Guest Lecture, ShanghAI Lectures 2022

Soft robots for the hard problem of picking soft berries

Dr. Martin F. Stoelen

Associate Professor, Western Norway University of Applied Sciences

Founder and CSO, Fieldwork Robotics Ltd/Norway

Western Norway University of Applied Sciences

Fieldwork ROBOTICS

Robot carrying out commercial harvesting-as-a-service in Portugal

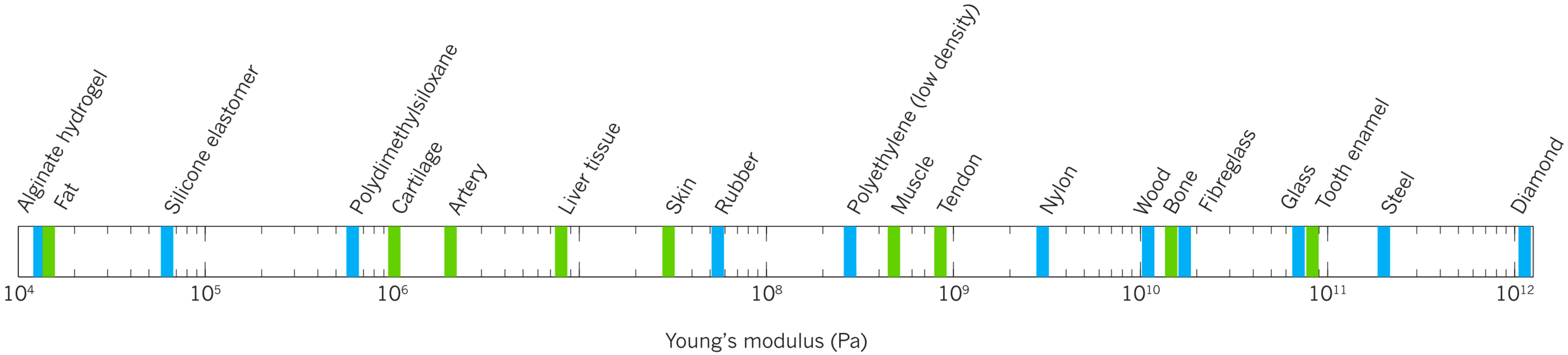
Human-picked:

Robot-picked:

THE SUMMER BERRY COMPANY EST. 2006

Fieldwork ROBOTICS

Biological vs engineering materials

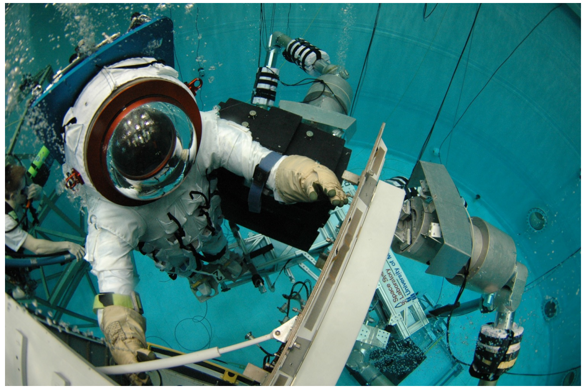


Rus & Tolley,
Nature, 2015

Kingston University London

Space Systems Laboratory

University of Maryland



Universidad Carlos III de Madrid

The ShanghAI Lectures 人工智能 上海授课

Western Norway University of Applied Sciences

The ShanghAI Lectures 人工智能 上海授课

MARIE CURIE ACTIONS

UNIVERSITY OF PLYMOUTH

Fieldwork ROBOTICS

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SUNQIAO

ROBOTICS WITH PLYMOUTH UNIVERSITY

Fieldwork Robotics Ltd

China Robot Harvest ++ project

Agri-Tech in China Newton Network+ (ATCNN), UK

With thanks:

ROTHAMSTED RESEARCH

Newton Fund

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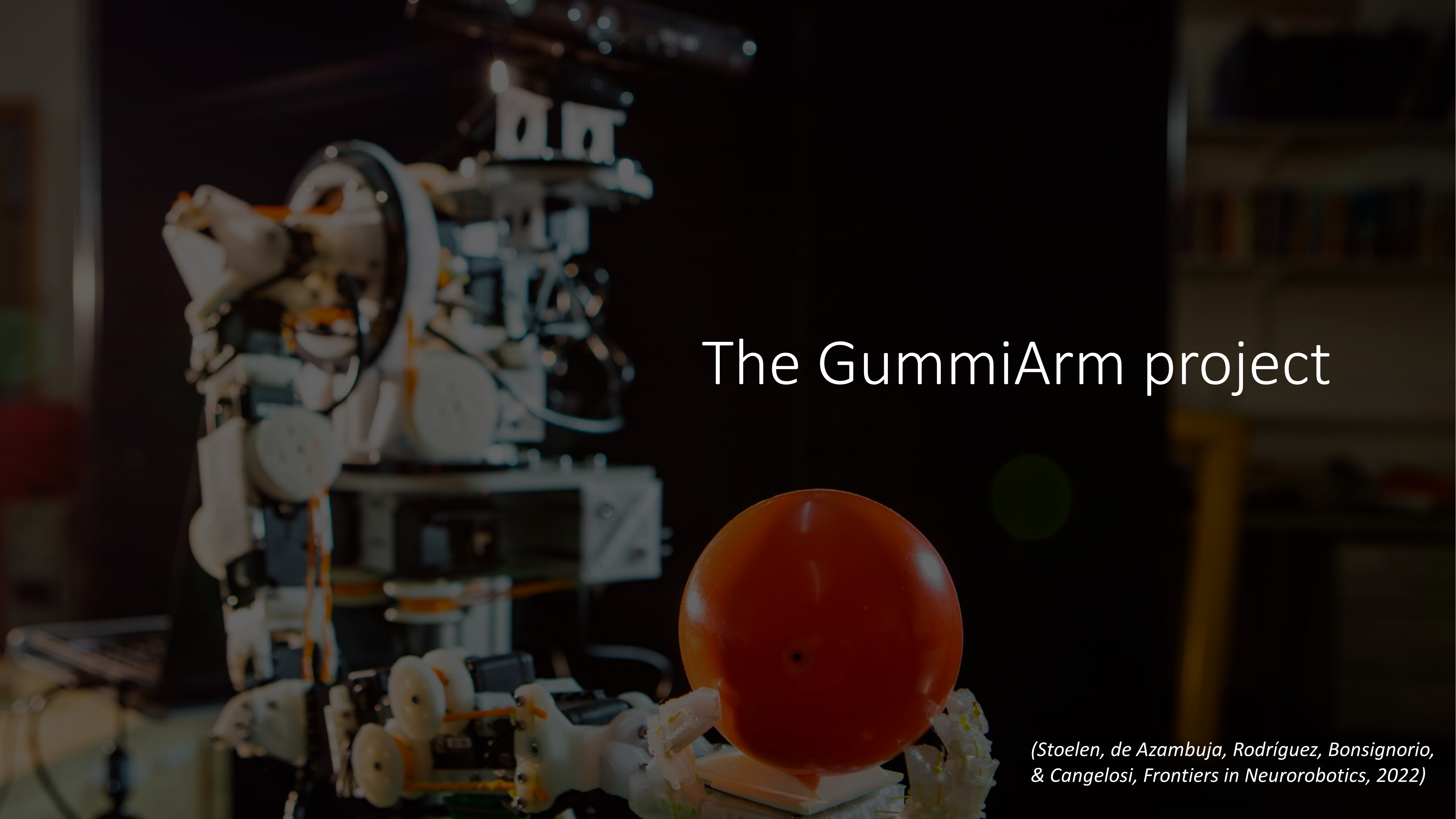
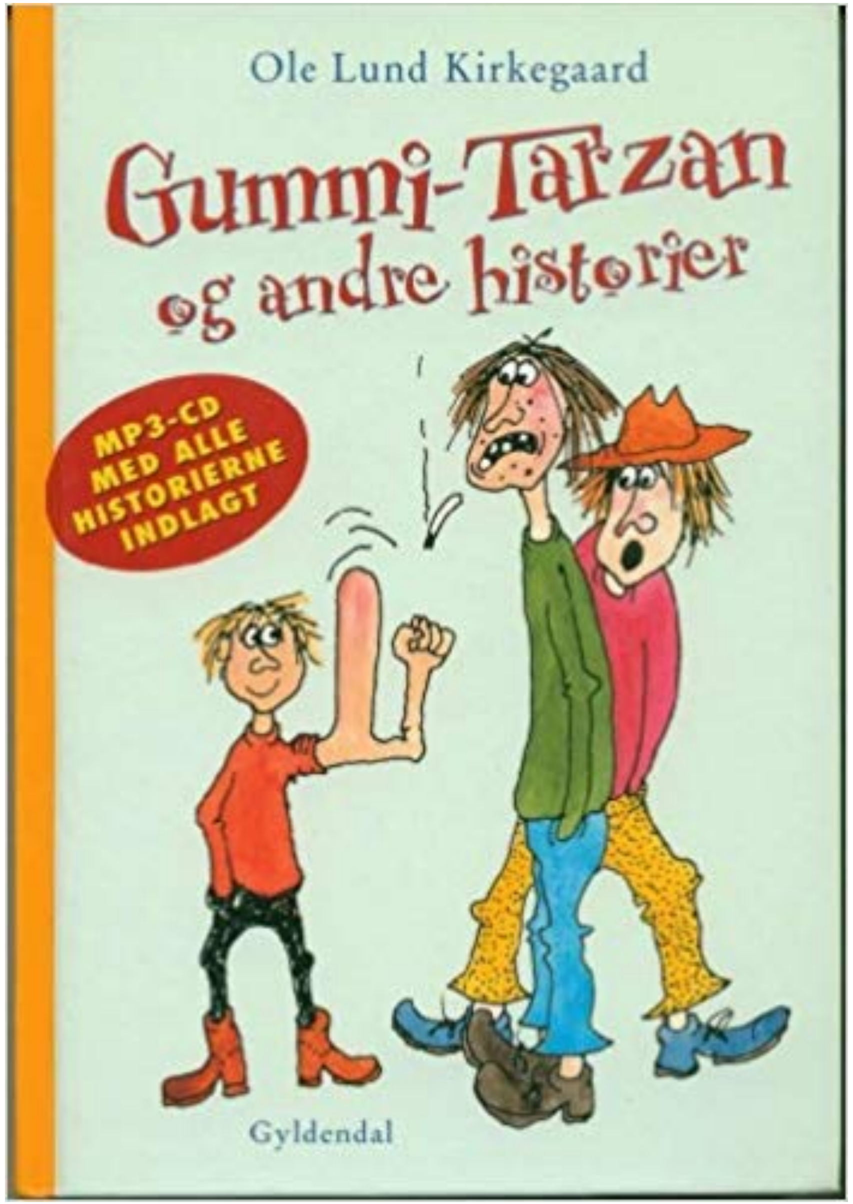
NORWEGIAN INSTITUTE OF BIOECONOMY RESEARCH

