3. Einicke GA and White LB. Robust extended Kalman filtering. IEEE transactions on signal processing 1999;47:2596–9.
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THE UNIVERSITY OF RHODE ISLAND

Development of a novel seamless magnetic-based actuated planar robotic platform for upper limb extremity rehabilitation

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Translational Neurorobotics Lab

Introduction

- **Background**
- Post-stroke individuals mostly tackle upper-limb motor control.
- The rehabilitation platforms assist patients through upper-limb extremity training.
- The user interface and mechanical motion lack the proper smoothness and transferability of the driver mechanism.

- **Objectives**
- We introduced a magnet-based driver mechanism to improve usability.
- To test the achievability, we designed a one-dimensional planar robotic device for exercising horizontal shoulder movements.
- For safety, the whole system is enclosed with plexiglass. A magnet is mounted on the end-effector and one is on the top of the glass.
- Our system is capable of seamless force transfer from driver elements (e.g. motor) to the follower elements (e.g. hand wrist).

Materials and Methods

- **Hardware design**
- There is a Teknic DC motor grounded, whose rotor is coupled with a driving pulley.
- There is a belt wound around two grounded pulleys on either side of the linear slider upon which the end-effector is connected.
- Five photo interrupter sensors are affixed alongside the slider and interfaced with an Arduino Nano board.
- One cylindrical disc permanent magnet is mounted on the end-effector. The armrest encloses another.
- For safety, plexi plates enclose this system, separating the magnets (**Figure 1**).

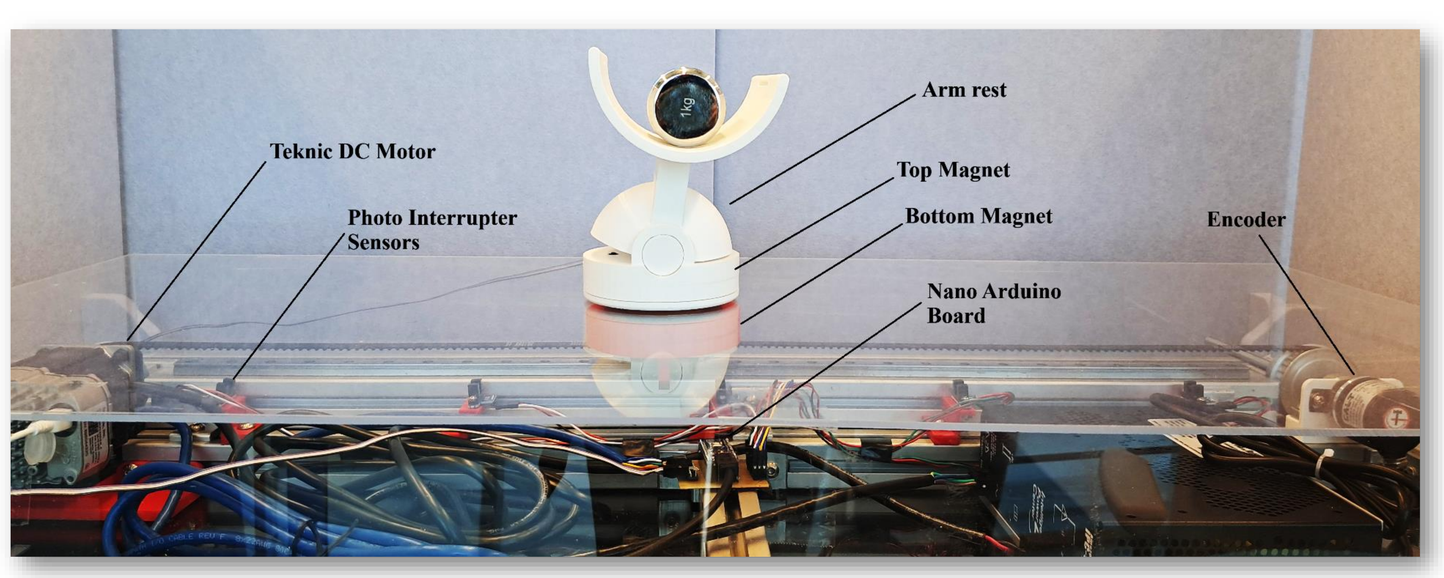

Figure 1: The designed planar robotic platform

- **Software design**
- The Graphical User Interface (GUI) is designed using Python.
- Its patient's view depicts a turtle modeling the end-effector (**Figure 2**).
- The technician control panel controls the speed and direction of the bottom magnet (**Figure 3**).

