**Exposé**

for Specialization 2

**Algorithmic Payload Estimation**

Ausgeführt von: Moritz Dönges

Personenkennzeichen: 2310331024

BegutachterIn: Dr.nat.techn. Wilfried Wöber, MSc.

Wien, 17.10.2024

Abstract

**Keywords:**

Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content Content

Inhaltsverzeichnis

[1 Überschrift des ersten Kapitels 5](#_Toc102978697)

[1.1 Überschrift Tiefe 2 5](#_Toc102978698)

[1.1.1 Überschrift Tiefe 3 5](#_Toc102978699)

[2 Überschrift des zweiten Kapitels 5](#_Toc102978700)

[2.1 Überschrift Tiefe 2 5](#_Toc102978701)

[2.2 Überschrift Tiefe 2 5](#_Toc102978702)

[2.2.1 Überschrift Tiefe 3 6](#_Toc102978703)

[2.2.2 Überschrift Tiefe 3 6](#_Toc102978704)

[Literaturverzeichnis 7](#_Toc102978705)

[Abbildungsverzeichnis 8](#_Toc102978706)

[Tabellenverzeichnis 9](#_Toc102978707)

[Abkürzungsverzeichnis 10](#_Toc102978708)

[Anhang A: Überschrift des ersten Anhangs 11](#_Toc102978709)

[Anhang B: Überschrift des zweiten Anhangs 12](#_Toc102978710)

# **Motivation**

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

## Überschrift Tiefe 2

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

### Überschrift Tiefe 3

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

#### Überschrift Tiefe 4

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

# Überschrift des zweiten Kapitels

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

## Überschrift Tiefe 2

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

## Überschrift Tiefe 2

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

### Überschrift Tiefe 3

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

### Überschrift Tiefe 3

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

#### Überschrift Tiefe 4

Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text Text

Querverweise sollten automatisch erzeugt und verwaltet werden, damit sie leicht aktualisiert werden können. Hier wird zum Beispiel auf Abbildung 1 verwiesen.



Abbildung 1: Beispiel für die Beschriftung eines Buchrückens.

Und hier ist ein Verweis auf Tabelle 1. Das gezeigte Tabellenformat ist nur ein Beispiel. Tabellen können individuell gestaltet werden.

|  |  |  |
| --- | --- | --- |
| **Datum** | **Thema** | **Raum** |
| **20. 08. 2008** | Graphentheorie | HS 3.13 |
| **01. 10. 2008** | Biomathematik | HS 1.05 |

Tabelle 1: Semesterplan der Lehrveranstaltung „Angewandte Mathematik“.

Hier wird auf die Formel (1) verwiesen.

|  |  |
| --- | --- |
|  | (1) |

Literaturverweise sollten automatisch verwaltet werden, vor allem dann, wenn es viele Quellenverweise gibt. Hier wird auf [1] und [2] verwiesen. Das hier verwendete Zitierformat (bzw. das Format des Literaturverzeichnisses) ist nur ein Beispiel. Es hängt von der Fachdisziplin bzw. von den Möglichkeiten der automatischen Literaturverwaltung ab.

Literaturverzeichnis

|  |  |
| --- | --- |
| [1] | H. Balzert, Lehrbuch der Objektmodellierung - Analyse und Entwurf mit der UML 2, 2. Ausg., Elsevier GmbH, München 2005., München: Elsevier GmbH, 2005. |
| [2] | K. W. Wagner, Performance Excellence. Der Praxisleitfaden zum effektiven Prozessmanagement, München: Hanser Fachbuch, 2007. |

Abbildungsverzeichnis

Abbildung 1: Beispiel für die Beschriftung eines Buchrückens. 8

ANMERKUNG: Dieses Abbildungsverzeichnis generiert sich selbst.

Tabellenverzeichnis

Tabelle 1: Semesterplan der Lehrveranstaltung „Angewandte Mathematik“ 8

ANMERKUNG: Dieses Tabellenverzeichnis generiert sich selbst.

Abkürzungsverzeichnis

|  |  |
| --- | --- |
| WWW | World Wide Web |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

ANMERKUNG: Sortieren Sie die Liste mit der Funktion „Tabelle sortieren“.

### **1. Environment:**

* You are working with a UR5 robot arm simulation in Gazebo. The setup includes:
  + A Robotiq Fts300 sensor, mounted on the robot’s flange.
  + A Robotiq Gripper, attached to the sensor.
  + The measurement frame, located between the sensor and the gripper, is where the forces (F) and torques (T) are measured.
  + The gripper weighs 820g, resulting in a measured force of 8N in the z-direction when the frame is oriented facing down (due to the force of gravity, 820g \* 9.81 m/s²).

### 2. Main Goal:

* Your objective is to grab an object and isolate the forces (F) and torques (T) that result specifically from the object itself, excluding the gripper’s contribution.
* When grabbing the object, the measured force will reflect the combined mass of the gripper and the object, i.e., (820g + object mass) \* 9.81 m/s².
* To get the F and T resulting from the object, you need to subtract the gripper’s F and T from the overall measured values, leaving only the object’s contribution.

### 3. What Needs to be Done:

* To isolate the F and T caused by the object, you need to first:
  + Predict the forces and torques resulting from the gripper (without the object).
  + Subtract the predicted gripper F and T values from the total measured values.
* Since the relationship between motor positions, velocities, accelerations, and the resulting forces and torques is nonlinear, you will use Gaussian Process (GP) Regression Models to predict these values.