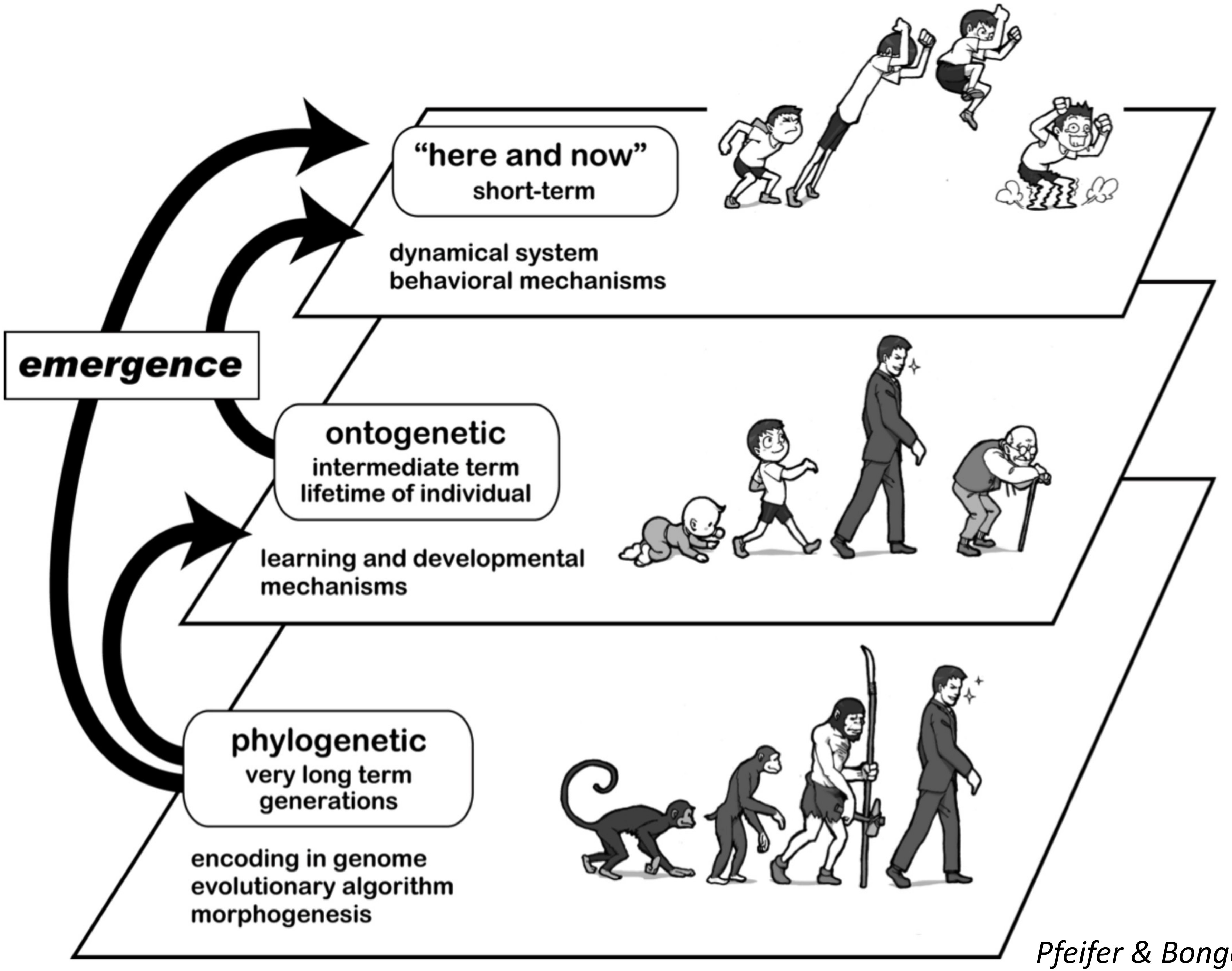


The GummiArm project

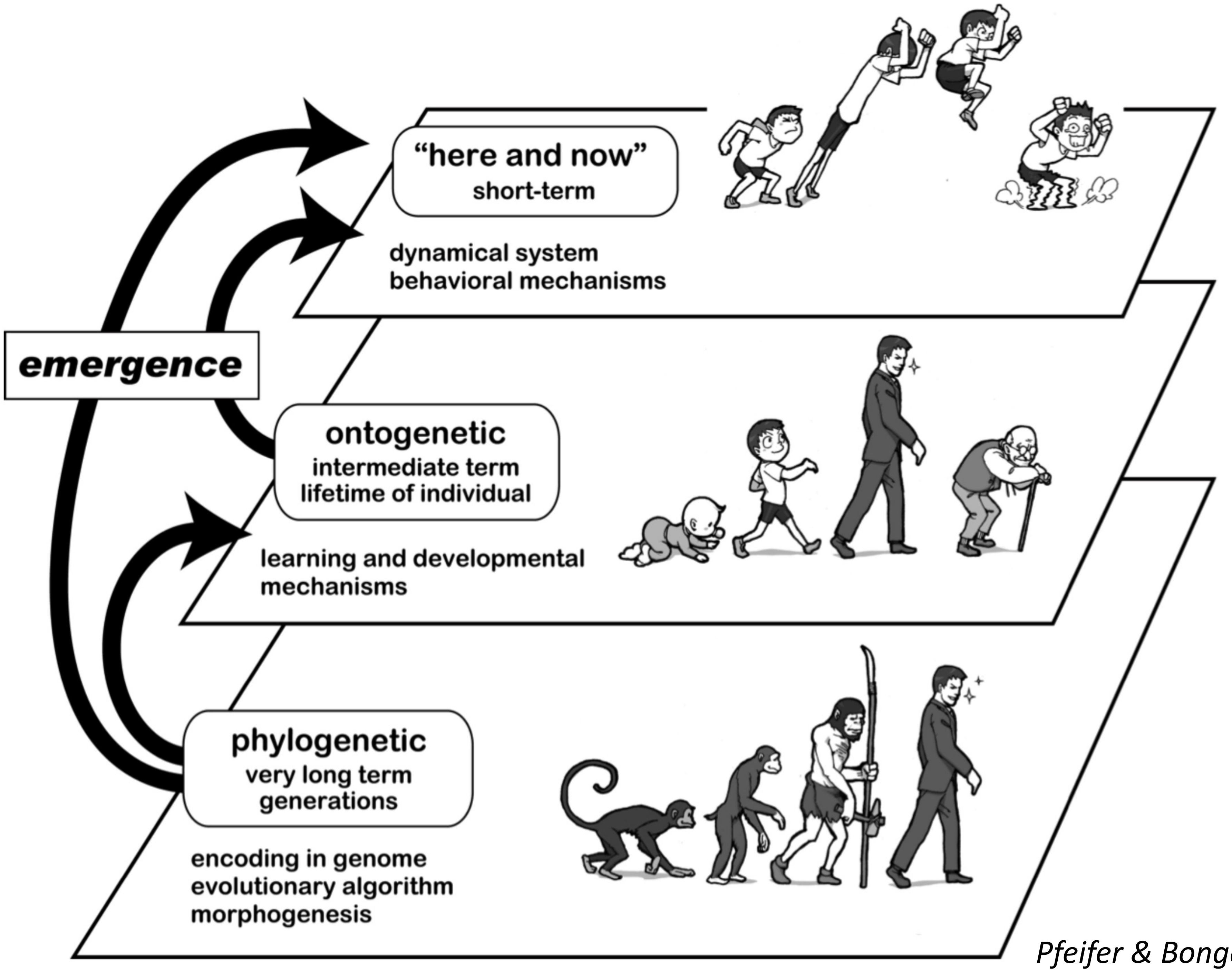
(Stoelen, de Azambuja, Rodríguez, Bonsignorio, & Cangelosi, Frontiers in Neurorobotics, 2022)



Gyldendal (1975, 2007)