Materials and Methods (Cont.)

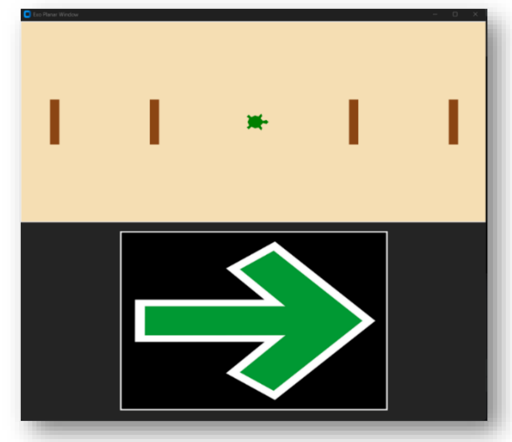

Figure 2: The patient's view of the GUI

Figure 3: The technician control panel of the GUI

- **Closed-Loop Extended Kalman Filter**
- Our magnets' magnetism is strong enough to withhold human hand weight and not become disengaged.
- However, we aimed to study the system's dynamics and compensate for the exerted forces by the human either actively or passively (resistivity) in terms of offset recovery.
- We modeled our platform as a 4-DOF system (**Figure 4**).

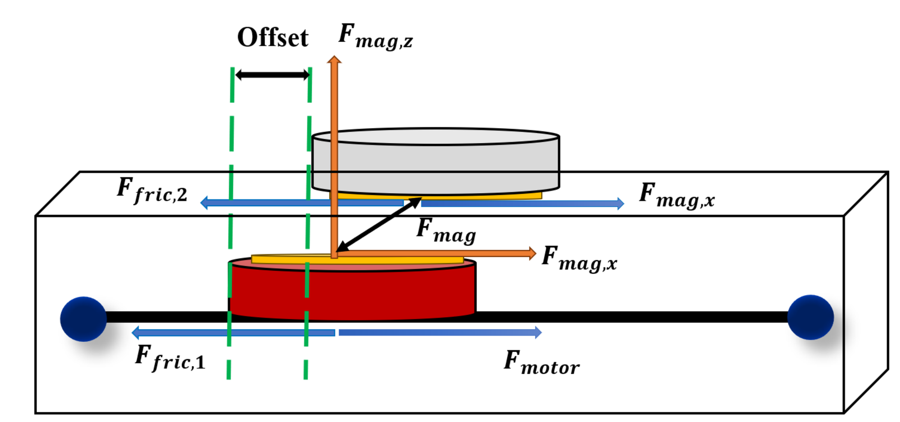

Figure 4: Forces acted upon magnets.

- Extended Kalman Filter is an extension of KF, used for estimating states of our non-linear system.
- For the sake of observability and validating our model, positions (measured by a rotary encoder and a Vl5310x laser sensor) were considered as our measurements with 4 state variables and motor force as input (**Figure 5**).

