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# Design Improvements and Experimental Characterization of a Sensored Rotating Crank for Arm Exercise

Polina Kopeikina[1], Cuauhtemoc Morales Cruz[1,2], Marco Ceccarelli[1], Susana Sanz [1,3]
1. LARM2: Laboratory of Robot Mechatronics, University of Rome Tor Vergata, Rome, Italy
2. Center for Genetic and Environmental Research (CIGyA-UATx). Autonomous University of Tlaxcala. 90120 Ixtacuictla, Tlaxcala, Mexico.
3. Institute for Vehicles Safety Assurance, Department of Mechanical Engineering, University Carlos III of Madrid, 28911 Madrid, Spain.

## INTRODUCTION & AIM

Upper limb injuries and mobility limitations are common and can result from trauma, chronic conditions, or neurological disorders, significantly affecting a person's quality of life. Effective rehabilitation requires repetitive, controlled movements to restore strength, flexibility, and coordination. Mechanotherapy devices, particularly those based on rotational motion, are widely used to support recovery by enabling both active and passive exercises. Among these, rotating crank mechanisms offer a simple and accessible solution for improving joint mobility through continuous cyclic motion.
This study aims to evaluate the performance of a rotating crank mechanism for arm rehabilitation by analysing its behaviour under different operating conditions, including passive use, stepper motor assistance, and DC motor-driven motion. The goal is to determine the most effective configuration in terms of smoothness, stability, and overall suitability for rehabilitation purposes.

## METHOD

**Mechanical setup**
- T-slot aluminium extrusion frame for stability and modularity
- Two prototype versions tested: V1 (stepper motor) → V2 (brushless DC motor)
- Crank length: 30 cm, connected via flexible coupling to motor shaft

**Sensing & data logging**
- Arduino Uno microcontroller for data acquisition
- 6-axis IMU sensor (LSM6DS3): 3-axis accelerometer + 3-axis gyroscope
- MicroSD logging shield: acceleration components, magnitude, roll/pitch/yaw

**Testing protocol**
- 6 volunteers (3F, 3M, ages 21–26), ethics approval: RS.197.22
- 3 repetitions per configuration per volunteer
- Two exercise planes tested:
  - Standing — horizontal plane rotation
  - Sitting — sagittal plane rotation
- Three motor configurations compared: passive · stepper · DC motor

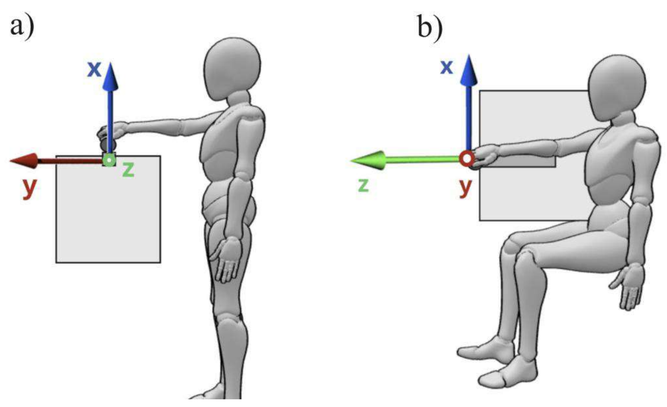
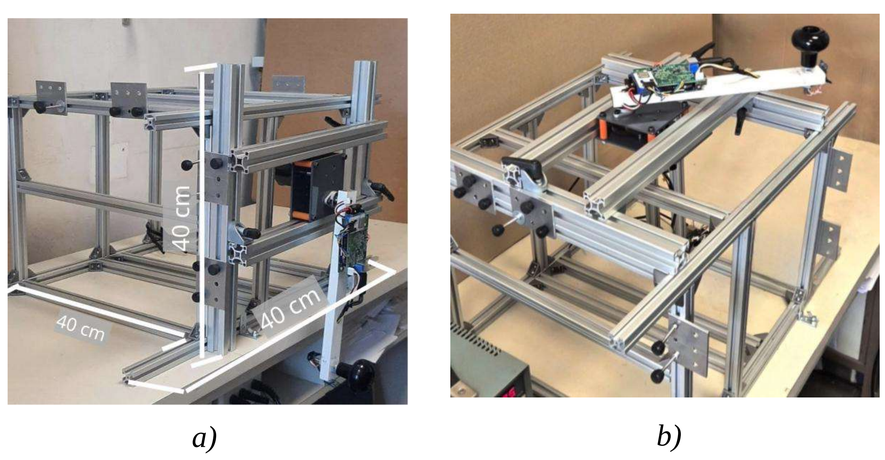



*Figure 1 Volunteer configuration during a test: (a) standing position with horizontal plane rotation; (b) sitting position with sagittal plane rotation.*




*a)* *b)*

*Figure 2 Prototype with the frame for the lab testing: a)crank is in the vertical plane with the frame size; b)crank is in the horizontal plane.*

