Biomechanical Motion Analysis with Computer Vision: A Case Study of Left-Hand Musculature in Violin Technique

Improving physical performance through applied computer vision

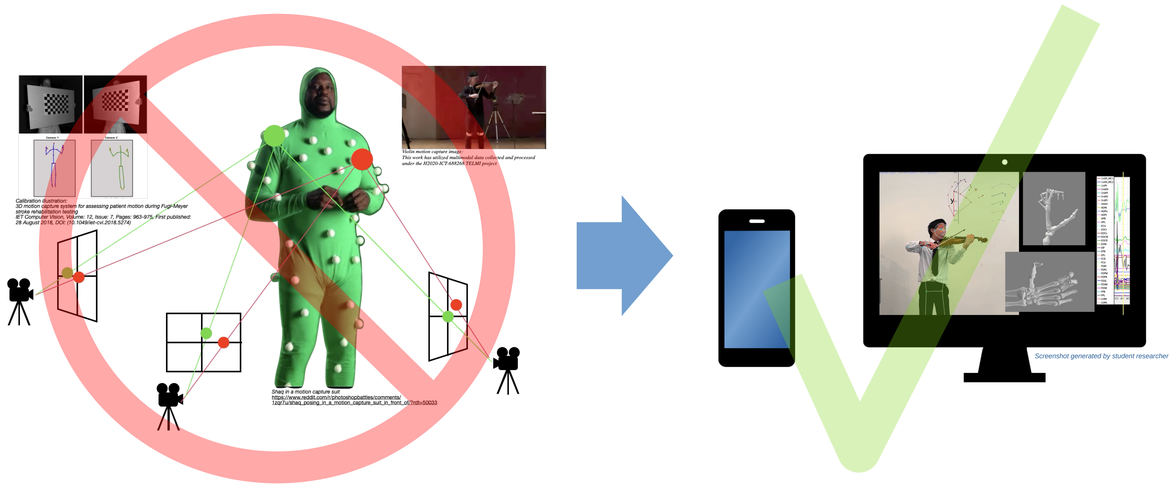
Problem & Engineering Goal

Problem:

- Performance techniques like violin vibrato—the expressive pitch oscillation played by the left hand—require precise coordination and the correct use of muscles to produce the desired sound in a sustainable way to avoid improper tension and long-term injury.
- Playing-related Musculoskeletal Disorders (PRMD's) affect between 62-93% of musicians. Over 80% of professional full-time orchestra players have had PRMD's severe enough to cause loss of wages at some point in their career.
- Traditional biomechanical modeling requires expensive 3D motion-capture schemes like studios equipped with multiple calibrated cameras to triangulate markers placed on the performer. For the fine-motor motion of fingers, these schemes interfere with movement and often fail due to occlusion.

Engineering Goal:

- To develop a system which can analyze the muscle tension of a user's physical performance using only widely-available equipment (a single smartphone and computer) to enable effective everyday personal practice. The project is focused on the fine motor motion of the left hand.

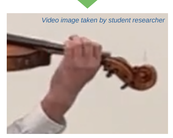


Design & Analysis Pipeline

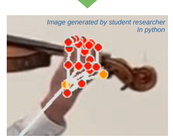
Input:
Smartphone Video

Video image taken by student researcher
Face blurred to preserve privacy

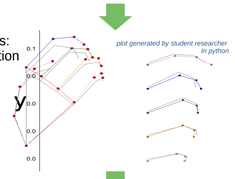
OpenCV
Video analysis



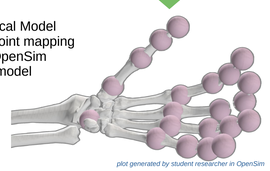
AI Pose Recognition
(MediaPipe library)
- 3D coordinate estimation



