# Teleoperation with memoryless, monotone, and bounded environments: A Zames-Falb multiplier approach

Harun Tugal
Supervised by: Joaquin Carrasco

Control Systems Center, The University of Manchester

*harun.tugal@manchester.ac.uk*

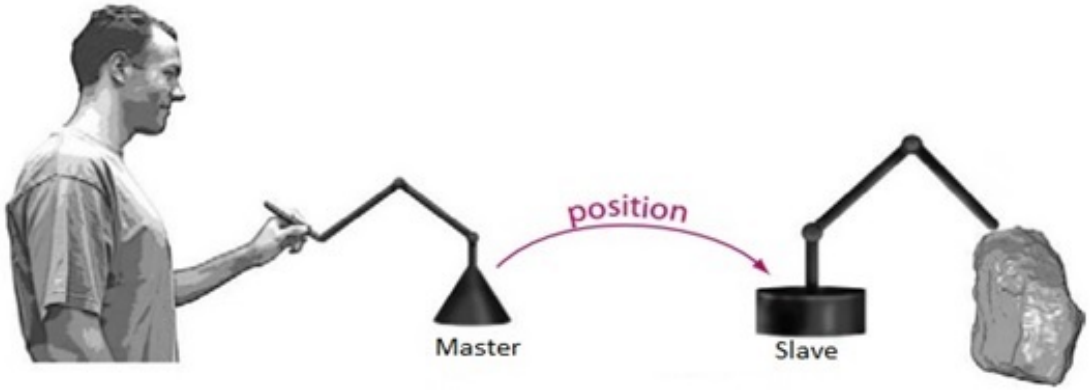
24 November, 2015

## Teleoperation

The user can manipulate object from a distance

## Bilateral Teleoperation

The user also gets feedback information from manipulated object !



## Teleoperation

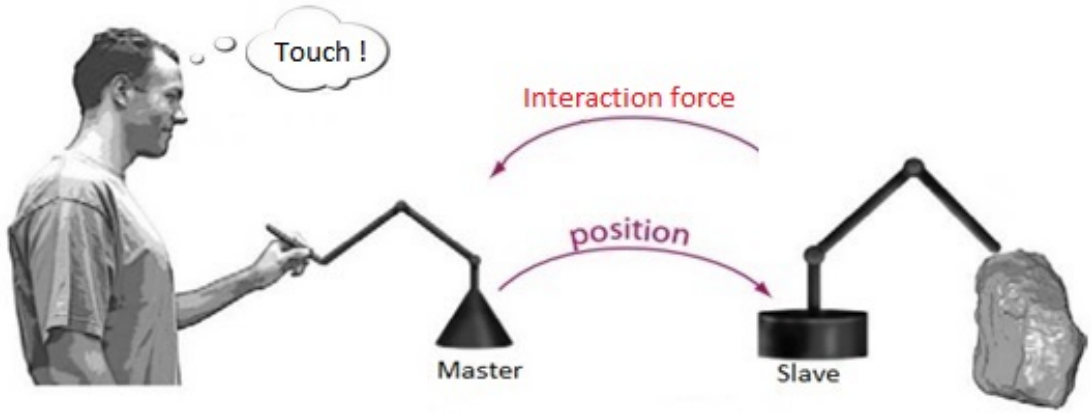
The user can manipulate object from a distance

## Bilateral Teleoperation

The user also gets feedback information from manipulated object !

## What type of information ?

Not visual, applied momentum to the object via "touch" !



# General aim and challenges

## Why bother ?


- Applications
  - Nuclear decommissioning
  - Space exploration
  - Underwater operation
- Performance Measure
  - Transparency
  - Tracking

# General aim and challenges

## Why bother ?


- Applications
  - Nuclear decommissioning
  - Space exploration
  - Underwater operation
- Performance Measure
  - Transparency
  - Tracking

## Challenges

- Uncertainties
- Trade-off
- Time Delay

# Stability Analyses

Passivity and Network theories are the main methodologies.

