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Design & 4D Printing of a Human Prosthetic Hand with Electrically Driven SMA Muscle-Like Actuation

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INTRODUCTION & AIM

- ❑ Hand injuries reduce dexterity, impairing a person's ability to perform everyday tasks.
- ❑ Current prosthetic hands depend on bulky motors + tendon routing, making them heavy, noisy and difficult to miniaturize.
- ❑ **Aim**: Create an anatomically accurate, motor-free, soft-tissue-integrated prosthetic hand with natural motion and reduced complexity.

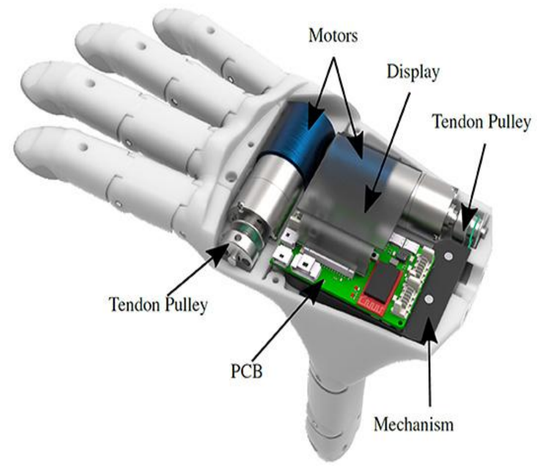

Figure 1. An example of current electrically driven prosthetic hand relying on bulky motors, gears & tendon-routing systems, resulting in heavy designs and limited anatomical realism.

MATERIALS & METHODS

- ❑ **CAD (SOLIDWORKS):** Bone geometry, pin joint (1DOF, DIP & PIP) universal joint (2DOF, MCP) ball-and-socket (3DOF, Thumb)

