

DIGITAL TWINS—SIMULATING AND MODELLING THE CONNECTED WORLD

Professor Peter Gorm Larsen
Leader of AUs DIG IT Centre
Leader of AUs Digital Twin Centre
Visiting professor York University
Visiting professor Newcastle University

AU

AARHUS
UNIVERSITET



WHO AM I?



Professor Peter Gorm Larsen, MSc, PhD, deputy-head of section
Worked 17 years in industry (IFAD, Systematic); at IHA/AU since 2005
Reviewer for EU and other countries on Research projects and applications
Consultant for most large defence contractors on large complex projects
Mostly proud of the firmware of NFC chip in 350+ million mobile phones
Served on 70+ program committees both as member and as chair
Supervision: 15 post -docs, 27 PhD students, 71 MSc thesis students
Has written books and 200+ articles (in particular about VDM, CPS and digital twins)
Member of the Independent Research Fund Denmark (FTP 2007-2020)
Have coordinated the INT-CPS (8M€) project and coordinate the HUBCAP project (8M€)
Lead DIGIT and the AU Centre for Digital Twins due to grant from the PDJ Foundation
See <http://pure.au.dk/portal/da/pgl@ece.au.dk> for details

DIGIT RESEARCH ORGANISATION

WP1

Smart products with focus on Cyber-Physical Systems



ECE



Peter Gorm Larsen

Professor

CS

WP4

Big Data Analysis



Ira Assent

Professor



CS

WP 7

Blockchain



CS



Bas Spitters

Assoc. Prof

WP2

Science and Engineering of Machine Intelligence



ECE



Alexandros Iosifidis

Professor

ECE

WP5

Internet of Things



Qi Zhang

Assoc. Prof



ECE

WP6

Digital business development



Annabeth Aagaard

Assoc. Prof

BSS

WP8

Automated verification and synthesis



CS



Jaco van de Pol

Professor

WP9

Scientific computing



Henrik Garde

Assis. Prof














MATH

OVERVIEW OF MAJOR SECTION PROJECTS

Project	Period	AU lead	Co-PIs	Funding from	Budget	AU part	#companies
DiT4CPS	2019-24	PGL		PDJ Foundation	12MDKK	12,0MDKK	0
HUBCAP	2020-22	PGL	HDM	H2020	60MDKK	6,0MDKK	8
MADE FAST	2020-24	PGL	AI	Innovation Foundation	250MDKK	15,6MDKK	(our part) 7
DIGITbrain	2020-23	PGL	XZ	H2020	63MDKK	3,3MDKK	24
UPSIM	2020-23	PGL	LE	ITEA	145MDKK	1,8MDKK	23
AgroRobottiFleet	2020-23	PGL	LE	Innovation Foundation	23MDKK	3,3MDKK	1
COGITO	2020-23	JT(CAE)	LE,CS,PGL	H2020	45MDKK	4,4MDKK	8
BIM2Twin	2020-23	JT(CAE)	CS,LE,PGL	H2020	45MDKK	2,6MDKK	9
Denmark-USA	2020-23	SH	PGL	Ministry of Education	0,3MDKK	0,3MDKK	0
Digital Transformation Lab	2020-24	PGL	AI	Municipality + companies	15,8MDKK	15,8MDKK	5
FLOCKD	2021-24	LE	AI	DFF	2,9MDKK	2,9MDKK	0
PROBONO	2021-25	CS	PGL	H2020	190MDKK	5,6MDKK	35
Embedded AI	2022-24	(PGL)	JB	DIREC (IFD)	23,8MDKK	3,9MDKK	4
In total					863MDKK	77,5MDKK	124

RESEARCH SOFTWARE ENGINEERING AND COMPUTING SYSTEMS

PhD students

 Morten Elvebakken PhD student Started 10/2021	 Iman Sharifirad PhD student Start 8/2022	 Christian Legaard PhD student Graduates 8/2023	 Till Bottjer PhD student Started 8/2020	 Santiago Gil Arboleda, PhD Started 6/2021	
 Simon T Hansen PhD student Graduates 8/2023	 Fatemeh Kakavandi PhD student Started 10/2020	 Daniella Tola PhD student started 11/2020	 Hao Feng PhD student Graduates 10/2022	 Peter Høgh Mikkelsen, PhD Started 8/2021	
					

Permanent researchers

 Jim Woodcock Extern professor 40%	 Jalil Boudjadar Associate Professor	 Carl Schultz Associate Professor
 Stefan Hallested Associate Professor	 Lukas Esterle Associate Professor	 Claudio Gomes Assistant Professor