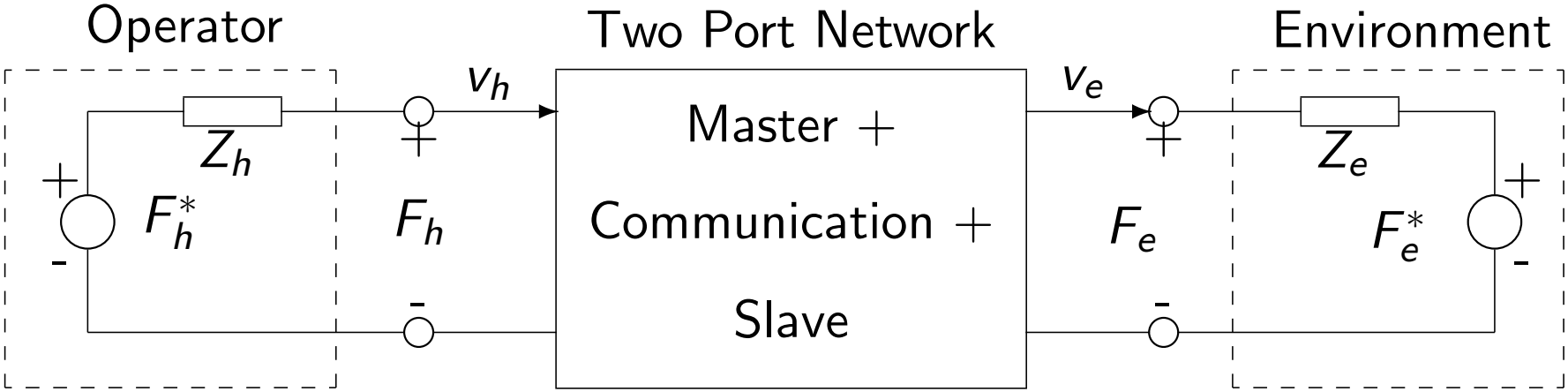



Figure: Network representation of the bilateral teleoperation

# $G$ - $\Delta$ Interconnection

## Modify the Assumption

Assume that environment is bounded monotone nonlinear operator.

## Uncertainties

Define human, environment, and time delays as structured uncertainty.

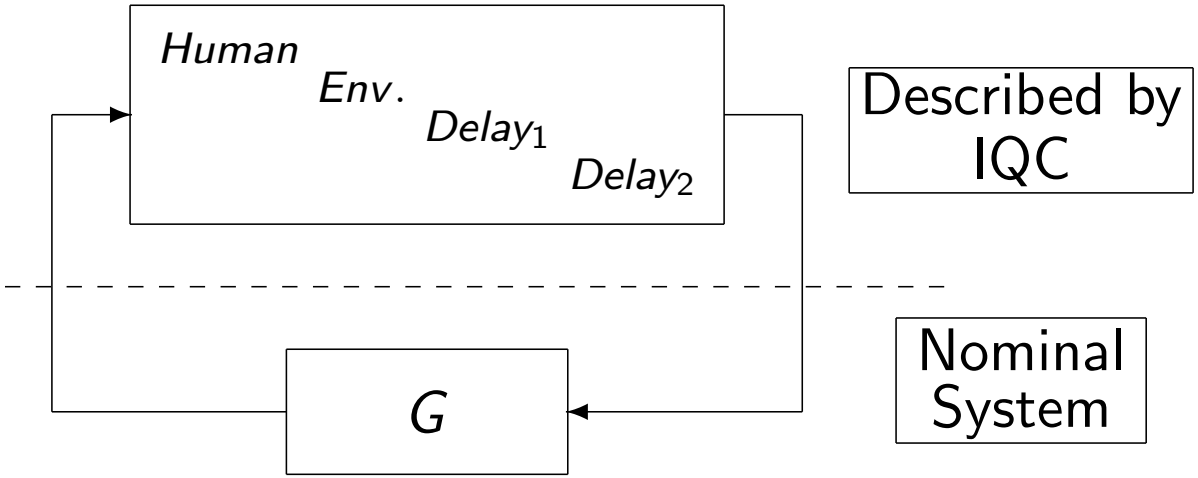



Figure: Bilateral teleoperation as a classical nominal plant-uncertainty interconnection


Table: Maximum Obtainable Transparency Indexes

| | Controller | |
|---|---|---|
| | P-F Architecture | PD-F Architecture |
| Passivity | 0.399 | - |
| With symmetric poles | **0.645** | **0.418** |
| With asymmetric poles | **0.809** | **0.622** |