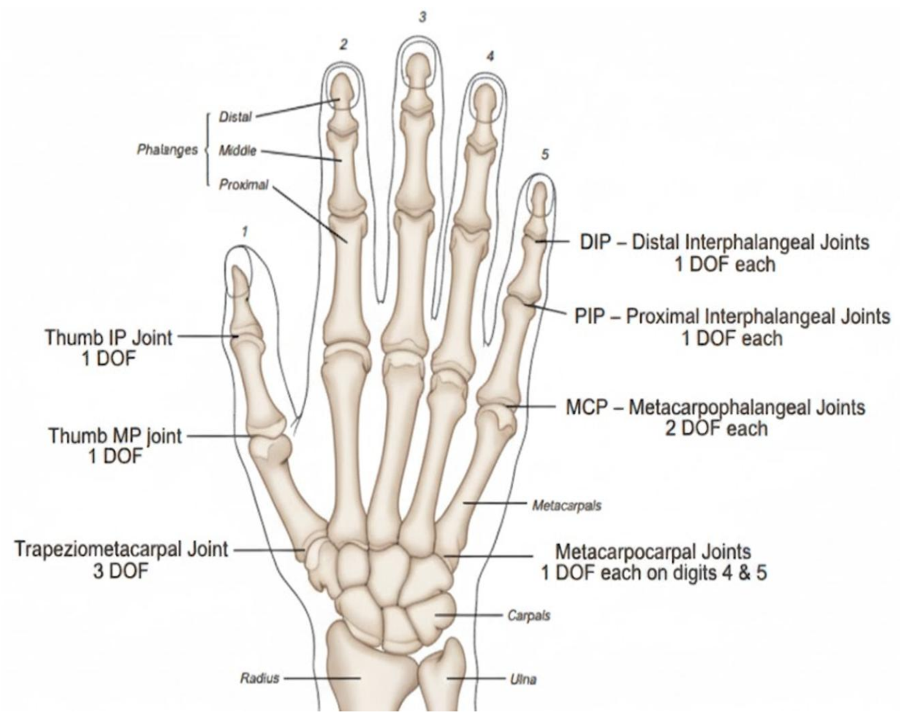

Fig. 2. Schematic of the physiological structure of human hand

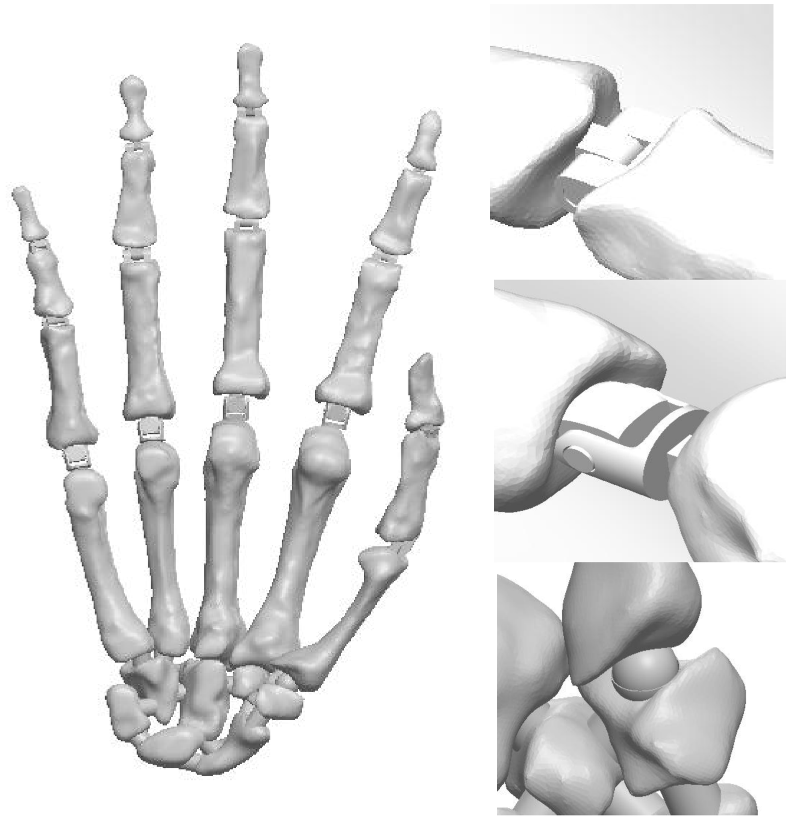

Figure 3. SOLIDWORKS CAD model of hand skeleton with joint types (at right): hinge joints at the DIP & PIP enabling 1-DOF flexion–extension (top), universal joint at the MCP with 2-DOF motion (middle) & ball and socket joint at thumb (bottom)

- ❑ **Simulation (ANSYS):** Cortical bone, soft tissue (neo-Hookean), SMA contraction behavior with rigid dynamics & transient motion.

Figure 4. SOLIDWORKS model of hand skin

Property	Cortical Bone (Rigid)	Skin (Compliant)
Material Type	Anisotropic, Mineralized Composite	Non-linear Viscoelastic (Soft Tissue)
Young's Modulus (E)	10 – 30 GPa (High Stiffness)	0.005 – 0.5 MPa (Low Stiffness)
Stiffness Ratio	Extremely High	Very Low (1/100,000th of bone)
Ultimate Strength	50 – 150 MPa	5 – 30 MPa
Strain at Failure	Low (0.5% – 3%)	Very High (30% – 70%+)
Poisson's Ratio (v)	0.18 – 0.45	~0.49 (Nearly Incompressible)

Table 1. Mechanical properties of cortical bone and skin used in the simulation model.

- ❑ **Prototyping (3D Printing):** Initial prints of bone segments and surface shapes were produced using FDM (PLA) to confirm manufacturability and tolerances.

Fig. 5. QiDi FDM 3D printer at the NBM² Lab used for printing PLA material filament prototypes of the hand model.

RESULTS & DISCUSSION

- ❑ SMA-like actuation produced smooth, lifelike flexion without motors.
- ❑ ANSYS simulations validated bending, opposition & deformation.
- ❑ Rapid CAD–simulation–print loop accelerated development of a functional prototype.