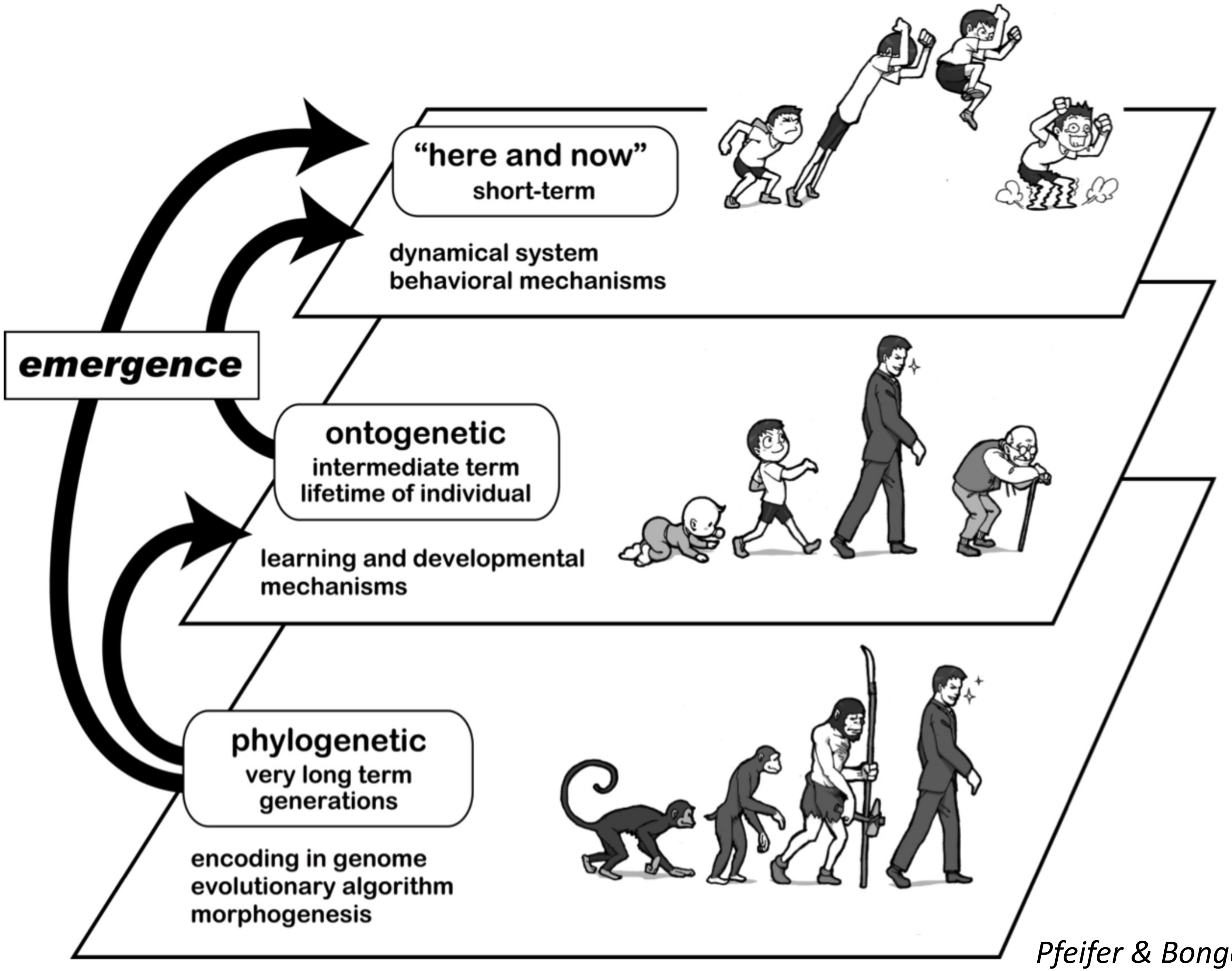


Pfeifer & Bongard, 2006



Pfeifer & Bongard, 2006

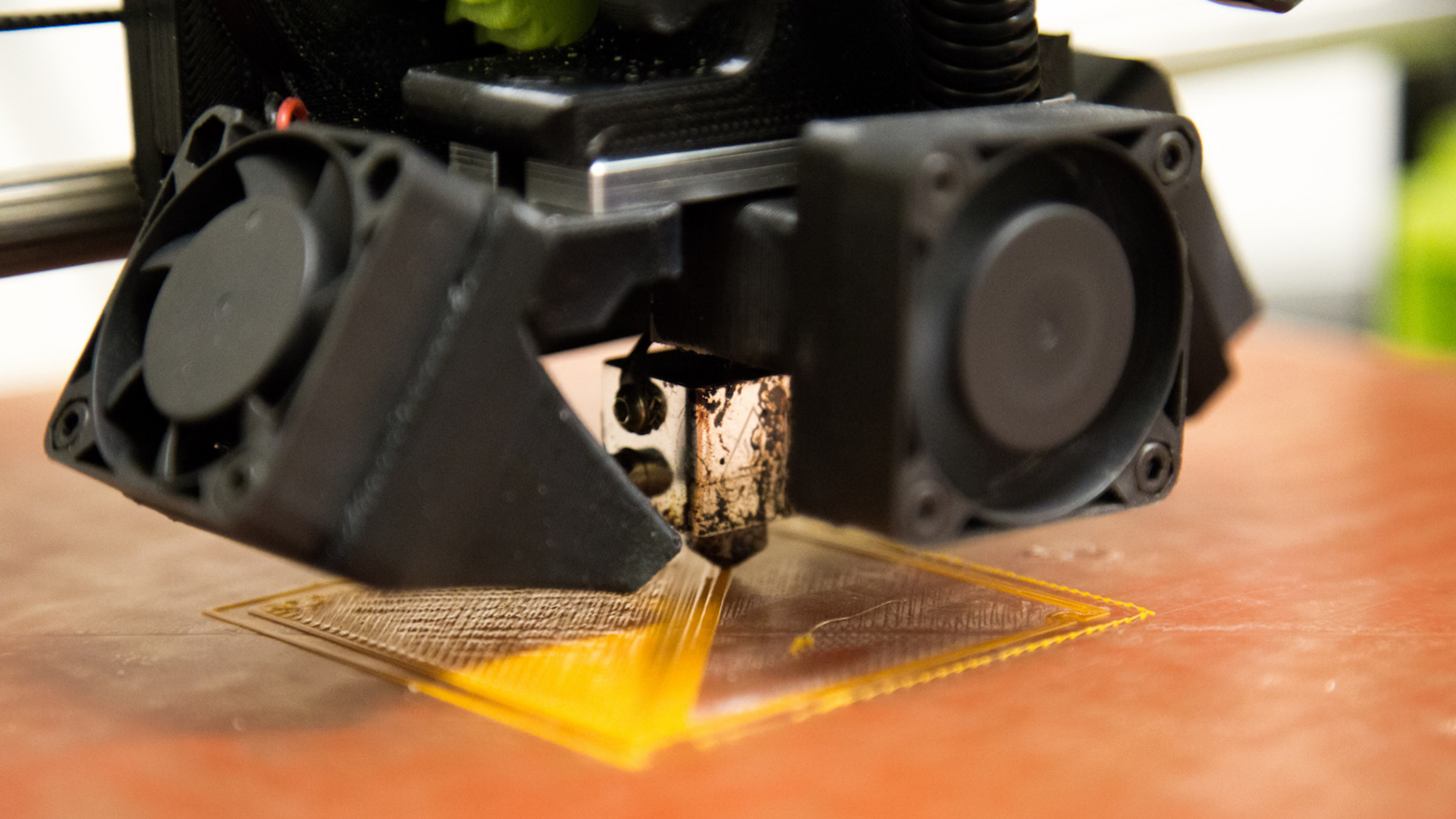
A developing mind requires a robust body…

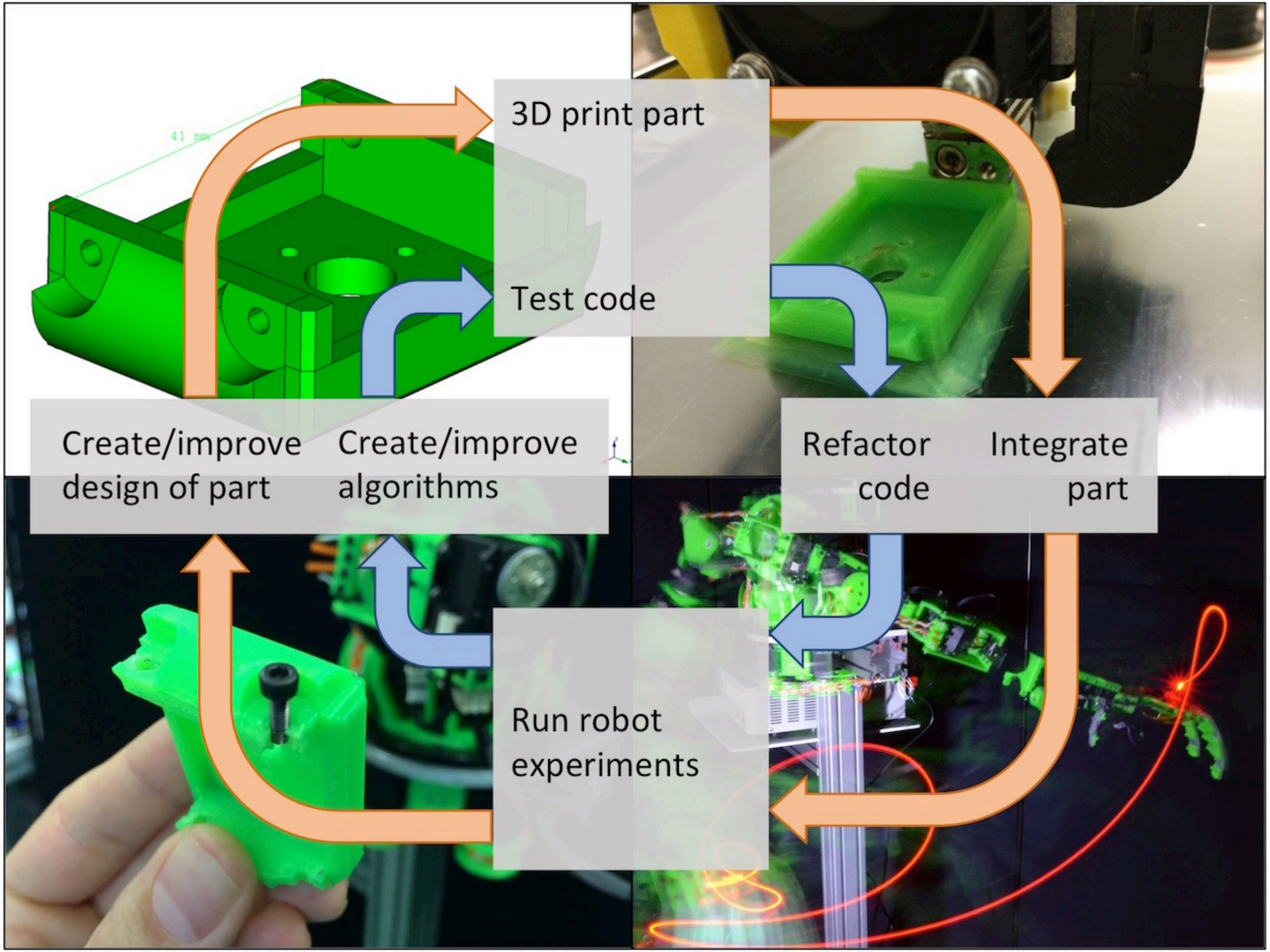


Pfeifer & Bongard, 2006

A developing mind requires a robust body…

Brain and body evolved together





41 mm
3D print part
Test code
Create/improve
design of part
Create/improve
algorithms
Refactor
code
Integrate
part
Run robot
experiments

frontiers in Neurorobotics

TECHNOLOGY REPORT
published: 11 March 2022
doi: 10.3389/fnbot.2022.836772

Check for updates

The GummiArm Project: A Replicable and Variable-Stiffness Robot Arm for Experiments on Embodied AI

Martin F. Stoelen[1,2,3], Ricardo de Azambuja[4], Beatriz López Rodríguez[1]*, Fabio Bonsignorio[5] and Angelo Cangelosi[6]*

[1] Department of Computer Science, Electrical Engineering and Mathematical Sciences, Western Norway University of Applied Sciences, Bergen, Norway, [2] Fieldwork Robotics Ltd., Cambridge, United Kingdom, [3] Centre for Robotics and Neural Systems (CRNS), University of Plymouth, Plymouth, United Kingdom, [4] MISTLab.ca, Polytechnique Montréal, Montreal, QC, Canada, [5] Heron Robots, Genoa, Italy, [6] Department of Computer Science, University of Manchester, Manchester, United Kingdom

Robots used in research on Embodied AI often need to physically explore the world, to fail in the process, and to develop from such experiences. Most research robots are unfortunately too stiff to safely absorb impacts, too expensive to repair if broken repeatedly, and are never operated without the red kill-switch prominently displayed. The GummiArm Project was intended to be an open-source "soft" robot arm with human-inspired tendon actuation, sufficient dexterity for simple manipulation tasks, and with an eye on enabling easy replication of robotics experiments. The arm offers variable-stiffness and damped actuation, which lowers the potential for damage, and which enables new research opportunities in Embodied AI. The arm structure is printable on hobby-grade 3D printers for ease of manufacture, exploits stretchable composite tendons for robustness to impacts, and has a repair-cycle of minutes when something does break. The material cost of the arm is less than $6000, while the full set of structural parts, the ones most likely to break, can be printed with less than $20 worth of plastic filament. All this promotes a concurrent approach to the design of "brain" and "body," and can help increase productivity and reproducibility in Embodied AI research. In this work we describe the motivation for, and the development and application of, this 6 year project.

OPEN ACCESS

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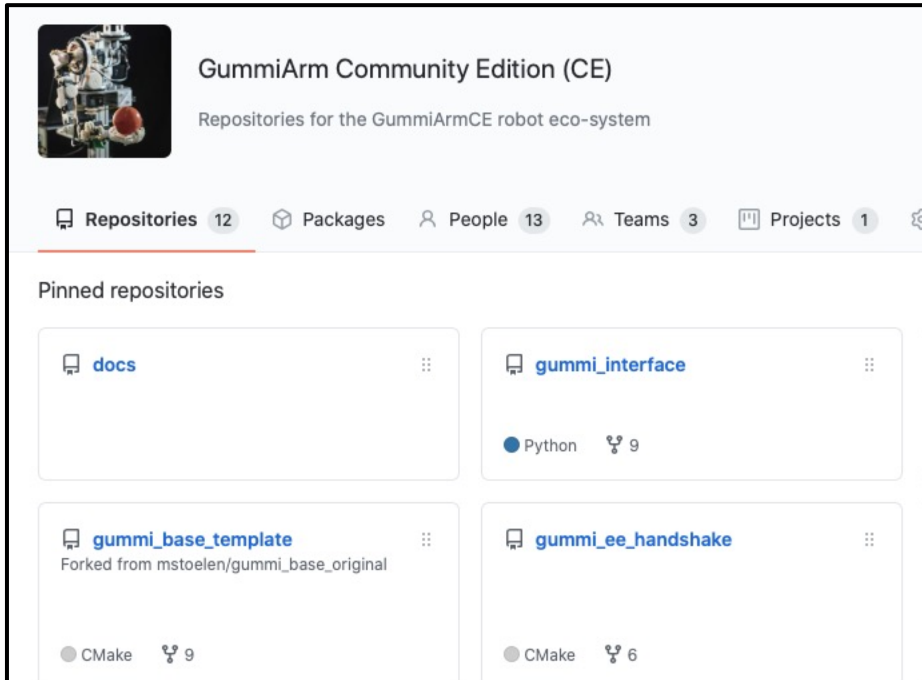
***Correspondence:**

(Stoelen, de Azambuja, Lopez Rodríguez, Bonsignorio, & Cangelosi, Frontiers in Neurorobotics, 2022)

https://github.com/GummiArmCE



Name	Performance		Joints		Replicability		
	Payload, kg	Reach, m	DOF	Soft (VSA)	RP*	Open HW	Cost, $
GummiArm	0.5–1	0.7	7	5 (Yes)	FFF	CC BY-SA	~5730
Quigley et al. (2011)	2	>1	7	4 (No)	JET**	N/A	4135
Reachy[a]	0.5	0.65	7	0	FFF	CC BY-SA	<4000
Niryo One[b]	0.3	0.44	6	0	FFF	CC BY-NC-SA	1200
RBX1 - Remix[c]	0.25	?	6	0	FFF	CC BY-SA	800
Thor[d]	0.75	0.6	6	0	FFF	CC BY-SA	<450
Myorobotics Arm[e]	?	~1	4	4 (Yes)	SIN***	CC BY-4.0	?
VSA-CubeBot[f]	< 0.5	0.4	4	4 (Yes)	STP	CC BY-4.0	?
H2Arm[g]	0.15	0.10	4	3 (Yes)	FFF	CC BY-4.0	225

That is, robot arms that strive toward easily available and open-source hardware and software, and that can be built and maintained using commonly available low-cost rapid prototyping approaches. Costs relate to materials only, they do not include salaries for building and sourcing.

