Multi-sensor dataset of a tendon-driven continuum robot in dynamic motion

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Abstract

This data descriptor presents a multi-sensor dataset on the quasi-static and dynamic motion of a tendon-driven continuum robot, including scenarios with and without contact with objects in the workspace. The robot is instrumented with a motion capture system, fiber Bragg grating sensors, cable tension gauges, motor encoders, a base force-torque sensor, inertial measurement units, and a contact force-torque sensor. The dataset covers planar, circular, and Lissajous trajectories at multiple speeds, organized in four batches: quasi-static motions, dynamic motions, dynamic motions with body-mounted inertial measurement units, and dynamic motions with contact. Both raw sensor recordings and processed data (filtered, time-aligned, uniformly resampled) are provided. The dataset enables benchmarking of dynamics models, training of data-driven methods, study of contact interactions, and sensor fusion research for continuum robots.

1 Background & Summary

Continuum robots are manipulators whose body undergoes continuous elastic deformation, actuated by tendons, pneumatics, or other distributed mechanisms [**?**, **?**]. Their dynamics have been studied through various modeling approaches [boyer, renda, shooting], and there is growing interest in applying machine learning methods and in studying their contact and interaction with the environment [Rao, Matthew]. However, experimental validation in continuum robotics typically relies on ad-hoc prototypes instrumented with lab-specific sensors, and the resulting data is rarely made publicly available.

The limited availability of open datasets hampers reproducibility and the comparison of competing modeling, control, and learning approaches on common ground. A related effort produced a dataset for concentric tube robots [**?**], but no publicly available dataset currently combines kinematics and force measurements for a tendon-driven continuum robot undergoing both quasi-static and dynamic motions, including contact with objects in the workspace.

This data descriptor presents a multi-sensor dataset recorded on a single-segment tendon-driven continuum robot (length 0.48 m, 4 tendons). The robot is instrumented with: an OptiTrack motion capture system providing poses of frames mounted along the robot body; Fiber Bragg Grating Sensors (FBGS) providing distributed strain and reconstructed shape; Mark10 force gauges measuring each cable tension; motor encoders measuring tendon displacements; an ATI force-torque sensor measuring the wrench at the robot base; IMU sensors providing accelerations and orientations; and a Resense force-torque sensor measuring contact forces with objects in the workspace. The dataset is organized in four batches: (i) quasi-static motions, (ii) dynamic motions (planar, circular, Lissajous trajectories at different speeds), (iii) dynamic motions with IMUs mounted on the robot body, and (iv) dynamic motions with contact with an object in the workspace. Both raw sensor recordings and processed (filtered, resampled, time-aligned) data are provided.

The dataset is intended for benchmarking dynamics models against experimental data, training and evaluating data-driven methods, studying contact and interaction forces, investigating sensor fusion approaches, and performing parameter identification. The robot design uses commercially available components and is documented in sufficient detail to allow replication.

2 Methods

This section defines the methodology used to collect the data. We first describe the specifics of each sensor, we then detail how they where mounted on the robot and how we ensured alignment and validity of the recorded data. Finally, we describe how the data is collected giving a general idea of the data collection pipeline, the programming language and the use of CPU wall-time timestamps.

2.1 Design

Puspita: desribe the design rationale, the constraints given by the usage of the Mark10 sensors and how the setup can be modified (eg. if they don't have the MArk10 sensors). Detail how the disks are designed and how we can mount sensors on them.

2.2 Sensors

In this section, we describe the characteristics of each sensor in terms of frequency readings, range of outputs, and a summary of their specifics available on their datasheet.

2.2.1 Mark 10

Tongjia: Add specifics for the Mark-10 sensors

2.2.2 FBGS

Tongjia/Spencer: Add specifics for the FBGS sensor

2.2.3 ATI-FT

Tongjia: Add specifics for the ATI-FT sensor

2.2.4 Gyroscopes

Spencer: Add specifics for the Gyroscopes

2.2.5 Actuators

The tendons are actuated by two brushless DC motors (Cybergear, Xiaomi, China) with custom 3D-printed tendon spools of radius 20 mm. They are position controlled at ??Hz to track desired tendon displacement or tension inputs, with tension sensing from the Mark 10 sensors for the latter.