## RESULTS & DISCUSSION

Three configurations were compared. In the passive V1 (no motor), the IMU captured clean, repeatable cyclical patterns confirming correct planar rotation — horizontal tests showed Ax fluctuating near 0, Ay stable around 9 m/s², while vertical tests produced large Ax and Az oscillations consistent with full sagittal rotation. The stepper motor configuration (semi-active mode) introduced higher vibration and less smooth motion, with acceleration magnitude fluctuating 12–13.5 m/s², reflecting mechanical irregularities unsuitable for sustained rehabilitation use. The DC motor prototype (V2) produced the most consistent results: acceleration magnitude remained stable around 8–13 m/s² across all 6 volunteers, with roll and pitch sweeping the full ±150° range expected for complete crank revolutions. Minor inter-subject differences were observed — male volunteers showed slightly higher peak accelerations, suggesting more active grip engagement, while female volunteers showed smoother profiles as the DC motor governed motion more completely. Yaw remained flat across all configurations, confirming controlled single-plane rotation throughout.

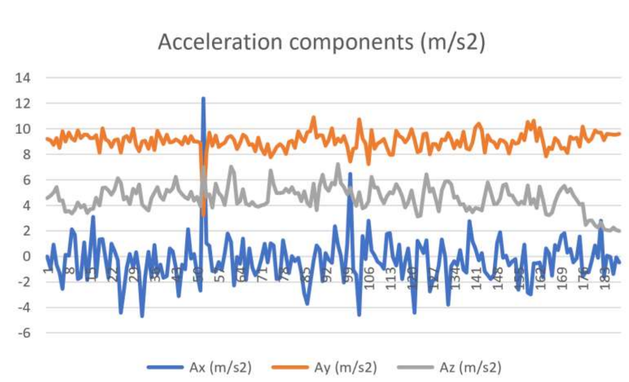



*Figure 3 Acquired data of a test with prototype V1 (no motor) in terms of acceleration components.*

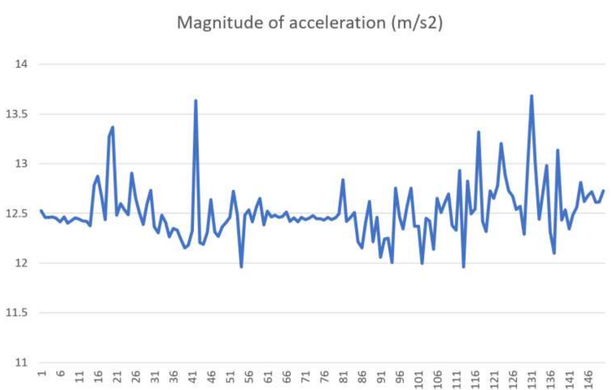



*Figure 4 Acquired data of a test with prototype V1 with stepper motor in terms of magnitude of acceleration.*

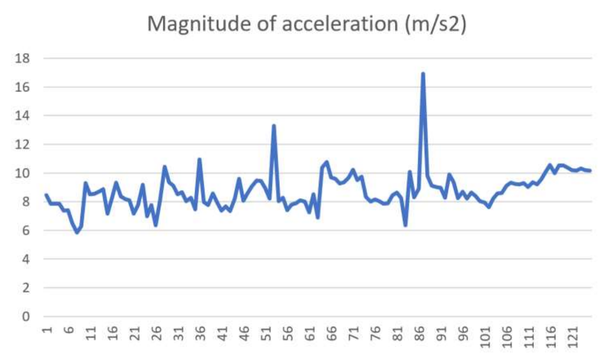



*Figure 5 Acquired data of a test with prototype V2 with DC motor in terms of magnitude of acceleration.*

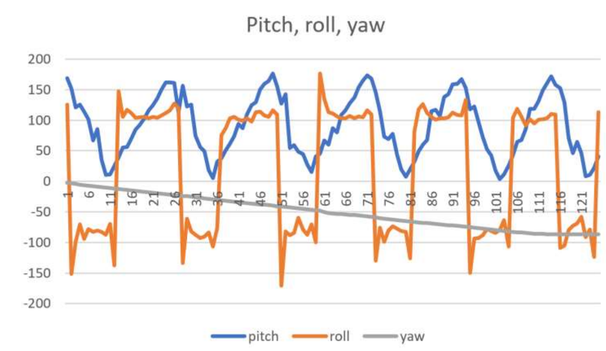



*Figure 6 Acquired data of a test with prototype V2 with DC in terms of roll, pitch, yaw.*

## CONCLUSIONS

The experimental results demonstrate that motor selection significantly influences rehabilitation device performance. The passive prototype confirmed baseline IMU measurement accuracy. The stepper motor, while functional, introduced excessive vibration limiting its therapeutic suitability. The brushless DC motor proved the optimal solution, delivering smooth, consistent, motor-assisted rotation across both exercise planes and all volunteers, and supporting both passive and active rehabilitation modes from a single platform.

## FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

Several improvements are proposed for future development. An adjustable crank length would broaden the device's user range, accommodating individual anthropometric differences. Reducing the frame size would increase portability for home or clinical use. Higher-precision force sensors would provide richer feedback on patient effort. Closed-loop speed control using the encoder signal could enable adaptive resistance — automatically adjusting motor load based on real-time patient performance — bringing the device closer to full clinical-grade rehabilitation standards.