Rapid prototyping approach.

**Jet cutting.*

***Laser sintering.*

[a] *https://www.pollen-robotics.com/reachy/.*

[b] *https://niryo.com/docs/niryo-one/.*

[c] *https://roboteurs.com.*

[d] *https://hackaday.io/project/12989-thor.*

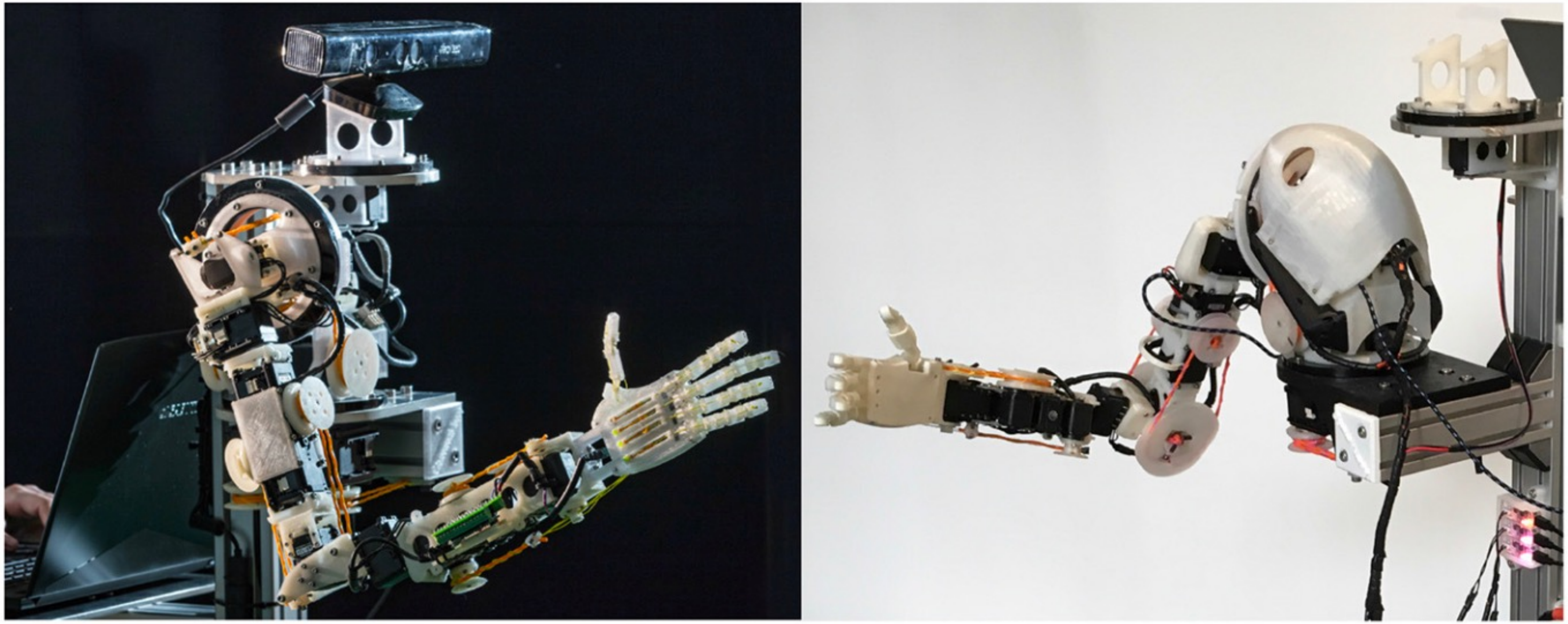
[e] *https://roboy.org/partners/myrobotics-arm/.*

[f] *https://qbrobotics.com/it/prodotti/qbmove-kit-base/.*

[g] *https://ieee-dataport.org/open-access/h2arm-bsp-vs-pid-experiments.*

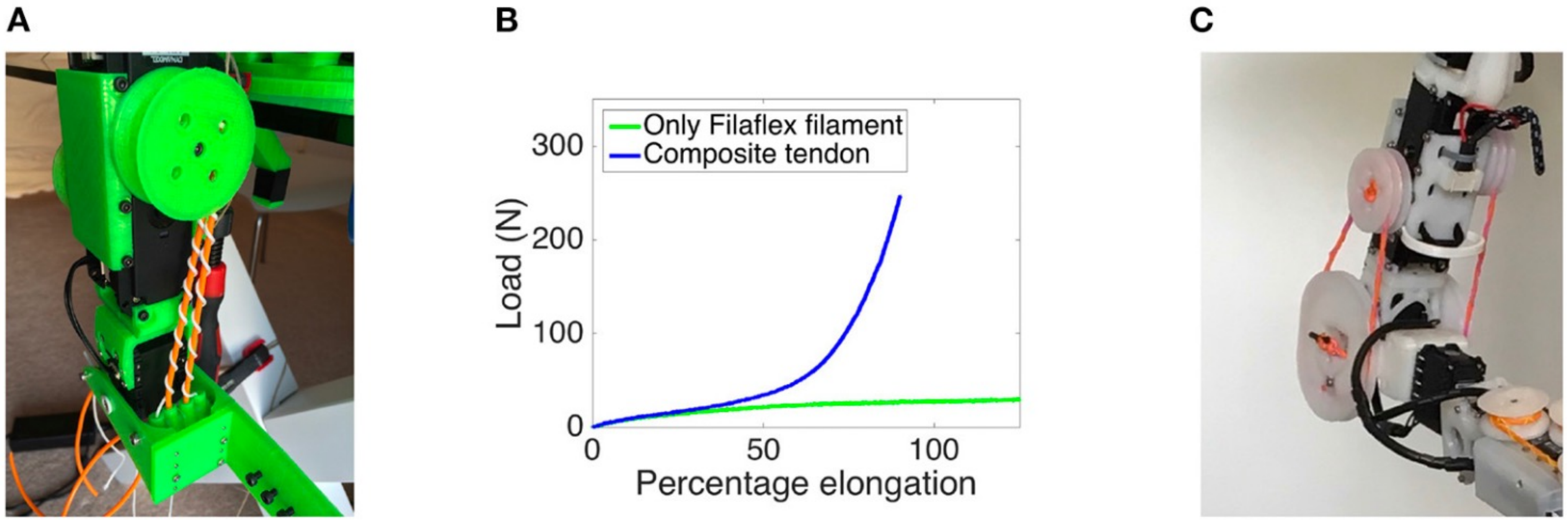
(Stoelen, de Azambuja, Rodríguez, Bonsignorio, & Cangelosi, Frontiers in Neurorobotics, 2022)

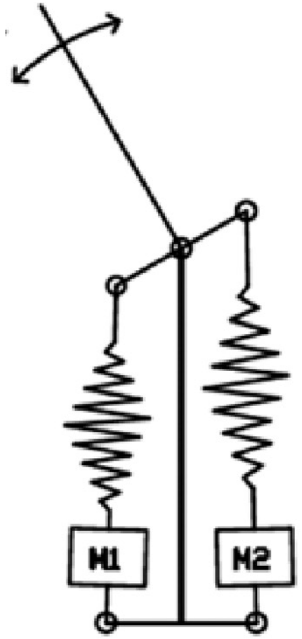
A B



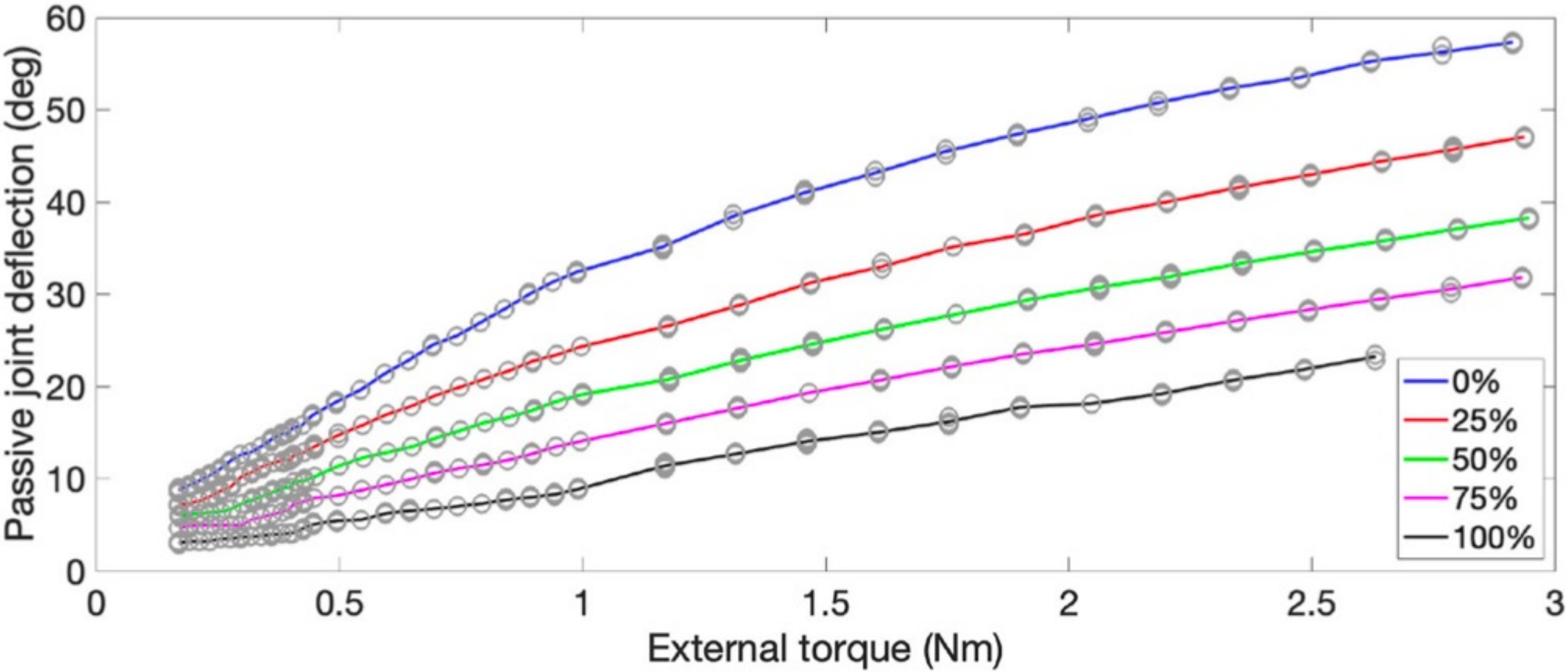
GummiArm 1.0

GummiArmCE





Vanderborght et al., Robotics and Autonomous Systems, 2013



Passive joint deflection (deg)
External torque (Nm)
0
10
20
30
40
50
60
0
0.5
1
1.5
2
2.5
3
0%
25%
50%
75%
100%