Peter Gorm Larsen
Professor







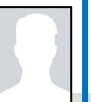

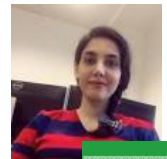

Hugo Macedo
Academic Research
Collaboration Officer



Prasad Talasila
Software development

Involved in Research and Innovation Projects

 Jung Min Kim Assistant Prof	 Brian Danielsen Assistant Prof	 Henrik Ejersbo Associate Prof	 Jakob Levisen Research assistant	 Frederik Madsen Research assistant	 Kenneth Lausdal Extern/AGCO 1/3 time
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 Nick Battle Developer 20%	 Negar Heidari Post-doc 50%	 Tomas Kulik Extern/SG 20%		

Postdocs

 Zahra Kazem Post-doc	 Mirgita Frasher Post-doc
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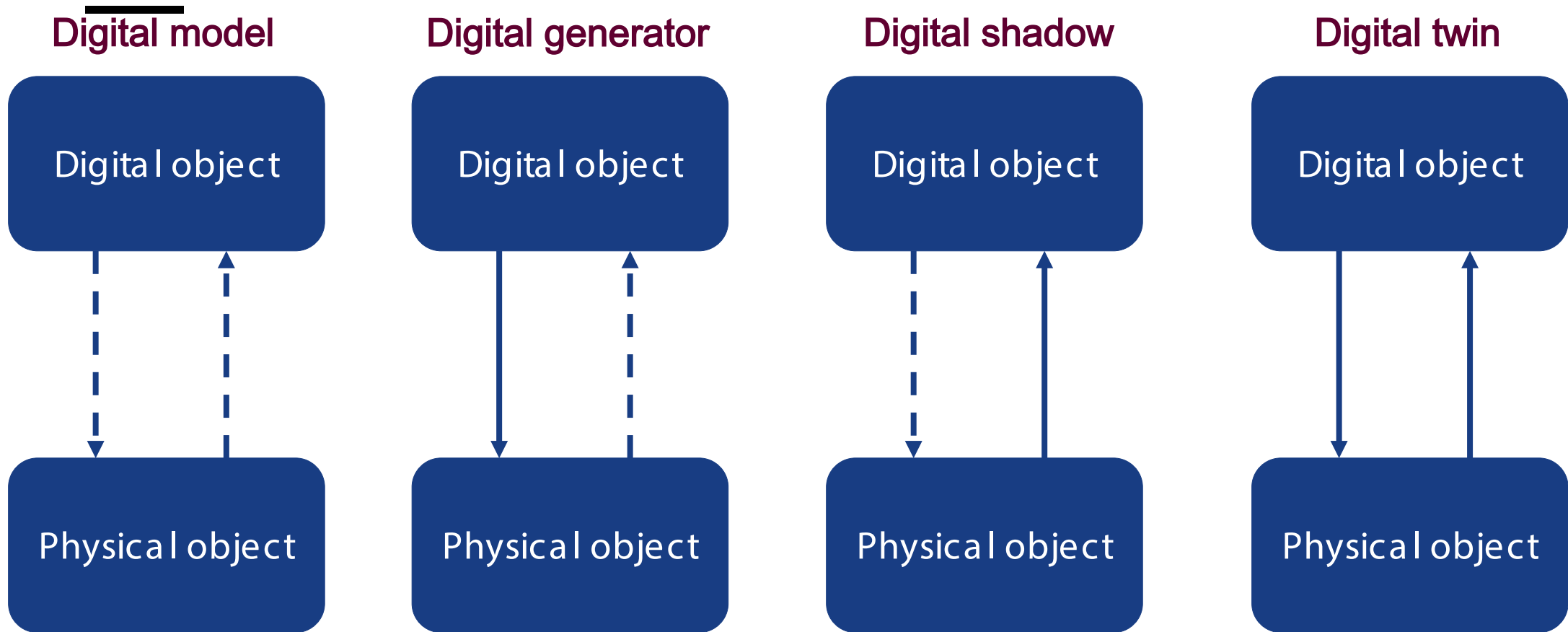


Jacob Lemming Christensen
Lab manager, RS-DTL

WHAT ARE DIGITAL TWINS?