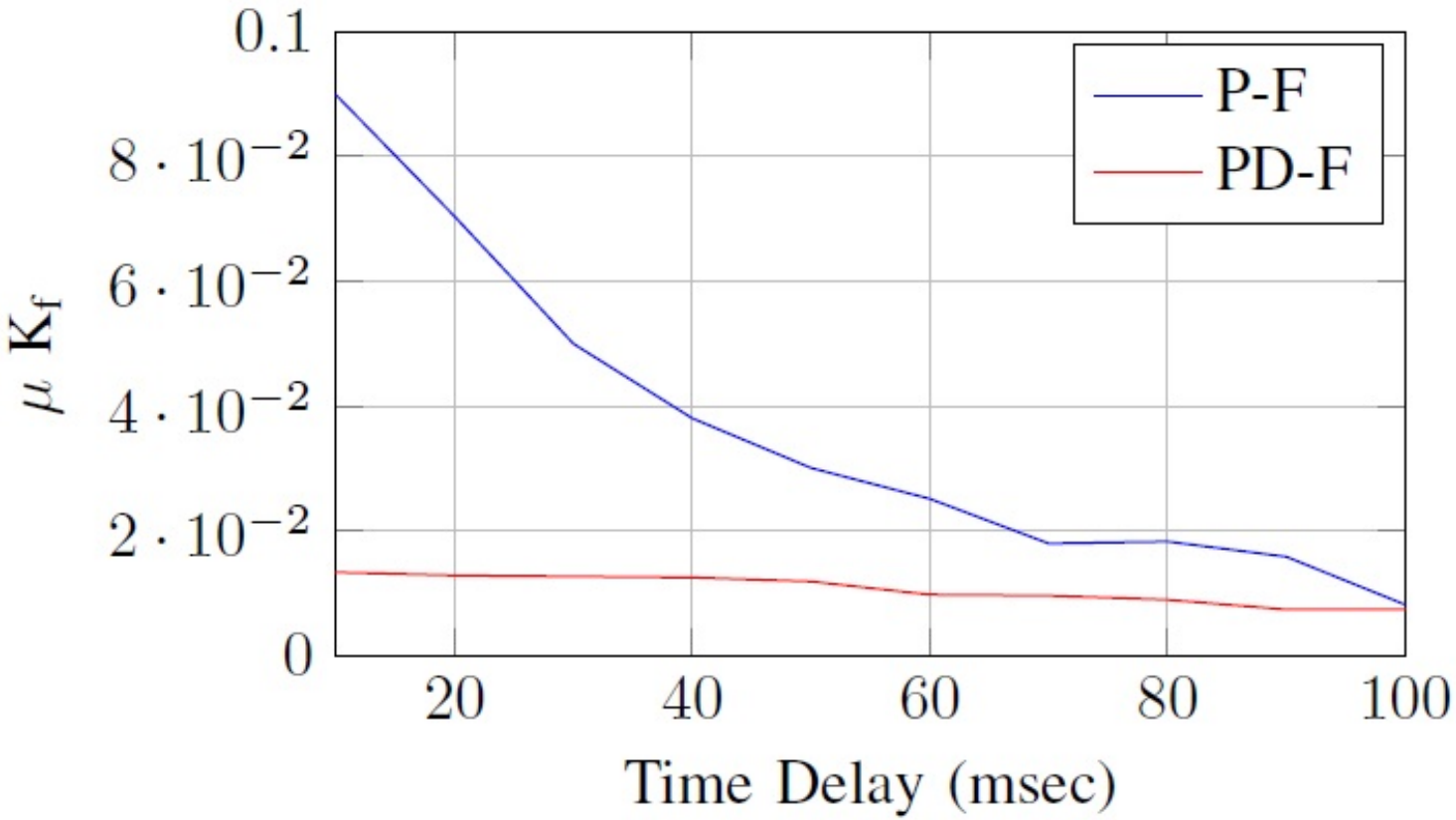



Figure: Transparency index reduction against maximum delay duration in the communication medium.