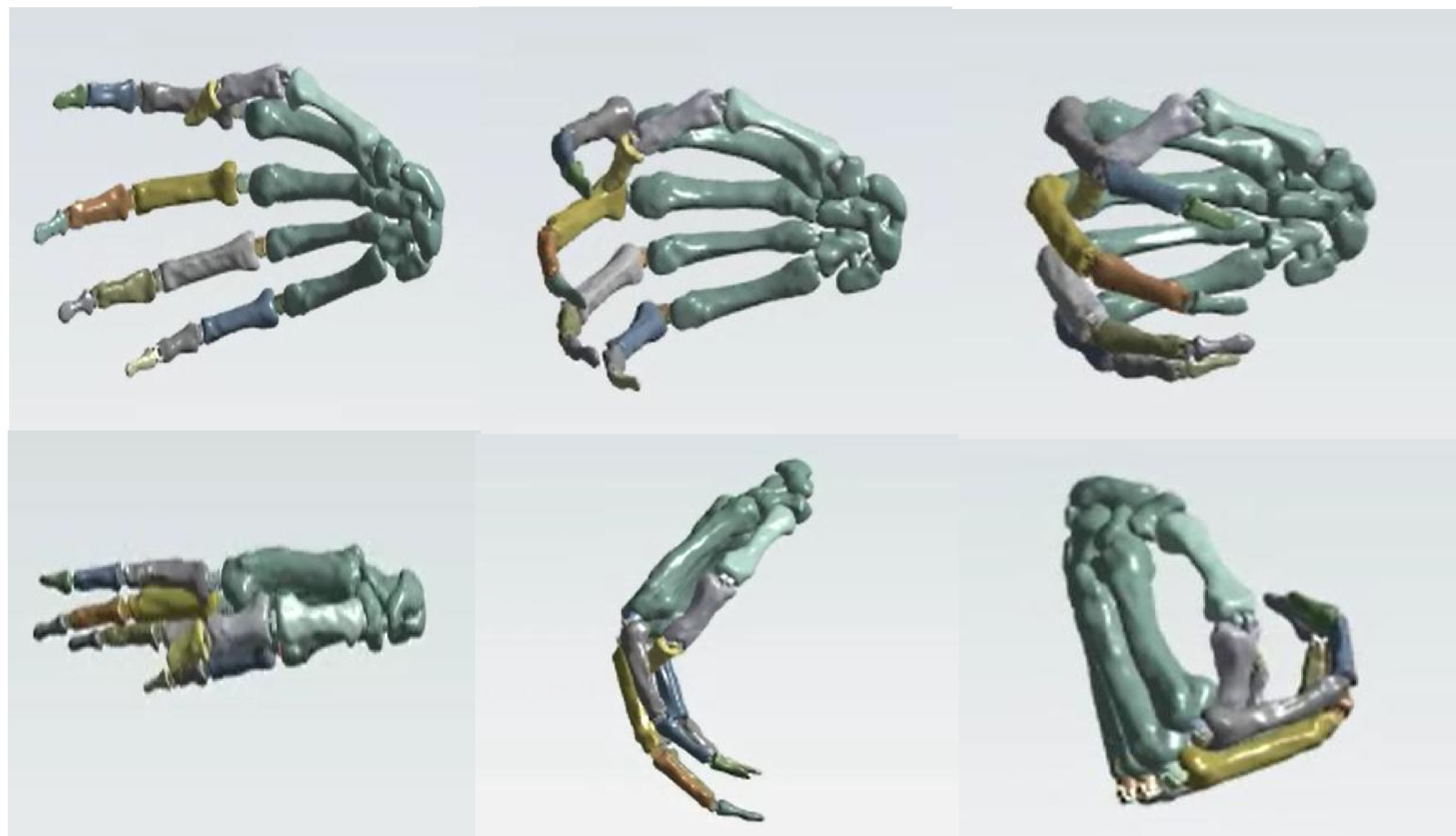

Fig. 6. Motion snapshots of the simulated finger joint: front-view swing motion (top 3) and side-view flexion profile (bottom 3).

JOINT TYPE	PURPOSE	SIMULATED MOTION RANGE	TYPICAL HUMAN RANGE
MCP (Knuckle)	Main bending joint at finger base	~70–90° flexion	90° flexion
PIP (Middle Joint)	Strongest bending joint	~90–110°	100–120°
DIP (Fingertip Joint)	Fine-control fingertip bending	~60–80°	70–80°
Thumb CMC	Thumb base joint enabling opposition	~45–60° rotation & abduction	40–60°

Table 2: Kinematic Comparison of Simulated & Typical Human Hand Joint Motion range

- ❑ Sample 3D-printed components matched the CAD dimensions well and verified that the design can be fabricated with 3D printing FDM/SLA methods.
- ❑ While the materials used (PLA, generic resin) don't exactly replicate bone properties, these prints helped verify design & provided feedback for future iterations.

Fig. 7. Segmented index finger prototype using QiDi FDM 3D printer with PLA filament material

CONCLUSION

- ❑ Demonstrated a motor-free, bioinspired prosthetic hand with SMA-like actuation.
- ❑ Achieved joint motions comparable to human biomechanics.
- ❑ Hybrid joint design & 3D printing enables compact, quiet, lifelike motion.

FUTURE WORK / REFERENCES

- ❑ Build full hand assembly; test grasp types, grip forces & opposition.
- ❑ Improve SMA speed via 4D printed hybrid SMA + tendon drive.
- ❑ Study fatigue of soft-tissue materials + long-term durability.
- ❑ Compare with commercial prosthetics for dexterity, smoothness & comfort.