### 4. Gaussian Process Models:

* Purpose: Use Gaussian Process (GP) models to predict:
  1. The effort used by the motors based on their positions, velocities, and accelerations.
  2. The forces and torques (F and T) resulting from the robot’s rigid body (without the object).

#### GP Effort Prediction Model:

* Input Features: Motor positions, velocities, and accelerations.
* Target: Predicted motor efforts (i.e., how much effort the motors would need to apply).

#### GP FT Prediction Model:

* Input Features: Motor positions, velocities, and the predicted efforts from the effort model.
* Target: Predicted forces and torques (F and T) from the robot’s rigid body (without object).

#### Updated Workflow Based on Note:

* When moving the robot with the object grasped, you will first predict the effort using the GP Effort Prediction Model (trained with data from the robot moving without the object). This predicted effort will represent the effort the robot would have used without the object.
* Then, using this predicted effort along with motor positions and velocities, you will predict the forces and torques (F and T) that would have been generated by the robot’s rigid body without the object using the GP FT Prediction Model.
* Finally, by subtracting the predicted F and T from the measured values, you can isolate the F and T resulting from the object alone.

### 5. Constraint Conditions:

* Effort Consistency (First Constraint):
  + The gripper’s mass and the forces and torques it generates remain constant during each trajectory.
  + When moving the robot along the same path repeatedly (e.g., 1000 times), the motors will always use the same effort, assuming no changes in the setup (same path, same velocity, same acceleration, and no object).
  + This allows you to use motor positions, velocities, and accelerations as features to predict the effort via the GP model consistently.
* Effort-Proportional Forces and Torques (Second Constraint):
  + Effort is proportional to the forces and torques generated by the motors.
  + Higher velocities and accelerations lead to greater effort, which in turn results in greater forces and torques. Thus, you can predict the F and T based on the effort.
  + When moving a given mass on the same trajectory but with higher velocity and acceleration, the motors will use more effort, and the resulting forces and torques will be higher.
  + The effort prediction model takes these relationships into account, and since the effort is constrained by the torques and forces, the GP FT Prediction Model uses this predicted effort to infer the forces and torques that would have occurred without the object.

**5. Constraint Conditions:**

#### Effort Consistency (First Constraint):

* The gripper’s mass and the forces and torques it generates remain constant during each trajectory.
* When the robot moves along the same path repeatedly (e.g., 1000 times), motor positions, velocities, and accelerations will remain the same if no external changes occur (e.g., no additional payload). This ensures that the motors use the same effort every time.
* This consistent relationship allows you to use motor positions, velocities, and accelerations as input features to predict the effort via the GP model, even across different movements or trajectories.

#### Effort-Proportional Forces and Torques (Second Constraint):

* The effort exerted by the motors is proportional to the forces and torques (F and T) measured by the sensor.
* Higher velocities and accelerations lead to greater effort, which, in turn, results in higher forces and torques.
* The GP model for predicting effort takes into account this proportionality, and since effort is directly correlated with F and T, the GP FT Prediction Model can use this predicted effort to infer the F and T that would have occurred without the object.
* When moving the robot with and without an object, the motor positions, velocities, and accelerations may stay constant, but the effort and the measured F and T will differ due to the additional payload from the object.

### 6. Independent Features for GP Models:

* Motor positions, velocities, and accelerations are treated as independent features in both the GP Effort Prediction Model and the GP FT Prediction Model.
* These features remain consistent, regardless of whether an object is being carried or not, as long as the payload is not too heavy (i.e., the motors can provide the necessary speed and acceleration for the mass they are carrying).
* At each timestamp, the motor positions, velocities, and accelerations fed into the Effort Prediction Model are exactly the same features fed into the FT Prediction Model.
  + This ensures that the models are synchronized and accurate across both predictions: the predicted effort will then be used to help predict the forces and torques in the next step.
* The key difference between trajectories with and without the object is in the effort required by the motors and the resulting measured F and T values. The independent features (positions and velocities) allow the GP models to predict the baseline effort and FT without the object, enabling you to isolate the object’s contribution.

### 7. Bringing it All Together:

* Step-by-Step Workflow:
  1. Object Grasped: The robot grabs an object and executes specific trajectories in various planes (X, Y, Z) to collect force and torque data.
  2. Measure Motor Data: At each timestamp during the trajectory, you measure the motor positions, velocities, and compute accelerations.
  3. Predict Effort without Object: Feed these values into the GP Effort Prediction Model (trained without the object) to predict the effort the robot would have used if it was moving without the object.
  4. Predict F and T without Object: Using the same motor positions and velocities, and the predicted effort, feed these into the GP FT Prediction Model to predict the forces and torques (F and T) of the robot’s rigid body (without object).
  5. Subtract to Isolate Object Forces: Finally, subtract the predicted F and T values (for the robot alone) from the measured F and T values (which represent the robot and object together). This will give you the forces and torques resulting solely from the object.
* Key Insight:
  1. The effort is correlated with the FT sensor values, and since effort increases with higher velocities and accelerations, this correlation allows you to predict the FT values that would result from the robot without the object. Subtracting these predicted values from the total measured FT values isolates the object’s contribution.
  2. The constraint conditions ensure that the predictions remain valid across repeated movements by maintaining consistent effort and the proportional relationship between effort, forces, and torques.