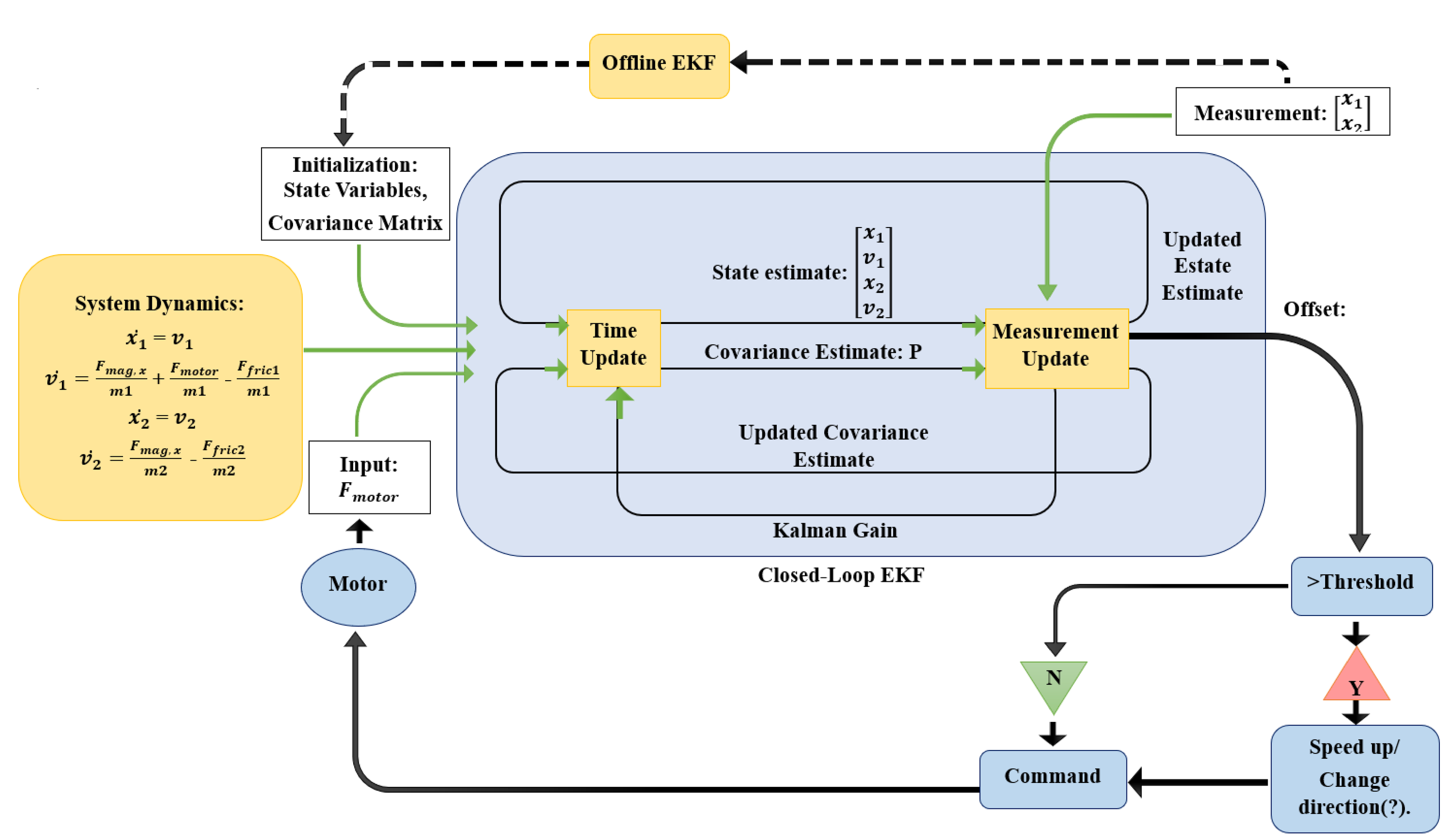

Figure 5: Block diagram of the algorithm development with Extended Kalman Filter.

x1, x2, v1, and v2 are the positions and the velocities of the bottom and the top magnet respectively.

Results

- **Offset recovery**
- The EKF algorithm monitors the offset momentarily, then in case it increases beyond a threshold, we use a proportional controller to tune the speed and direction of the motor to recover the offset (**Figure 6**).