## Position mismatches between master and slave.

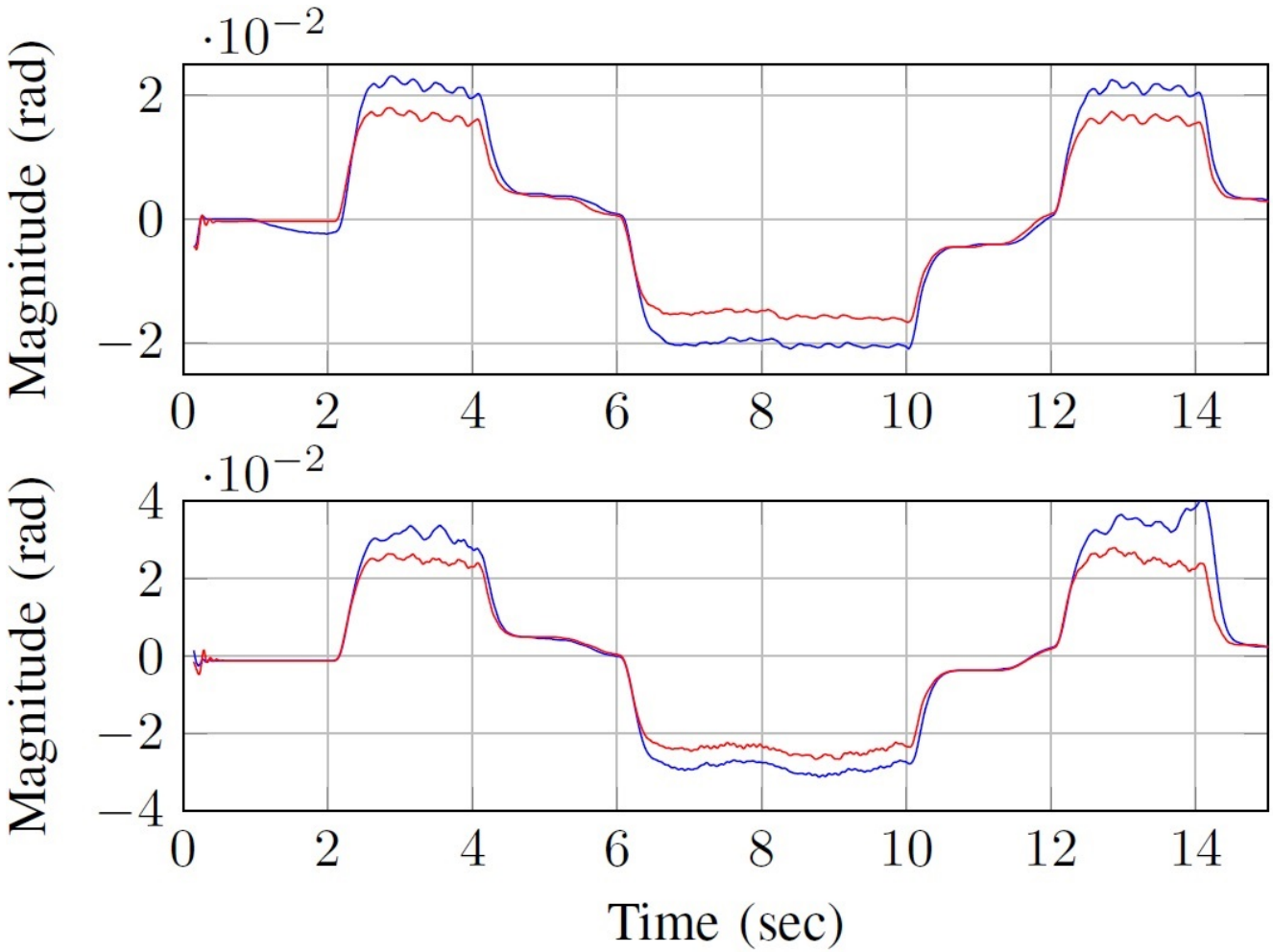



Figure: Constant delay in one way Tdmax = 28msec (top)

# CONCLUSION AND FUTURE WORK

- Outcomes
  - Theoretical contributions to search for Zames-Falb multipliers,
  - Novel more sophisticated description for the environment.

- Future direction
  - Novel Feedback controller design based on human sensation.