Impact-Aware Manipulation by Dexterous Robot Control and Learning in Dynamic Semi-Structured Logistic Environments

I.AM.

Minutes of the milestone review consortium meeting (focus TOSS scenario)

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www.i.am-project.eu

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Control sheet

Version history			
Versio	**Date**	**Modified by**	**Summary of changes**
0.1	25/02/2021	Jos DEN OUDEN	ToC & first contents
0.11	01/06/2021	Jos DEN OUDEN	Merged & reviewed minutes from Jari and Maarten
0.12	02/06/2021	Jos DEN OUDEN	Ready for internal review
0.2	16/02/2021	Alessandro SACCON	Pre-final version ready for peer-review
0.7	26/06/2020	Jos DEN OUDEN	Peer-review comments addressed
1.0	28/06/2021	Alessandro SACCON	Revised version ready for submission, quality check

Peer reviewers		
	Reviewer name	**Date**
Reviewer 1	Alessandro SACCON (TU/e)	16/06/2021
Reviewer 2	Stijn DE LOOIJER (Vanderlande)	25/06/2020
Reviewer 3	Alexander KURDAS (TUM)	21/06/2021
Reviewer 4	Marco MORGANTI (Franka Emika)	23/06/2021

Legal disclaimer

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ABBREVIATIONS

Abbreviation	Definition
EC	European Commission
WP	Work Package
TU/e	TECHNISCHE UNIVERSITEIT EINDHOVEN
EPFL	ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
TUM	TECHNISCHE UNIVERSITAET MUENCHEN
CNRS	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE
AGX	ALGORYX SIMULATION
FRANKA	FRANKA EMIKA GmbH
SR	SMART ROBOTICS BV
VDLANDE	VANDERLANDE INDUSTRIES BV

1. INTRODUCTION

1.1. Project background

Europe is leading the market of torque-controlled robots. These robots can withstand physical interaction with the environment, including impacts, while providing accurate sensing and actuation capabilities. I.AM. leverages this technology and strengthens European leadership by endowing robots to exploit intentional impacts for manipulation. I.AM. focuses on impact aware manipulation in logistics, a new area of application for robotics which will grow exponentially in the coming years, due to socio-economical drivers such as booming of e-commerce and scarcity of labour.
I.AM. relies on four scientific and technological research lines that will lead to breakthroughs in modelling, sensing, learning and control of fast impacts:

1. I.Model offers experimentally validated accurate impact models, embedded in a highly realistic simulator to predict post-impact robot states based on pre-impact conditions;
2. I.Learn provides advances in planning and learning for generating desired control parameters based on models of uncertainties inherent to impacts;
3. I.Sense develops an impact-aware sensing technology to robustly assess velocity, force, and robot contact state in proximity of impact times, allowing to distinguish between expected and unexpected events;
4. I.Control generates a framework that, in conjunction with the realistic models, advanced planning, and sensing components, allows for robust execution of dynamic manipulation tasks.

This integrated paradigm, I.AM., brings robots to an unprecedented level of manipulation abilities. By incorporating this new technology in existing robots, I.AM. enables shorter cycle time (10%) for applications requiring dynamic manipulation in logistics. I.AM. will speed up the take-up and deployment in this domain by validating its progress in three realistic scenarios: a bin-to-belt application demonstrating object tossing, a bin-to-bin application object fast boxing, and a case depalletizing scenario demonstrating object grabbing.

○ Purpose of the deliverable

Deliverable D6.7 is a document summarizing the reflections and decisions of the whole consortium taken to ensure up the reaching of all milestones up to M30 (in particular, the experimental execution of the TOSS scenario), during the 1st year consortium meeting, that took place online on 25 February 2021.

This deliverable is a follow-up of the first document deliverable D6.4 delivered in M1, which focused on defining software integration and the numerical simulation of the TOSS. This deliverable will be updated in M30 by deliverable D6.8, which focusses on the experimental execution of the GRAB and BOX scenarios, and finally with a final update (D6.9) in M42, focusing on the final validation TOSS, BOX, and GRAB scenarios.

- ### Intended audience

The dissemination level of D6.7 is 'public' (PU) and available to members of the consortium, the Commission (EC) services and those external to the project.

This document is primarily intended to serve as an internal guideline and reference for all I.AM. beneficiaries, and it's scientific and exploitation boards.

2. PARTICIPANTS

During the 1st year consortium meeting (online via Teams, due to COVID-19 restrictions), the following participants were invited to present their progress in the project and discuss next steps on integration and TOSS scenario. A list of the affiliation / institutes / company short names in the third column can be found in Abbreviations section at start of this document.