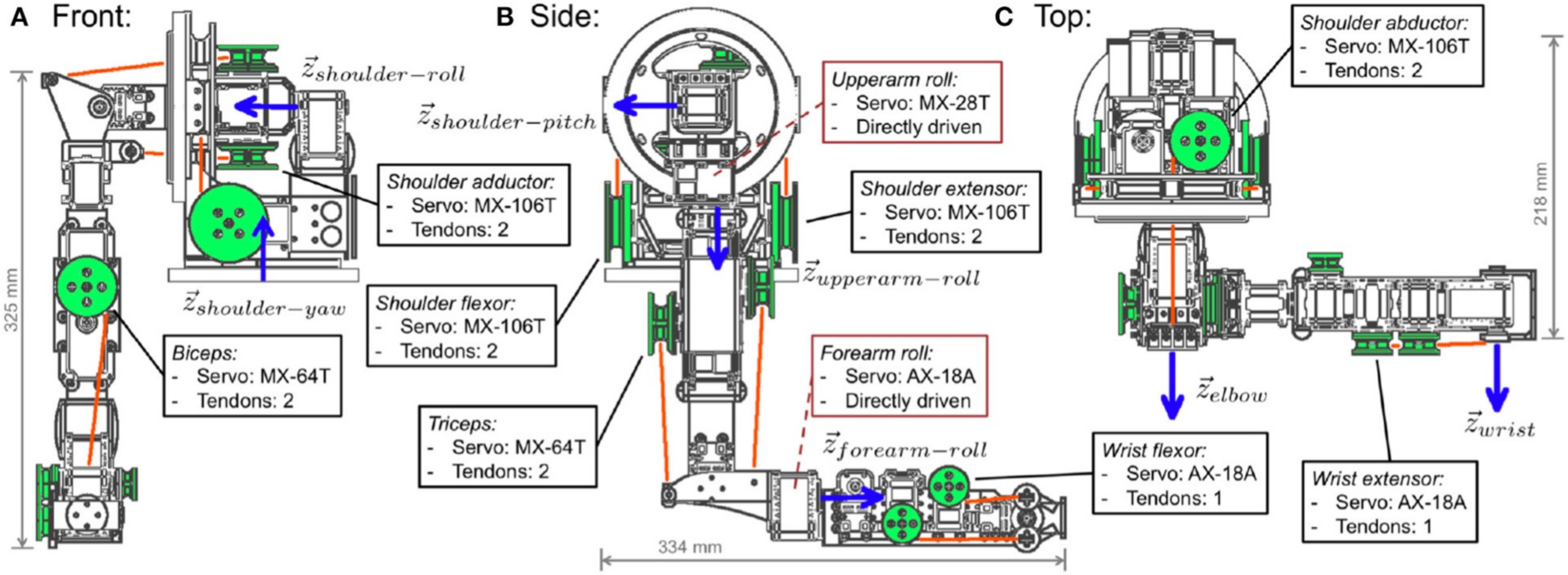
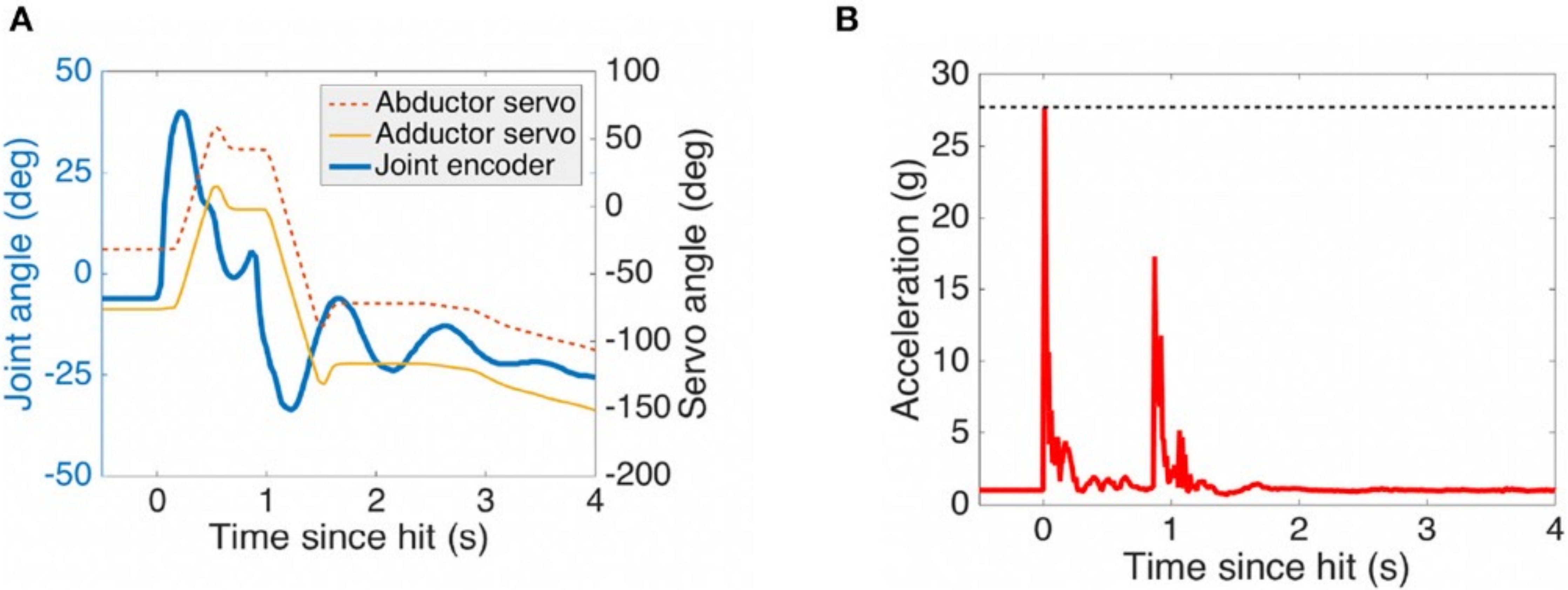
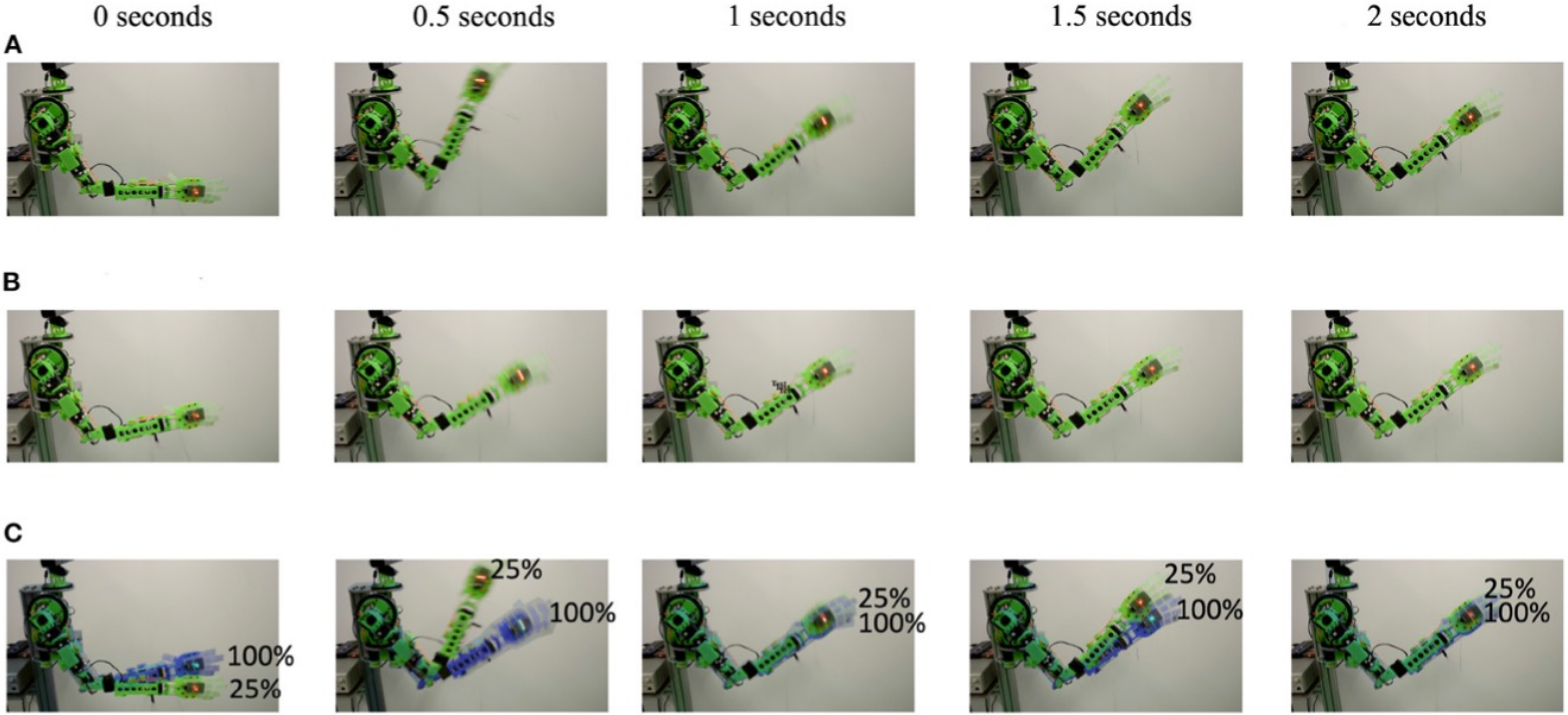
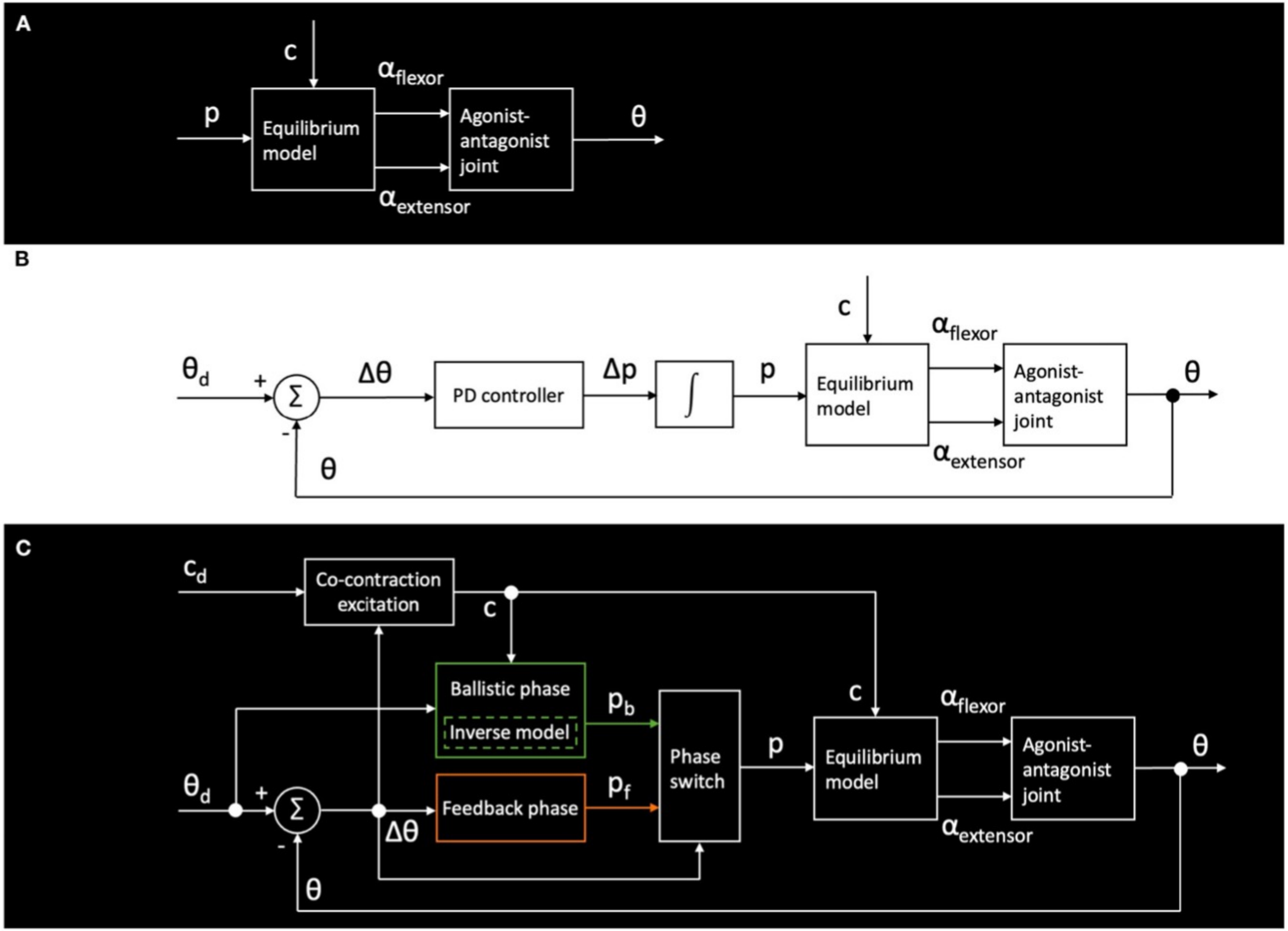


FIGURE 2 | The structural layout of the GummiArm v1.0, seen from the front **(A)**, side **(B)**, and top **(C)**. The 7 joint axes ($\vec{z}$) are indicated with thick blue arrows. The tendons are shown as orange lines, while the servo pulleys are highlighted in green (8 shown, corresponding to the 4 out of 5 antagonist joints). Resting pose shown (zero degrees on all joints). Note that the structure and servos corresponding to the *shoulder yaw* joint are not shown for clarity.