- Many different definitions can be found at wikipedia
- I use the definition: "A digital twin is a digital replica of physical assets, processes, people, places, systems or devices created and maintained in order to answer questions about its physical counterpart." based on multi-models as "digital replica"
- There are commercial digital twin suppliers who promise gold and green woods (without any reservations)
- There is a need for **independent** advice on when it is worthwhile to use digital twins (and how to avoid vendor lock-in)

DIFFERENT LEVELS OF AMBITION

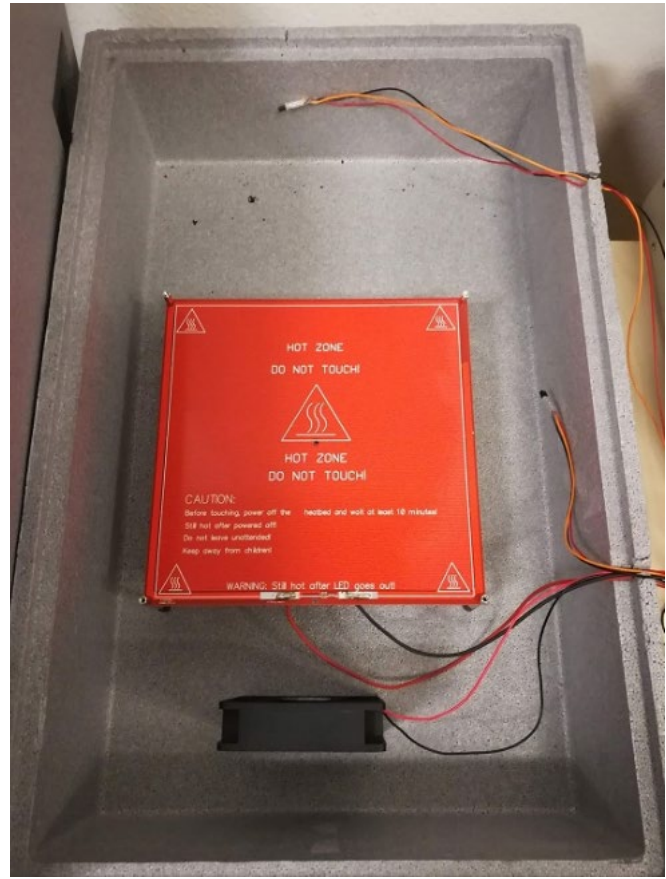
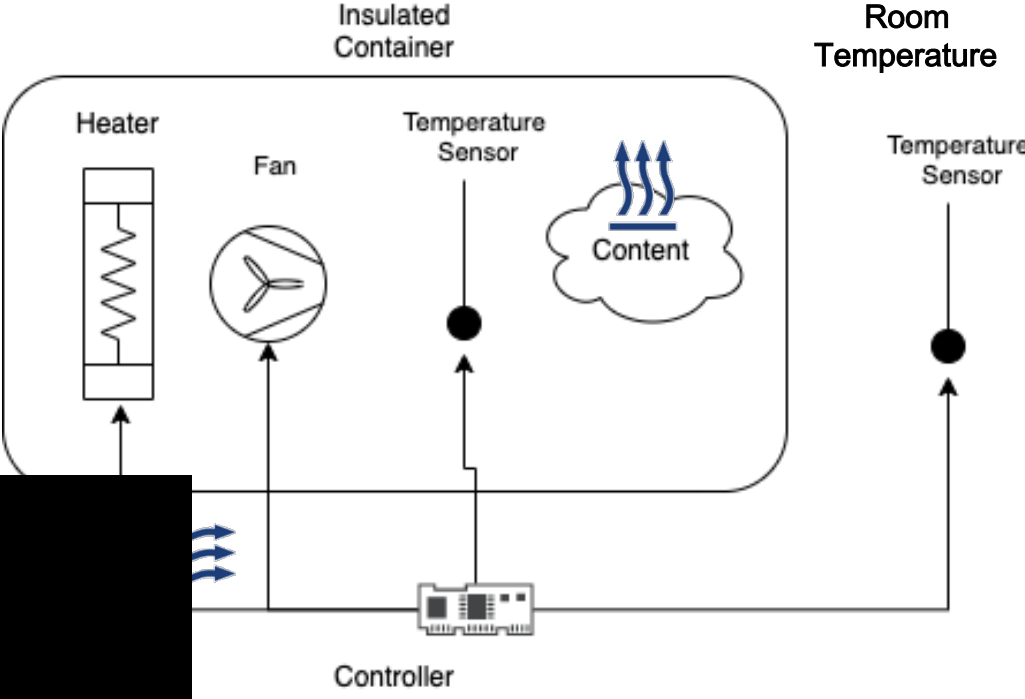
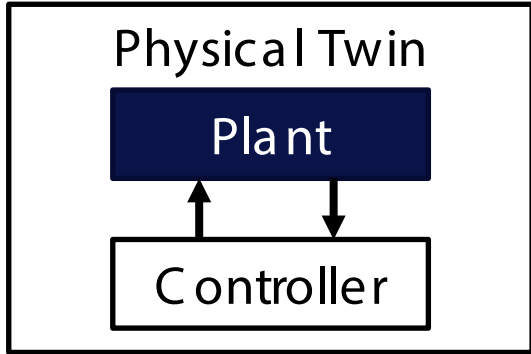


Legend:



Manual dataflow
Automatic dataflow

THE INCUBATOR CASE



Feng, Hao, Cláudio Gomes, Casper Thule, Kenneth Lausdahl, Michael Sandberg, and Peter Gorm Larsen. "The Incubator Case Study for Digital Twin Engineering." ArXiv:2102.10390 [Cs, Eess], February 20, 2021. <http://arxiv.org/abs/2102.10390>.