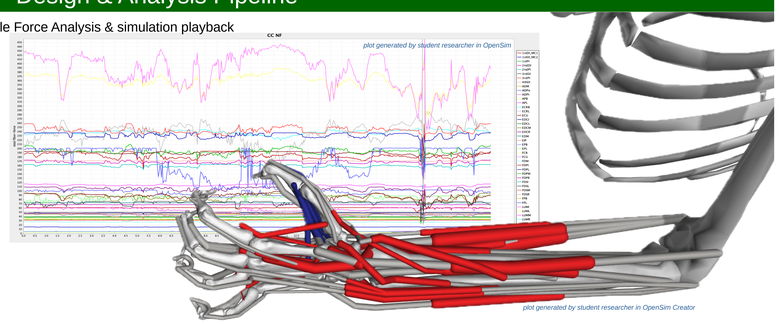
Custom Data Analysis:
- Point cloud registration (3D alignment)
- Scaling
- Interpolation
- Feature extraction



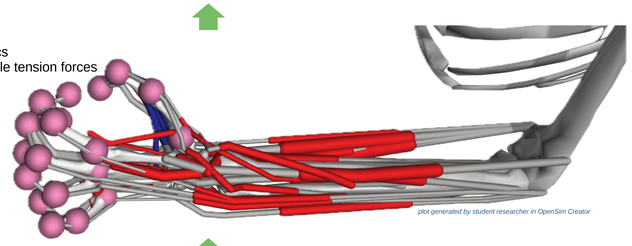
Biomechanical Model
coordinate/joint mapping
- Custom OpenSim left hand model



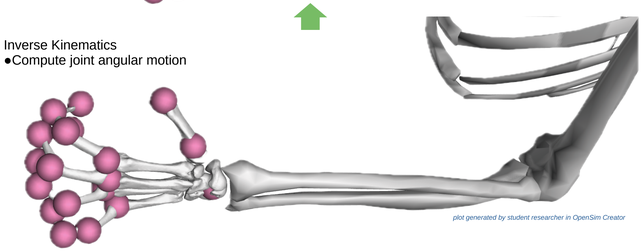
Muscle Force Analysis & simulation playback



Inverse Dynamics
- Compute muscle tension forces

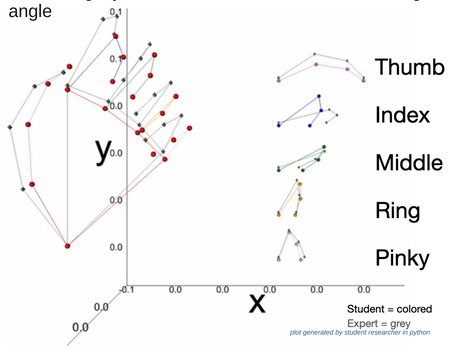


Inverse Kinematics
- Compute joint angular motion

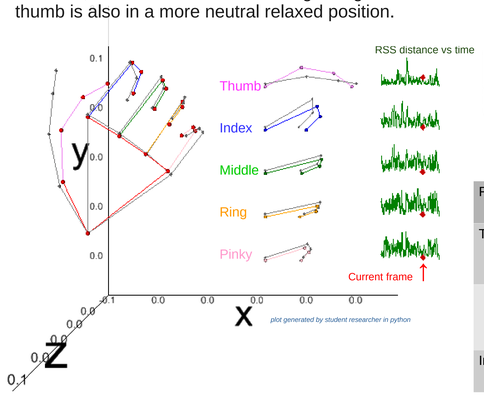


Results

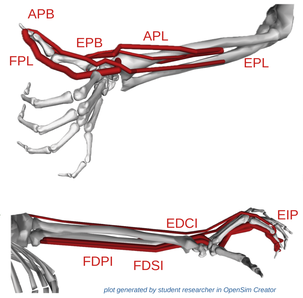
A) **High position vibrato:** the expert's palm (grey) is curved slightly further inward to achieve a better finger angle

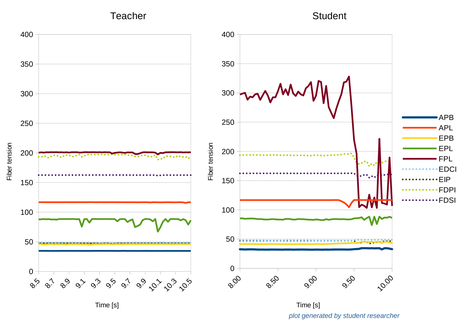


B) **Low position vibrato**: the expert's palm (grey) is flattened, also to achieve a better finger angle. The thumb is also in a more neutral relaxed position.

