Progress Report

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1 Specific Research Goals

- DLO Manipulation Dataset (ICRA - Sept. 19th) - on-going.

- VPQEKF (—): On pause. Asif may look into it.

2 To Do

- QEKF Paper (On pause):
  - Noise issue: noise cannot be modeled - DMD is a robust noise on high dimensional orthonormal time series and should be able to denoise QuEst solutions.
  - SfM: RQuEst cannot find solution - A potential solution is described briefly above.

- DLO Manipulation: (ICRA - section out of date)
  - Work on the paper everyday – up-coming
  - ICRA 2022 RL workshops: gym, stable-baseline3, and RL zoo – on-going
  - Setup digital twin reinforcement learing setup:
    * Unity Robotics extension setup – on-going.
    * Design dynamic DLO data collection system.
    * Build work cell. – on-going
    * Collect data and create a dataset.
    * Define evaluation metrics.
    * Create a high frequency RGBD dataset with UV-frames and open-loop input control actions as the ground truth.
  - Real-Time Preception – on hold
  - Learning DLO Dynamics and System Identification
    * List feasible approached for learing DLO dynamics – done
    * Model dynamics and deformity in a latent space

3 Progress

The following items are listed in the order of priority:

- DLO State Estimation (IROS): On piDMD $BCCB$, it stands for *block-continuous-continuous-block* and is a cubic configuration for performing 3D *fast Fourier transform*. The presented implementtation does not run and its root cause was not investigated. The implementtation is equivalent to multiplying data matrix $\mathbb{X}$ with the Kronecker product of two *discrete Fourier transform matrices* (DFTMat) with dimension factors of M and N as input. M and N are the least factors for square matrices to become the size. This condition is necessary for DFTMat to be applied to a Tensor. I wonder if using a tensor might be necessary to correctly meet 3D adjacency constraints of the physical world. (UpperTriangular and diagonal) constraints enforce 2D adjacency but we are only able to run the diagonal. Triangular methods use RQ decomposition (yields a singular and full-rank matrix for model) and are thought to be computationally more efficient as authors claimed [1].

I was able to run the algorithm with various *circulant* constraints which, resulted in poor performance but its surface plot clearly shows a frequency reconstruction in polar coordinated frame. The implementtation calls $fft2()$ routine which, performs *discrete Fourier transform* on a matrix (2D). Understanding these details is essential for constructing a viable solution for real-time manipulation and control on DLOs.

Furthermore, I continued testing and investigating piDMD and all it can possibly offer. I plotted reconstructions and model *performance surfaces* and made a startling realization that piDMD is only performing system identification task and as implemented, resultant reconstructions cannot possibly be very accurate. This is related to highly chaotic nature of DLOs; no matter how accurate and precise the model is, it will go out of *synch*. Chaotic systems are still nonlinear systems and they need to be treated *locally in time*. What we are aiming to achieve is to *model (or linearize)* a DLO *globally in space*. Thus, there needs to be online observations.

I went back to Murphy's paper to implement a Koopman-based controller where, they use data collected from a vertical take-off and landing (VTOL) pendulum system [2]. In the paper, they mentioned data collected is a combination of multiple test runs with different initial conditions. The purpose of this is to obtain a set of Koopman operators or model that is robust to a range of initial conditions. Moreover, they use Koopman operator only for system identification and utilize optimal control with a L2 regularizer. Currently, I am working on Koopman operator approximator routine that takes in number of

lifting dimensions and choice of basis functions. On a side note, we never lifted the space in the current implementation of DLO code with piDMD but we can as the feature exists.

- Maicol (REU): I want him to continue developing high quality model of workcell (not the lab) and implement basic manipulation tasks. I need this for DLO project and I can not do everything on my own. I can learn anything so I aim high enough that I can barely make it. You do not support that eventhough you have been patient with me. In my strategy, I work on cutting edge problems that others can not and I start with what is of most strategic importance to me, i.e. learning controls and classical computer vision while I am still a PhD student. I am sacrificing more than anybody else to achieve my goals and increasingly I feel isolated because of your comments. Comments that show no interest or respect for my work and seem be betting against me everytime. I came here to do good research and no one has any interest in that.

- DoD SMART (Dec 1st.): I started the application.

- XEst (RAL —): No update.

References

[1] P. J. Baddoo, B. Herrmann, B. J. McKeon, J. N. Kutz, and S. L. Brunton, "Physics-informed dynamic mode decomposition (pidmd)," *arXiv preprint arXiv:2112.04307*, 2021.

[2] I. Abraham, G. De La Torre, and T. D. Murphey, "Model-based control using koopman operators," *arXiv preprint arXiv:1709.01568*, 2017.