Test hardware before testing, if hardware gives out during testing purchase backup hardware, borrow backup piano for project duration in case of failure	Open
8	Time overrun due to integration &	Not being able to meet MS projects deadlines due to	Medium (3)	High (5)	(15) High	Aayam Regmi	Follow RAD methodology and complete testing	Open

	debugging complexity	implementation and data collection					system before MS project deadline, Prioritize more time for data collection	
9	Data loss or corruption during long recording sessions	Video datasets lost due to software crashes or memory corruption	Low (1)	Medium (3)	(3) Medium	Aayam Regmi	Have backup data in GitHub, rerecord data incase backup does not exist	Open

Summary:

Likelihood:

- 4 low
- 5 medium

Impact:

- 1 low
- 4 medium
- 4 high

Severity:

- 1 low
- 6 medium
- 2 high