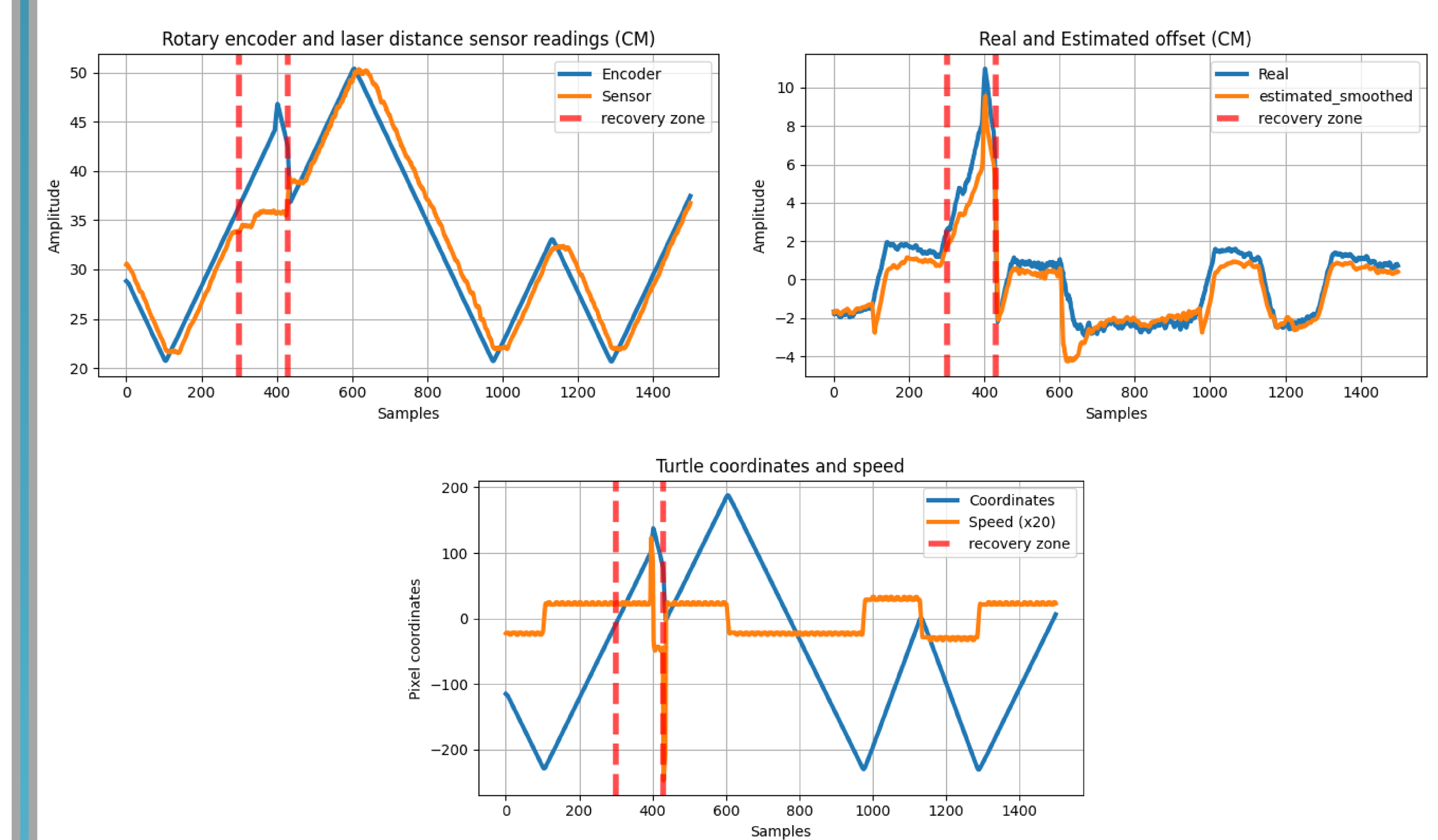

Figure 6: Encoder and laser sensor readings; real and estimated offset (EKF); and turtle pixel coordinates and speed throughout a trajectory.

Conclusions and Future Work

- Using our platform, the practicability of the magnets as a way for improved user interface and seamless force transfer has been studied and verified.
- Our ongoing research includes taking out the laser sensor which leads to a partially observable system and modifying the EKF algorithm to estimate the states using only the encoder readings.
- We also aim to use an electromagnet instead to control the strength of the magnetic field to prevent possible disengagement.
- Our current system opts for passive rehabilitation and in the case of active training we have to incorporate human's active force in different directions.
- Lastly, we are on our way to designing a 2-dimensional platform.

References

- Ribeiro MI. Kalman and extended kalman filters: Concept, derivation and properties. Institute for Systems and Robotics 2004;43:3736–41.
- Campolo D, Tommasino P, Gamage K, Klein J, Hughes CM, and Masia L. H-Man: A planar, H-shape cabled differential robotic manipulandum for experiments on human motor control. Journal of neuroscience methods 2014;235:285–97
- Einicke GA and White LB. Robust extended Kalman filtering. IEEE transactions on signal processing 1999;47:2596–9

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