INTERESTING RESULTS IN FAULT DETECTION

pewdcvqt "Vgo r gtcwgtg

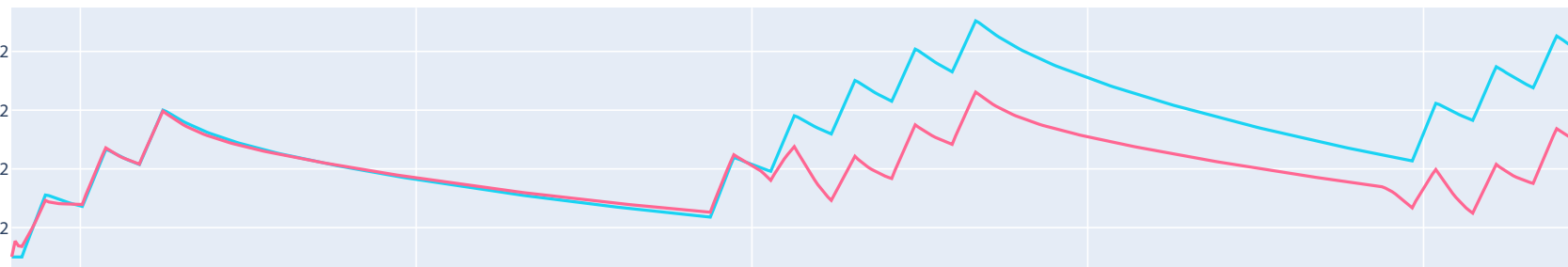


- cxi aV
- j gcvgtaqp
- cxi avgo r *6r O qf gn+
- cxi avgo r *Mc rø cp+
- tqgo
- Vaj gc vgt *6r O qf gn+
- Vaj gc vgt *Mc rø cp+

Tqqo "Vgo r gtcwgtg



J gcv/dgf "Vgo r gtcwgtg



Feng, Hao, Claudio Gomes, Casper Thule, Kenneth Lausdahl, Alexandros Iosifidis, and Peter Gorm Larsen. "Introduction to Digital Twin Engineering." In 2021 Annual Modeling and Simulation Conference (ANNSIM), 1-12. Fairfax, VA, USA: IEEE, 2021. <https://doi.org/10.23919/ANNSIM52504.2021.9552135>.

PREDICT CURRENT AT EACH JOINT

Universal Robots UR3e

- 6 joints
- 3 kg payload



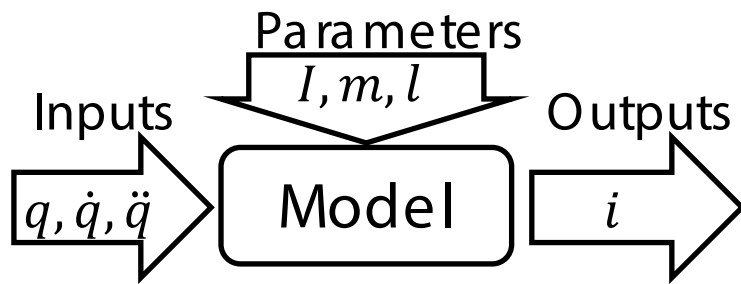
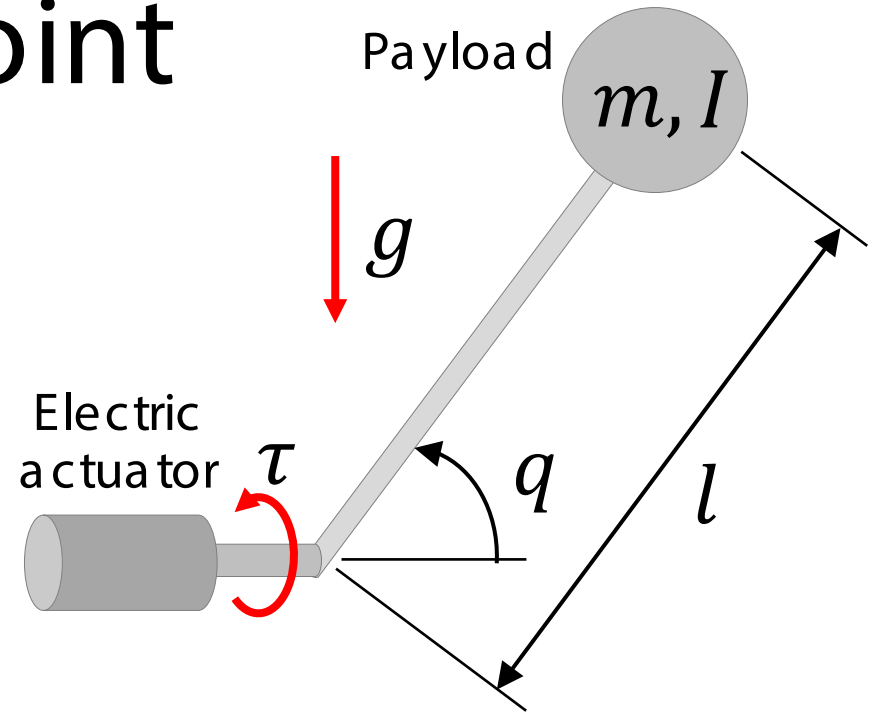
Madsen, Emil, Daniella Tola, Carlos Hansen, Claudio Gomes, and Peter Gorm Larsen. "AURT: A Tool for Dynamics Calibration of Robot Manipulators." In 2022 IEEE/SICE International Symposium on System Integration (SII), 190–95. Narvik, Norway: IEEE, 2022.
<https://doi.org/10.1109/SII52469.2022.9708769> .