A
Abductor servo
Adductor servo
Joint encoder
Joint angle (deg)
Servo angle (deg)
Time since hit (s)
50
25
0
-25
-50
100
50
0
-50
-100
-150
-200
0
1
2
3
4
B
Acceleration (g)
Time since hit (s)
30
25
20
15
10
5
0
0
1
2
3
4

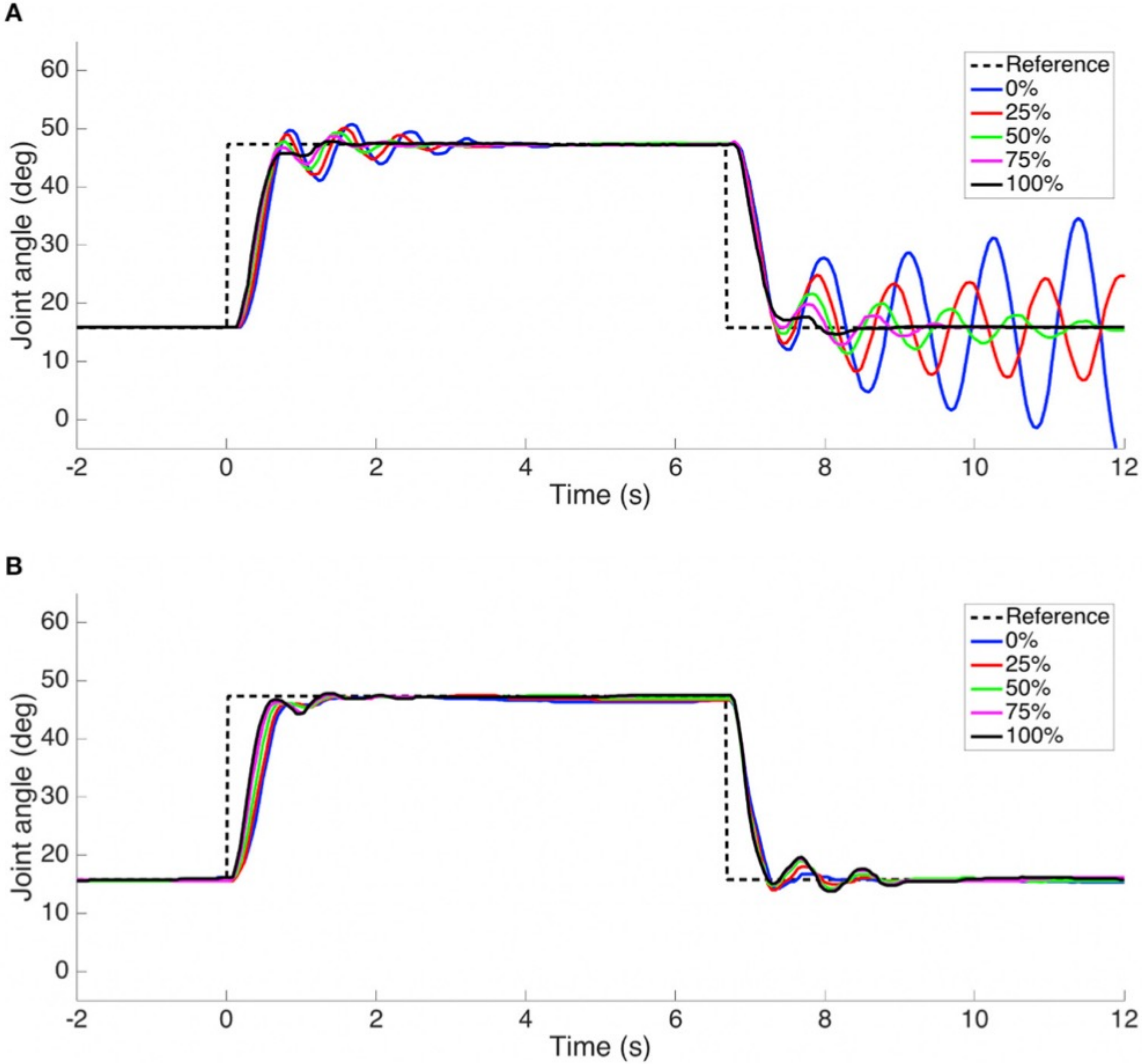

0 seconds
0.5 seconds
1 seconds
1.5 seconds
2 seconds
A
B
C
100%
25%
25%
100%
25%
100%
25%
100%
25%
100%



"Equilibrium model":

$$\alpha_{\text{flexor}} = p\frac{\gamma}{4} - c\frac{\pi}{2},$$

$$\alpha_{\text{extensor}} = p\frac{\gamma}{4} + c\frac{\pi}{2}.$$



A
Joint angle (deg)
Time (s)
Reference
0%
25%
50%
75%
100%
B
Joint angle (deg)
Time (s)
Reference
0%
25%
50%
75%
100%

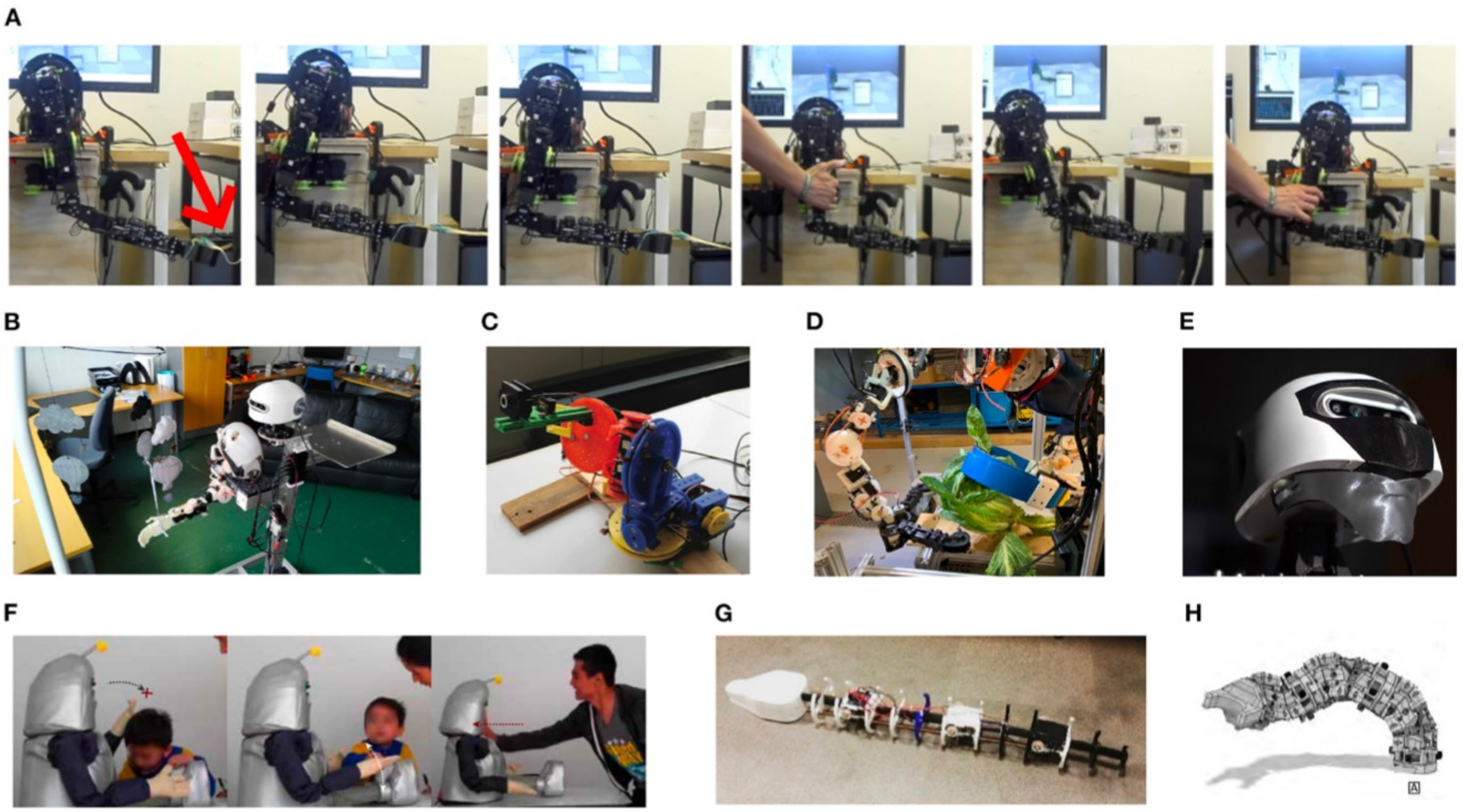
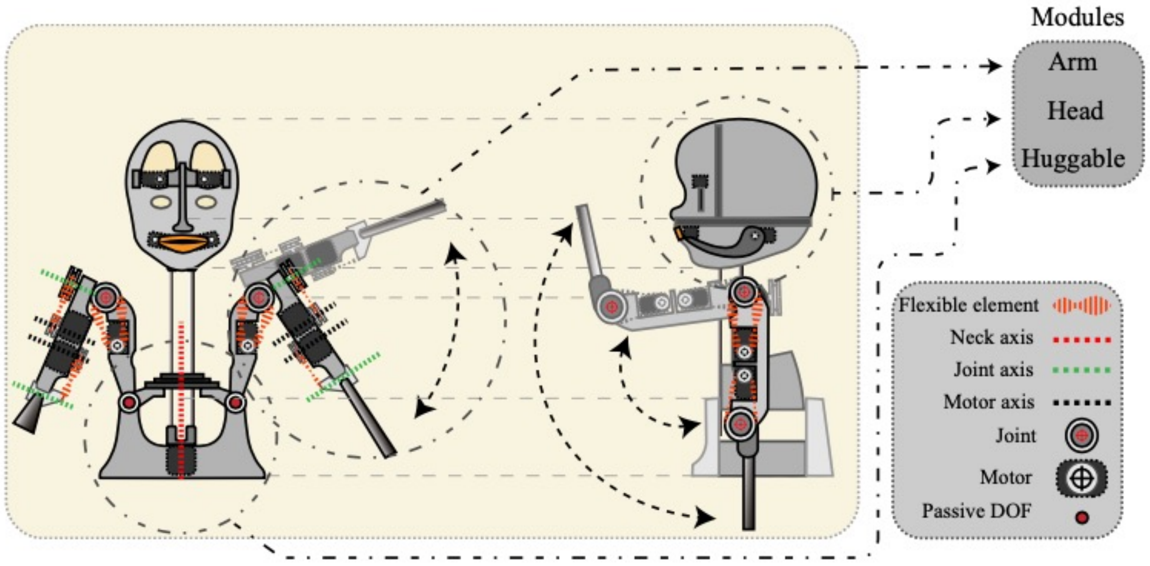