2.2.6 Mocap

Spencer: Add specifics for the Mocap

2.2.7 Resense FT

2.3 Experimental setup

- Details on the designed base (cables without pulleys, sturdy, non-occlusion for mocap)
- Experiments performed (static loads, planar motions, circle, Lissajous curve) with and without gyroscopes and with interaction with object in workspace.
- Experiments starting with planar motion first (alignment of sensors)

2.4 Data Collection

- Describe how data is collected
- Describe how synchronization is handled (using CPU wall clock)
- Note on the rawness of the released data.

3 Data Records

- Data available on figshare (with DOI) — GitHub for code only
- Define structure dataset
  - Number of folders
  - Number of files, total size
  - Processed and raw data organization
  - Sensors used and how data is organized for each sensor
  - Column-by-column description of every CSV file type

4 Technical Validation

This section presents the analyses performed to verify the technical quality and internal consistency of the recorded dataset. The dataset contains two families of measurements: kinematic quantities (OptiTrack poses, FBGS strain and reconstructed shape, IMU accelerations, motor encoder angles) and force quantities (Mark10 cable tensions, ATI-FT base wrench, Resense contact force). Within each family, sensors can be directly compared. However, no direct comparison is possible between kinematic and force measurements without invoking the governing physics of the continuum robot. For this reason, a reduced-order dynamics model is employed as a cross-validation tool to verify force–kinematics consistency, as detailed in Section 4.3.

4.1 Sensor noise and calibration

4.2 Kinematic cross-validation

The OptiTrack and FBGS sensors provide independent measurements of the robot shape. To verify their mutual consistency, we compare the tip position recorded by OptiTrack with the tip position reconstructed from FBGS strain data, evaluated at the same arc-length coordinate. Figure **??** shows the overlay of these two signals for a representative trajectory. Similarly, numerical differentiation of the filtered OptiTrack position data yields acceleration estimates that can be compared against the IMU readings at the corresponding disk locations.

4.3 Force–kinematics consistency

The cable tensions (measured by Mark10 sensors) and the base wrench (measured by the ATI-FT sensor) cannot be directly compared against the kinematic measurements (OptiTrack, FBGS) without a physical model relating forces to deformations. To verify that these two families of measurements are mutually consistent, we employ a forward dynamics simulation based on the Geometric Variable Strain (GVS) approach [**?**] as a cross-validation tool.

The procedure is as follows. The mechanical parameters of the robot (bending stiffness, linear density, cable routing geometry) are characterized independently through static loading tests (see Section 4.2). The measured cable tensions from the dataset are then used as the sole input to the GVS forward dynamics simulation. The simulation produces two outputs: the predicted time-varying robot shape and the predicted reaction wrench at the base. These simulated outputs are compared against the independently recorded OptiTrack measurements (for the shape) and ATI-FT readings (for the base wrench).

Figure **??** reports the comparison between simulated and measured tip position for a representative circular trajectory. Figure **??** reports the corresponding base wrench comparison. The qualitative and quantitative agreement confirms that the force and kinematic recordings in the dataset are physically consistent. We note that, since the model parameters were obtained from static characterization rather than identified from the dynamic data, an exact quantitative match is not expected; residual discrepancies reflect the combined effect of unmodeled dynamics (e.g., material damping, cable friction) and parameter uncertainty. Systematic parameter identification using this dataset is left as a downstream use case.

4.4 Contact force validation

To validate the contact force measurements from the Resense FT sensor, we perform a set of static equilibrium checks. A known external force is applied at the robot tip while the robot is held in a static configuration whose shape is recorded by the OptiTrack system. Using the measured shape and the applied force, the corresponding reaction wrench at the base is computed via static equilibrium. This computed wrench is then compared with the direct measurement from the ATI-FT sensor at the base.

4.5 Temporal synchronization

All sensors are acquired as concurrent threads in a single Python process on a single machine. Each thread timestamps its readings using the operating system wall-clock (`time.time()` in Python), ensuring that all sensors share the same clock source without requiring hardware synchronization. The resulting synchronization error is bounded by the operating system thread scheduling jitter, which is on the order of 1 ms to 2 ms on the acquisition machine, well below the signal periods of interest (the highest dynamic content in the dataset is below 20 Hz).

4.6 Repeatability

To assess measurement repeatability, the same commanded trajectory is executed in multiple trials.

5 Usage Notes

Add here any issue observed with the data collection.

6 Data Availability

Many people in Nature Scientific Data use figshare for which I have created an account.

7 Code Availability

Statement about releasing the code for the data acquisition and the postprocessing & technical validation.

8 Author Contributions

9 Competing Interests

The authors declare no competing interests.

10 Funding