Predict Current at each Joint

The **dynamic model** relates the **current** of each electric actuator to the motion of the robot.

The dynamic coefficients for *each* link include;

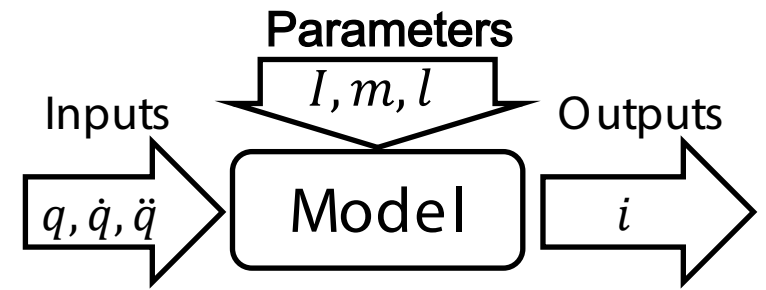
- 1) the mass,
- 2) the centre-of-mass position, and
- 3) the mass moments of inertia.



$$\tau = K_\tau i = \underbrace{(I + m l^2)}_{\text{mass moment of inertia}} \ddot{q} + \underbrace{m g l \cos(q)}_{\text{gravity torque}}$$

Labels for the equation: τ is torque; K_τ is torque constant; i is Current; $(I + m l^2)$ is mass moment of inertia; \ddot{q} is angular acceleration; $m g l \cos(q)$ is gravity torque; q is angular position.