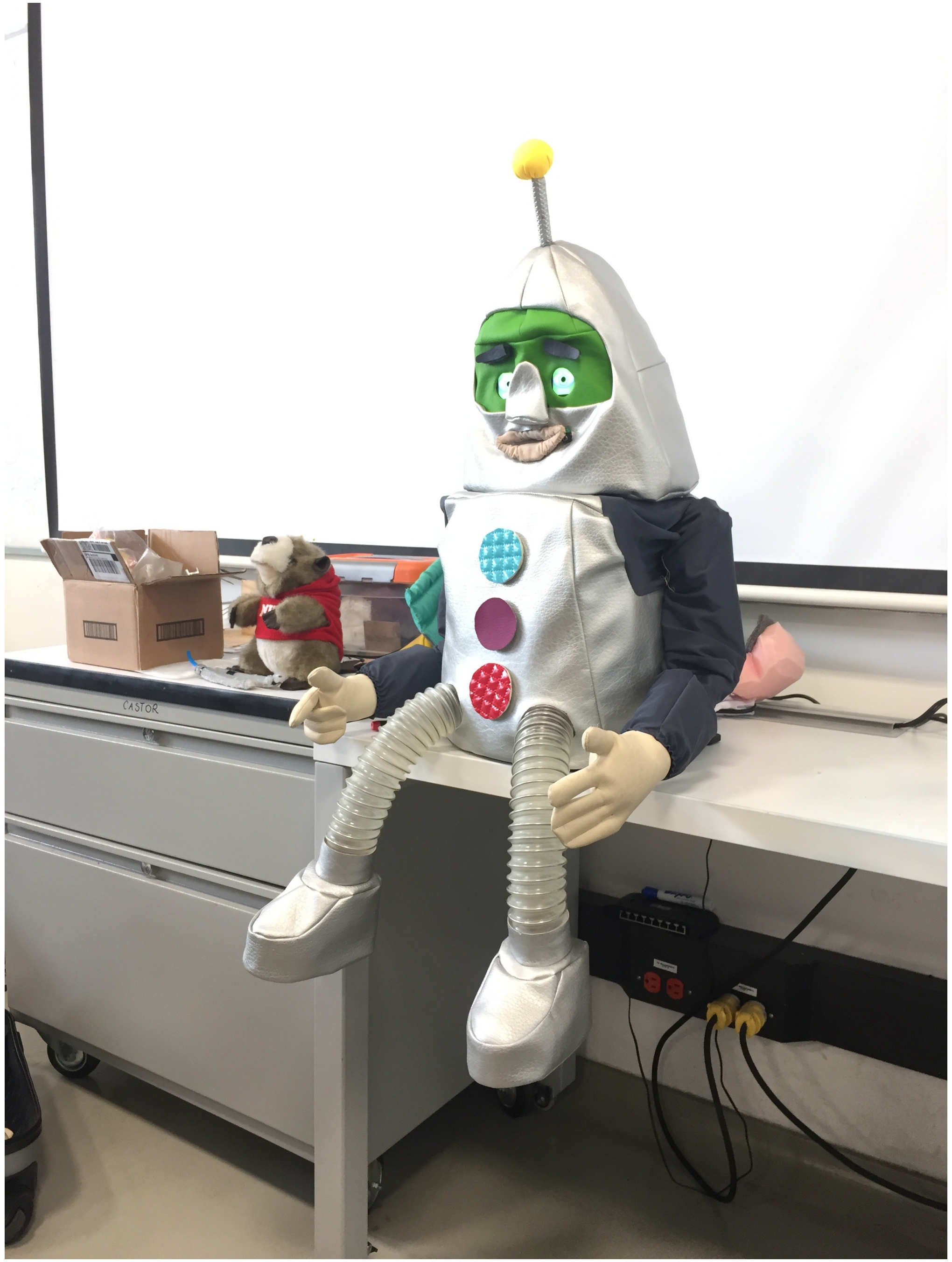
FIGURE 14 | Example applications of the GummiArm, and its related concepts. **(A)** rhythmic movement generation and online frequency adaptation (Degroote et al., 2020). **(B)** exploration and exploitation of sensorimotor contingencies (Houbre et al., 2020). **(C)** visual-servoing on low-accuracy, low-cost arms (Bonsignorio and Zereik, 2020). **(D)** robust Arms for robotic cauliflower harvesting (Klein et al., 2019). **(E)** a parametric, modular and open source robot head for the GummiArm (Netzev et al., 2019). **(F)** soft and robust arms for a huggable social robot (Casas-Bocanegra et al., 2020). **(G)** a variable stiffness actuated snake (Draper et al., 2017). **(H)** a modular and stackable actuator with variable stiffness (Wilmot and Howard, 2021).

CASTOR

"CompliAnt SofT Robotics"



(Casas-Bocanegra, Gomez-Vargas, Pinto-Bernal, Maldonado, Munera, Villa-Moreno, Stoelen, Belpaeme, & Cifuentes, Actuators, 2020)

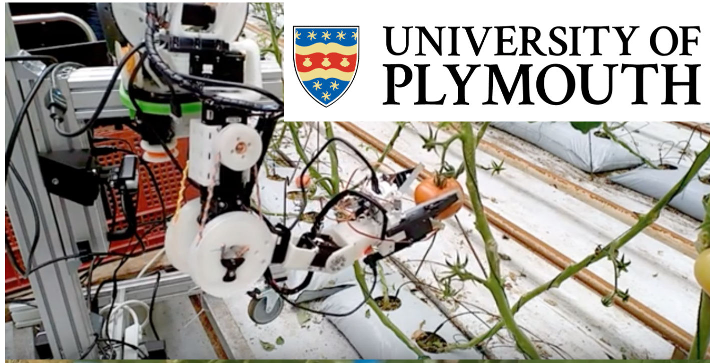



The New York Times
Illegal Immigration Is Down, Changing the Face of California Farms
Farmers are turning to workers on seasonal visas and mechanizing what they can. Many labor-intensive crops are shifting south of the border.
Fears gro
this Chris
Victoria Bell
Yahoo News
labour shortfall
nd army'
t more than 90,000 jobs
uit 'left to rot' due to labour shortages
Share
Up to £60m in UK crops left to rot owing to lack of workers, says NFU
Farming union chief says situation 'nothing short of a travesty', as
also hit by drought and record heat
UK po
Labour shortfall leading to 'catastrophic' food waste, UK farmers warn
Limited numbers of visas for seasonal worker threatens contraction of sector and risks some farms going bust
British asp
The farmi
and veget
interest i
t: farn
ultura
ne to help
sas a year
ABC RURAL
Farm labour shortage continues despite surge of working holiday visa applications
ABC Rural / By national rural reporters Kath Sullivan and Clint Jasper
Posted Fri 11 Feb 2022 at 9:32pm, updated Sun 13 Feb 2022 at 5:16am
Australia's fruit and vegetable farmers rely heavily on backpackers to harvest their crops. (Supplied: LuvaBerry/Sara Vasseghi)
's expected to fail because it
because of a labour
which found at least
this year.
members said they had

UNIVERSITY OF PLYMOUTH

Impact case: Soft and robust robotic systems for horticulture

- Dr Stoelen (PI), Dr Howard (co-I), Dr Millard (co-I)
- Substantial Research/Innovation funding
  - More than £1.2M in 4 years
- University spin-out: Fieldwork Robotics Ltd
  - First-use agreement with the UK's largest raspberry producer
- Extensive national & international media coverage