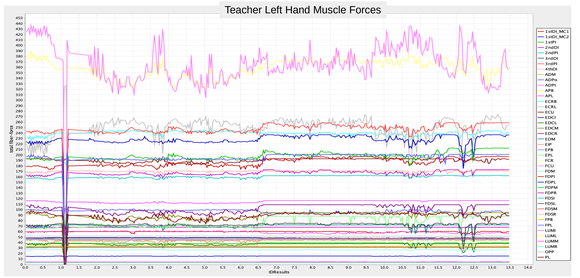


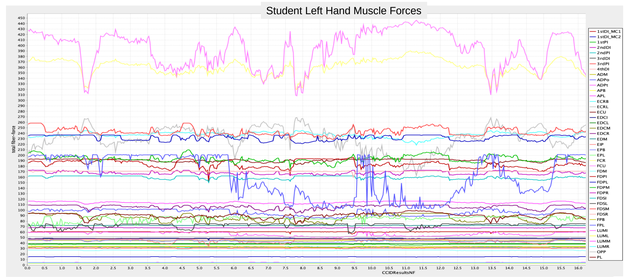
		Thumb	Index	Middle	Ring	Pinky
A) High position vibrato	Teacher	Relaxed (Angled away from violin)	Relaxed (index is extended)	Relaxed	Relaxed (More contact with violin, flatter angle)	Relaxed
	Student	Stiff (thumb grips violin more)	Stiff (too curved)	Relaxed	Fingers too high, knuckles stiff	Relaxed
B) Low position vibrato	Teacher	More relaxed	Relaxed	Relaxed	Relaxed	Relaxed
	Student	Stiff (Grabbing violin)	Too far extended (possible intonation issue)	Relaxed	Relaxed	Relaxed





Finger	Teacher/Student comparison	Muscle	Clinical Significance / Potential Injury Type
Thumb	Teacher = relaxed thumb Student = Excessive tension from gripping violin neck between index/thumb	FPL, APL	Carpal Tunnel Syndrome, Wrist pain
	Teacher = active w/ fast release of tension Student = sustained tension	EPL	Crucial for diagnosing/treating conditions affecting thumb/wrist Inflammation can cause pain, limited movement
Index finger	Teacher = more relaxed index position Student = more curled index position	FDPI	Strain and Tendinopathy: persistent pain, stiffness

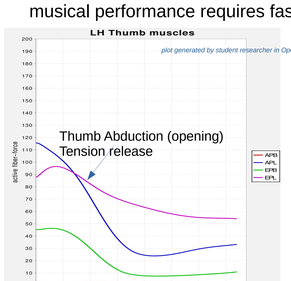


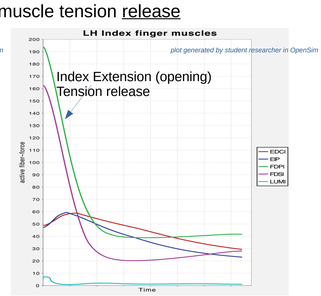


Conclusions & Future Directions

Findings:

- My system successfully computes fine-motor muscle tension of the hand using only single-smartphone video and custom software built with open-source components.
- Even occluded members like the thumb can be tracked and analyzed
- Unlike in sports, where muscle activation speed is critical, sustainable musical performance requires fast muscle tension release





Future Directions:

- My framework can be readily adapted to model the rest of the human body.
- Potential applications span a wide range: other musical performance techniques, dance, sports, and even training occupational tasks like surgery, where precise and efficient dexterity is needed.
- This can also be expanded to aid in physical therapy and rehabilitation
- The large quantity of muscle data—43 individual muscles in the hand alone—presents challenges in interpretability for the performer. Near-term enhancement plans include muscle aggregation and AI classification of muscle tension patterns.
- Future enhancement plans include realtime muscle tension calculation from live video, as well as visualization of results through augmented reality overlays: realizing my dream of creating "X-ray vision"