PARAMETER ESTIMATING

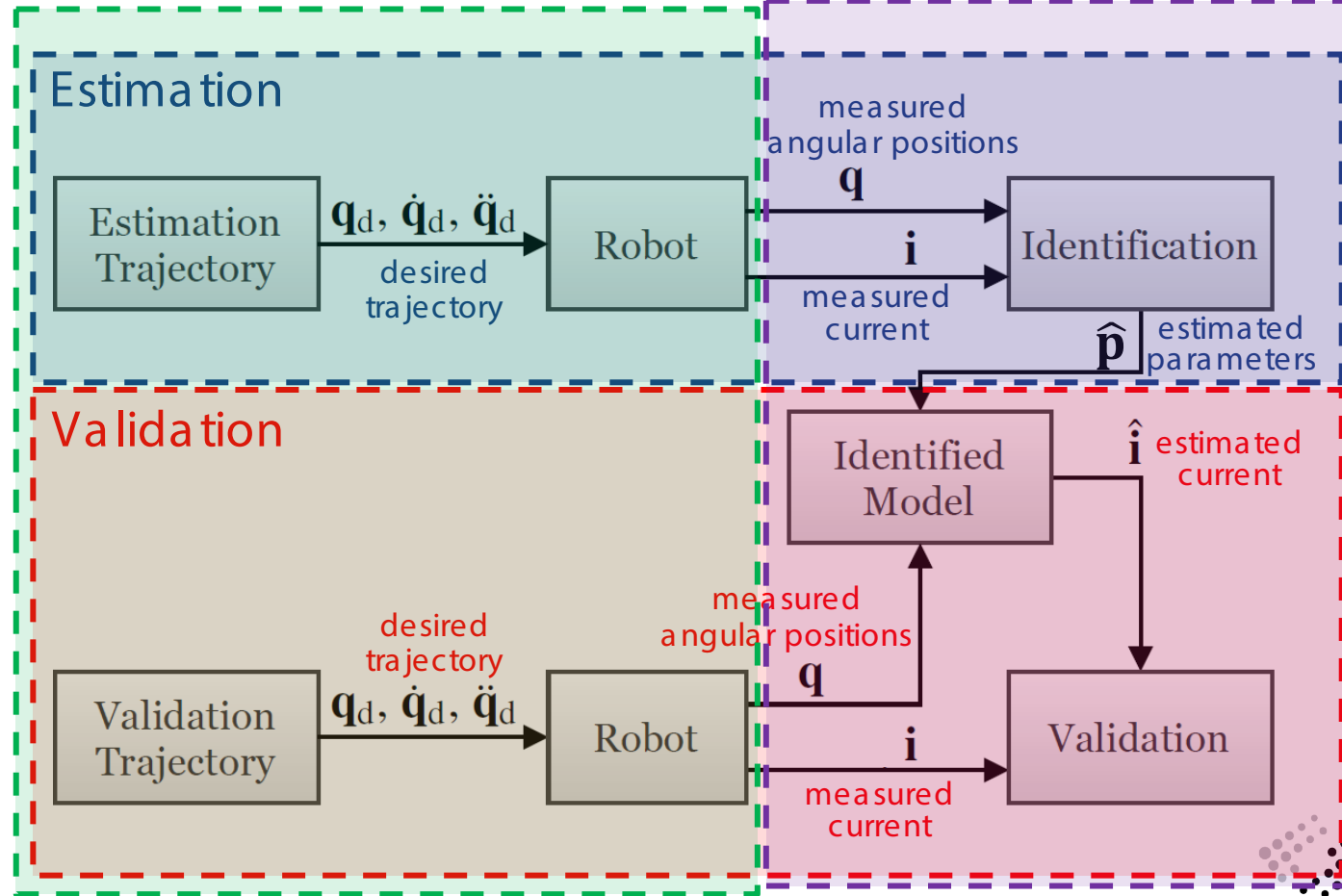


`pip install urinterface`

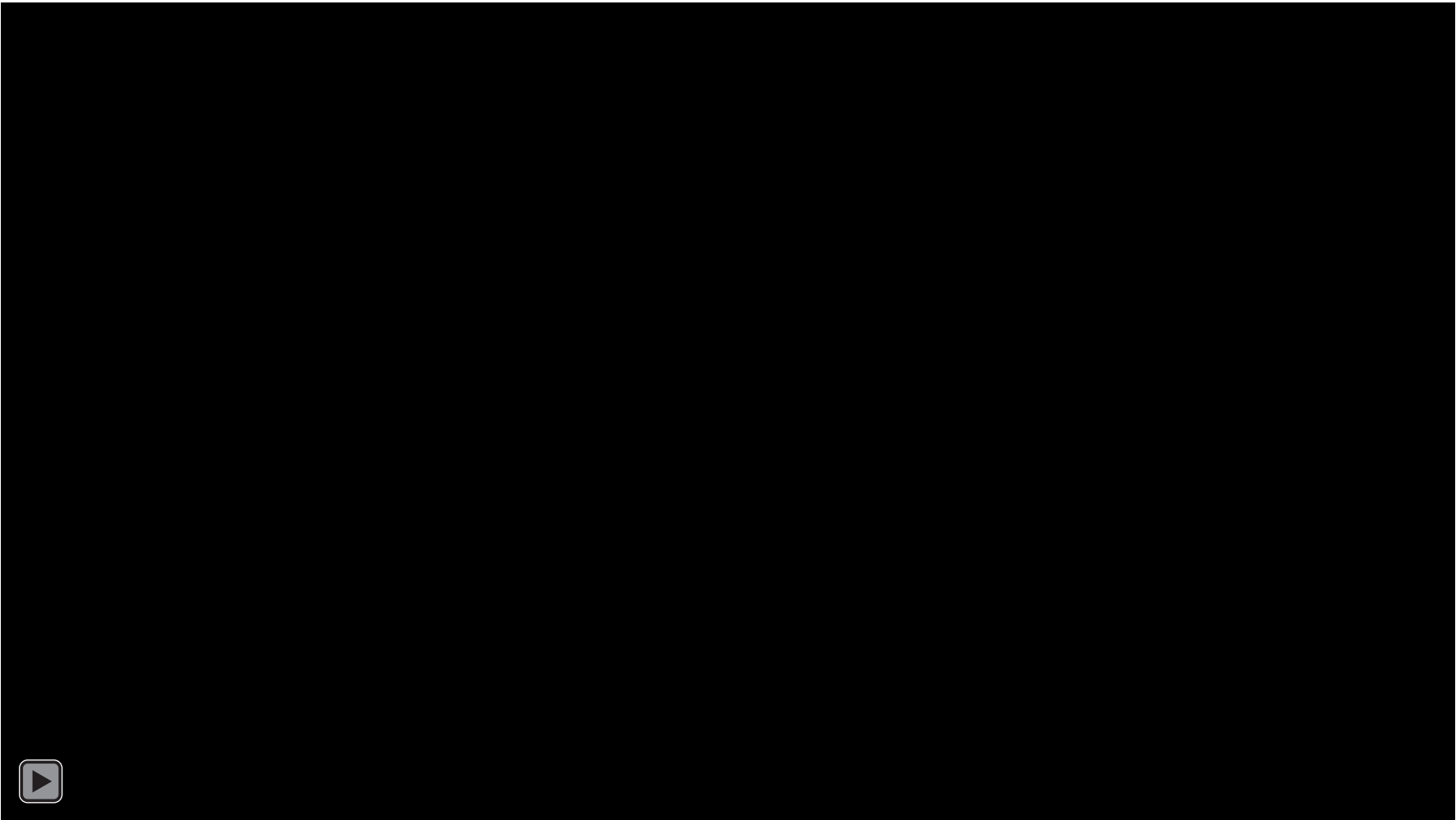
URInterface Tool

`pip install aurt`

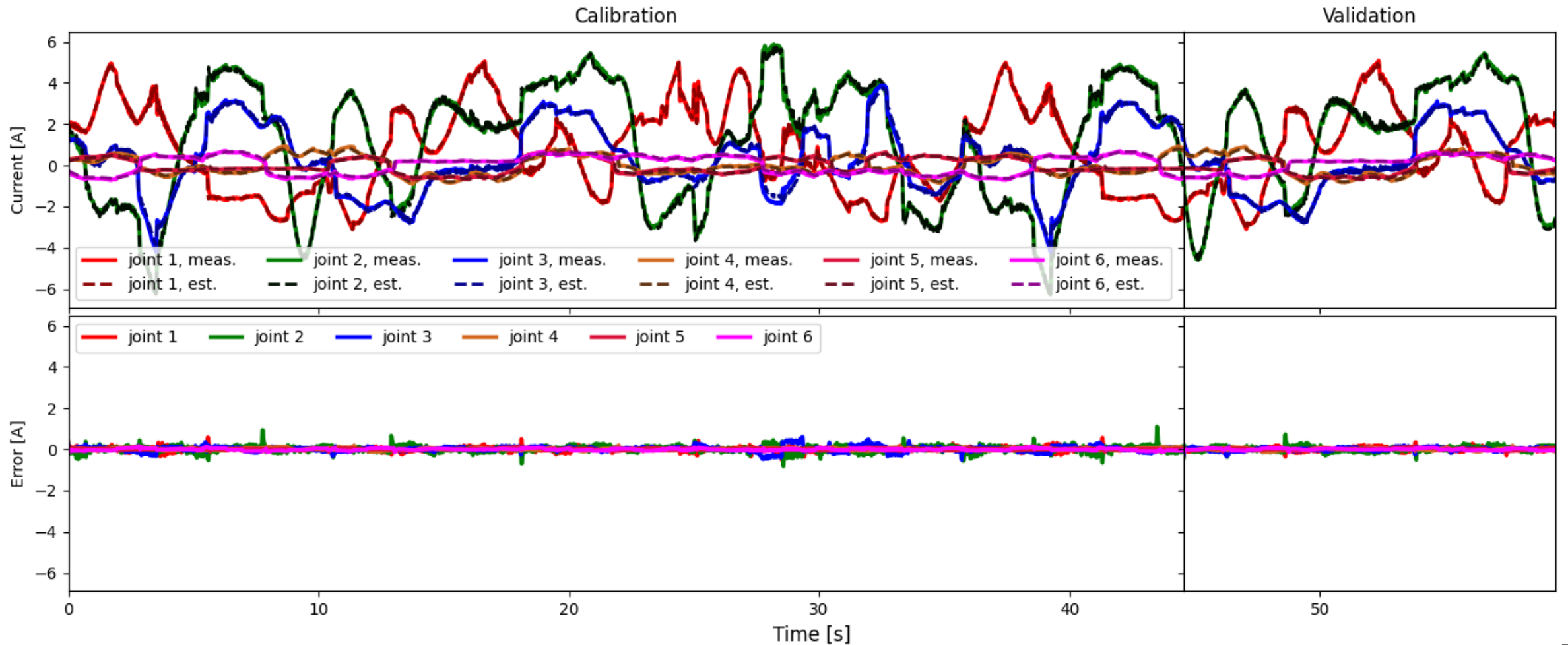
AURT Tool



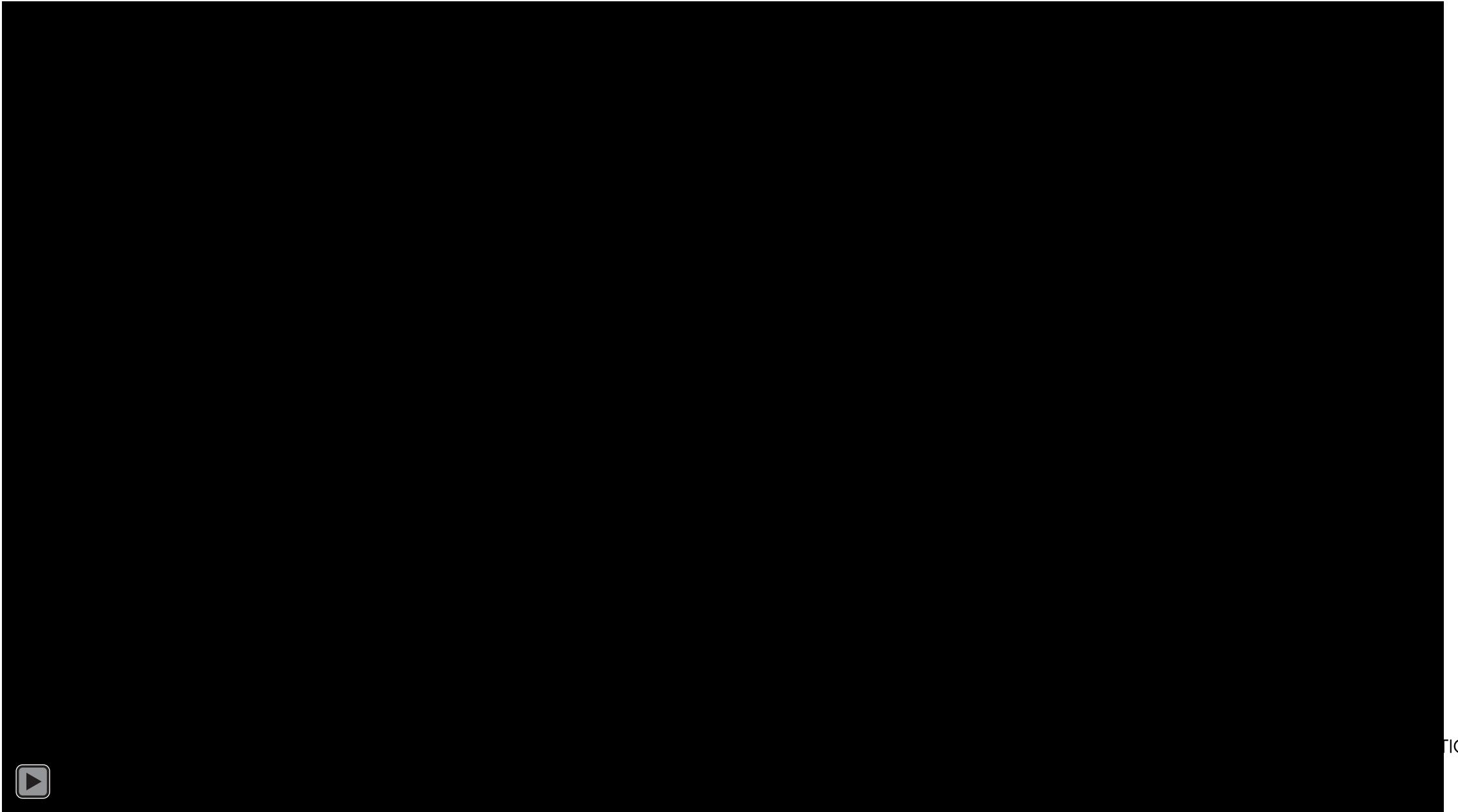
GATHERING DATA



CALIBRATING RESULTS



VISUALISER RESULTS



THEFULLCIRCLE

RESEARCH, INNOVATION AND EDUCATION

- Funding from the Poul Due Jensen Foundation is used for fully **independent research** about the *limits of digital twins*
- More **applied research** will be carried out together with *external partners* including combinations with *machine learning* and *visualisation* and scaling up to the *System of Systems level*
- Digital twin **innovation** together with SMEs (will take place also together with Global Technological Service (GTS) organisations)
- As a Digital Innovation Hub *advice* will be provided on digital twins
- All new *research results* also be tested in our **educations**
- New student research projects using our research results