Fieldwork Robotics Ltd

Riviera Produce
Cornwall's grower of choice

Hall Hunter Partnership
Sustainably producing quality British berries

Frontier IP Group plc

Teagle

SUNQIAO
MODERN AGRICULTURE
孙桥现代农业

Shanghai Jiao Tong University
1896

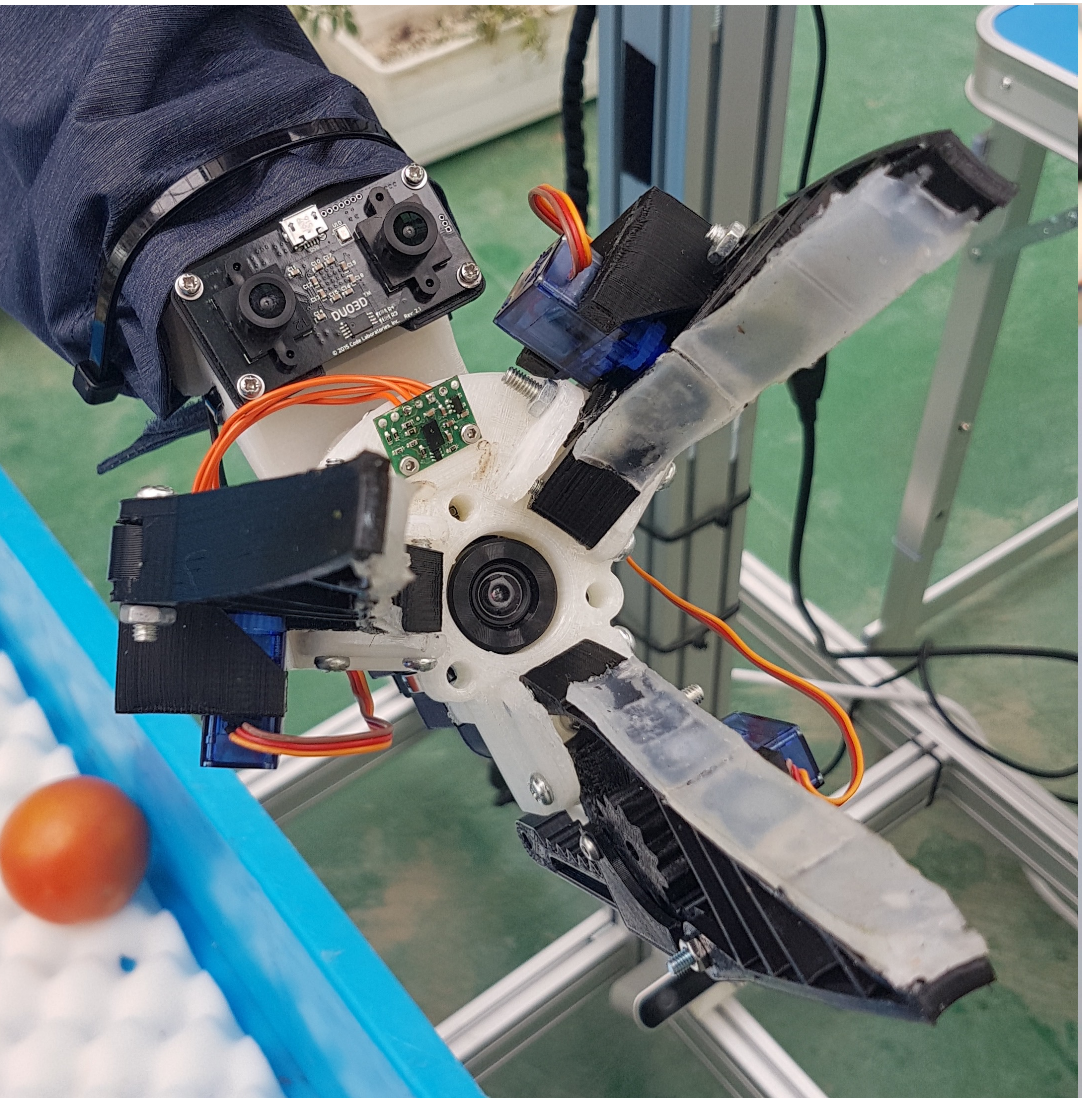
NPL
National Physical Laboratory

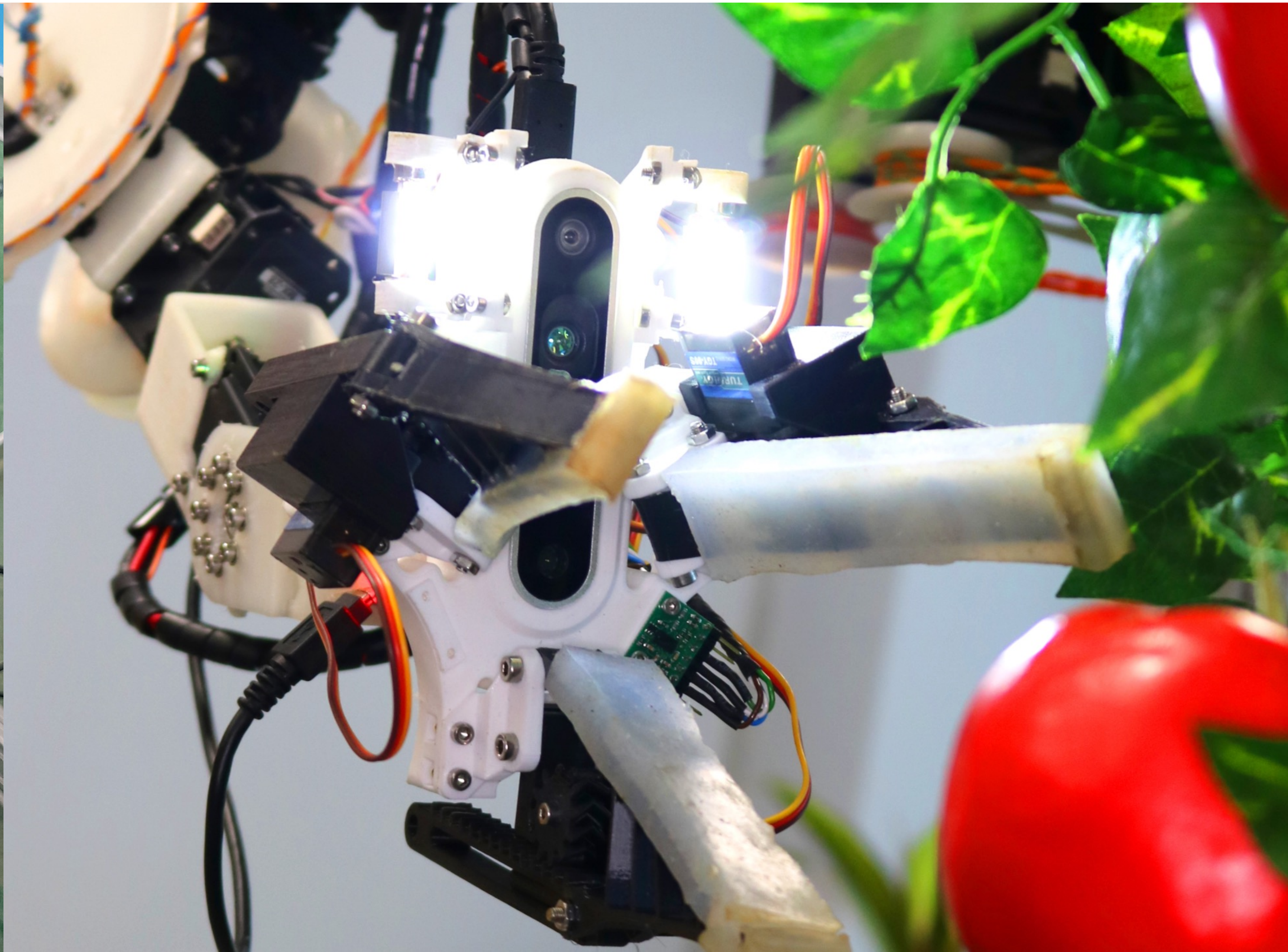
Innovate UK

DE TAO GROUP 德稻

Newton Fund

Soft tomato gripper for one-handed picking





SUNQIAO
MODERN AGRICULTURE
孙桥现代农业

ROBOTICS WITH PLYMOUTH UNIVERSITY

Fieldwork Robotics Ltd

SHANGHAI JIAO TONG UNIVERSITY 1896

China Robot Harvest ++ project

Agri-Tech in China Newton Network+ (ATCNN), UK

With thanks:

ROTHAMSTED RESEARCH

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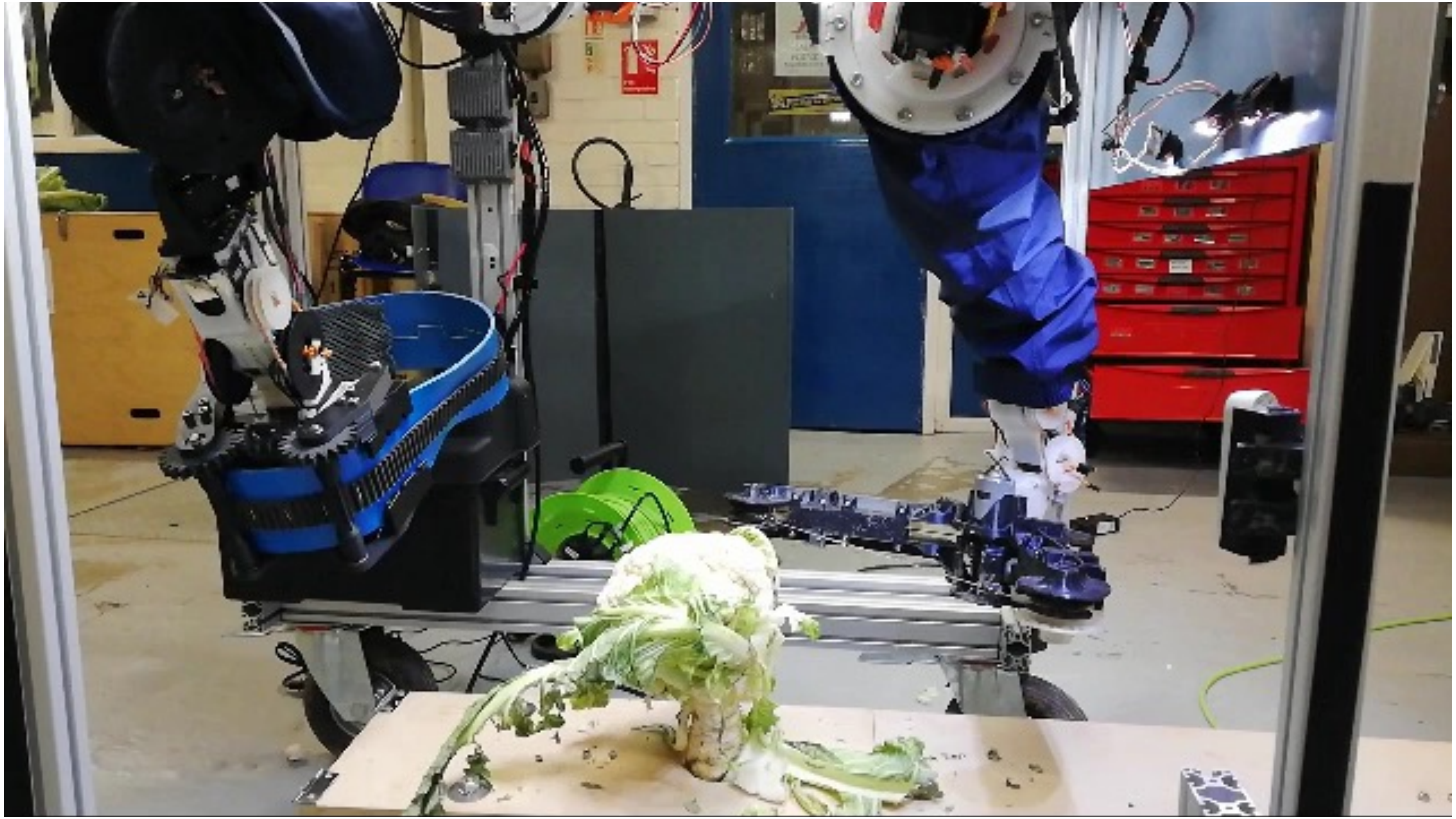
Cauliflower soft belt gripper



Fieldwork ROBOTICS

AGRITECH CORNWALL

European Union
European Regional Development Fund

UNIVERSITY OF PLYMOUTH

Fieldwork
ROBOTICS

In collaboration with

BOSCH

The Summer Berry Company
EST. 2006

Bonduelle


hvlrobotics
Western Norway
University of
Applied Sciences

HVL robotics – members

– Academic staff:
  - Erik Kyrkjebø, Associate Professor (PI)
  - Martin Stølen, Associate Professor
  - Knut Øvsthus, Professor (Bergen)
  - Marcin Fojcik, Associate Professor
  - Olav Sande, Associate Professor
  - Joar Sande, Assistant Professor
  - Bjarte Pollen, Teacher
  - Eli Nummedal, Assistant Head of Institute
– Research/engineering staff
  - Beatriz Lopez Rodriguez, Researcher
  - Raquel Motzfeldt Tirach, Senior Engineer
  - Sivert Benjaminsen, Trainee
  - 1 Post-Doc to be hired in 22/23 (FutuRaPS project)
– PhD students:
  - Gizem Ates, PhD student
  - Daniel Schäle, PhD student
  - Laurenz Elstner, PhD student
  - 2 PhD students to be hired in 22/23 (FutuRaPS project)









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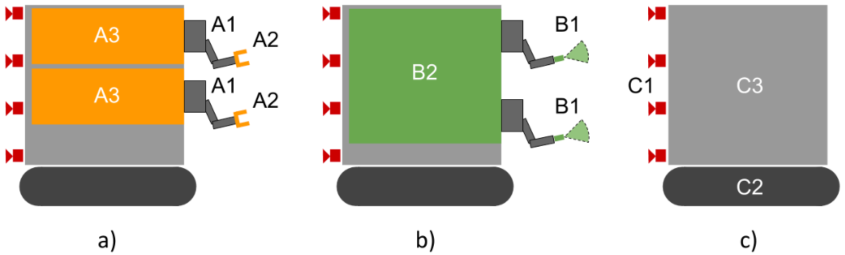
FutuRaPS: Future Raspberry Production System for Western Norway

- System-of-systems: New varieties of raspberries, new ways of growing, combined with robotics and big data
- Modularity for maximising utilisation of robot, beyond short harvest season

- FFL/JA, collaboration project
- Project start: 1st of January 2023
- 3 year project, 9 MNOK in NFR funding
- 2x PhD positions, 1x post-doc



Three configurations: a) Harvesting, b) precision spraying, and c) monitoring

Western Norway University of Applied Sciences
Fieldwork ROBOTICS
nLink
NJØS frukt- og bærsenter
Sognabær
SOGN FRUKT OG GRØNT SA
GROFONDET
WESTERN NORWAY RESEARCH INSTITUTE VESTLANDSFORSKING
sparebankstiftinga sogn og fjordane
The Research Council of Norway

SMARAGD: Smart Agriculture Data Fusion and Analytics for Automated Decision Support

Agdir

SINTEF

Fieldwork
ROBOTICS

aersea
AERIAL & SEA WORKS

The Research Council of Norway

HVL robotics – research and innovation activity

Core research focus

- Human-Robot Cooperation
- Soft Robots

New research/innovation activities

- Agricultural robotics
- Robotics in healthcare

Ongoing projects

- **Teknoløft** Sogn og Fjordane (NFR), with Vestlandsforsking, Kunnskapsparken and SINTEF
- **CoBotAGV** (EU) with polish partners
- **Probad** (NFR - IPN) automated production of bathroom-modules
- **DigiSpek** (NFR) with Nortura, Rocketfarm and SINTEF

New projects

- **FutuRaPS** (NFR) Raspberry picking robots with Njøs, nLink, Sognabær and Fieldwork
- **Retrams** (NFR) RobotHandleS
- **Robot Rehabilitation after Stroke** with SINTEF and Sunnaas
- **RoCutO** (HVL - POC) Robot grasscutter for orchards

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Questions?

Dr. Martin F. Stoelen

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Western Norway University of Applied Sciences

Fieldwork ROBOTICS