Table 1: invited participants

Name	Initials	Affiliation
Alessandro Saccon	ASa	TU/e
Jos den Ouden	JdO	TU/e
Nathan van de Wouw	NvdW	TU/e
Maarten Jongeneel	MJo	TU/e
Jari van Steen	JvS	TU/e
Aude Billard	ABi	EPFL
Michael Bombile	MBo	EPFL
Harshit Khurana	HKh	EPFL
Saeed Abdolshah	SAb	TUM
Sami Haddadin	SHa	TUM
Alexander Kurdas	AKu	TUM
Ali Baradaran	ABa	TUM
Abderrahmane Kheddar	AKh	CNRS
Pierre Gergondet	PGe	CNRS
Niels Dehio	NDe	CNRS
Yuquan Wang	YWa	CNRS
Claude Lacoursiere	CLa	AGX
Fredrik Nordfeldth	FNo	AGX
Heico Sandee	HSa	SR
Teun Bosch	JLu	SR
Sjouke de Zwart	SdZ	SR
Marco Morganti	MMo	FRANKA
Kamal Mohy	KMo	FRANKA
Bas Coenen	BCo	VDLANDE

Stijn de Looijer	SdL	VDLANDE

3. AGENDA

The consortium meeting's agenda was the following.

9:00h - 9:15h: General intro and welcome

9:15h – 10:00h: WP6 Management and WP8 – Ethics (lead: TU/e)

10:00h – 10:30h: WP1 – Modeling (lead: TU/e)

10:30h – 11:00h: Break

11:00h - 11:30h: WP2 – Learning (lead: EPFL)

11:30h - 12:00h: WP3 – Sensing (lead: TUM)

12:00h - 12:30h: WP4 – Control (lead: CNRS)

12:30h – 13:30h: Lunch

13:30h - 14:00h: WP5 – Integration and Scenario validations (lead: Smart Robotics)

14:00h - 14:30h: WP7 – Dissemination and exploitation (lead: Vanderlande)

14:30h - 15:00h: Break

15:00h - 17:00h: General discussion:

- Preparation software integration Toss scenario
- Preparations for EC Review meeting (June 2021)
- ERF 2021 workshop (13/14 April 2021)
- IROS 2021 workshop

4. OUTCOME OF THE MEETING - ACTIONS AND DECISIONS

4.1. Actions

#	Description	Who	Added	Due	Status (28/06/2021)
1	Two Gitlab groups are currently used: TU/e Gitlab and Algoryx Gitlab. Algoryx wants to move all their applications to TU/e Gitlab and need a dedicated computer to have this running. Ongoing discussion about setting up pipeline for continuous integration.	AGX / TU/e	25-02-2021	1-04-2021	Decided to keep both Gitlab groups. Algoryx's Gitlab has now a working CI/CD pipeline in place, that helps in verifying software integrations/updates are working correctly. On TU/e Gitlab, there is now a Git project which is used to track any software and documentation update requests from the whole consortium and provide the current development status
2	"Scenario" section and "about" section, "vlogs" and "videos" to be added to the website.	TU/e	25-02-2021	By 1st review period	About section and separate videos added.
3	Twitter, YouTube, and LinkedIn are up and running. Partners are asked to use this more actively for dissemination of the project.	all	25-02-2021	Ongoing till end of project	Videos of ERFs have been uploaded on I.AM. YouTube channel. Partners' resharing/posting on LinkedIn has increased. I.AM. website also updated with pictures of new members.
4	Ensure compliance with the 'ethics requirements' -> check WP8 deliverables for guides	all	June 2020	Ongoing till end of project	Deliverables written and shared with consortium

5	Creation of a scenario document (continuation of MS1) to ensure up-to-date detailed description and software implementation of the TOSS, BOX, and GRAB scenarios are available to whole consortium	Smart Robotics Vanderlande, TU/e, Algoryx	25-02-2021	Continuous effort	TOSS scenario detailed, together with its implementation in Algoryx Dynamics (using BRICK) and simple mc_rtc controller also available as template for the whole consortium
6	Switching to using Algoryx Dynamics for parameter identification in place of MATLAB implementation	Algoryx, TU/e	25-02-2021	June 2021	Identification software is in place and TU/e will report about progress (also in form of one or more scientific publications) in the coming months
7	TOSS planner and controller in mc_rtc	CNRS, EPFL	25-02-2021	June 2021	Some planar results have been obtained. Generalization on 3D ongoing. Positive completion of this activity will correspond to milestone M7 success.
8	Create an integration document, to allow the consortium to prioritize activities in view of the milestones M3, M4, M5, M6, and M7 @M30 (June 2021) related to TOSS scenario (request by TUM)	TU/e	25-02-201	April 2021	Confidential document has been created and shared with consortium members: it contains explanation of each milestone (with must/should/could be done tags)

5. MINUTES

5.1. Meeting goal

Schematically, the main goals of this consortium meeting have been:

- Get project progress updates from all partners, discuss current research progress and future research, and discuss upcoming 5 deliverables.
- Prepare for the TOSS scenario that should be implemented by end of 2021.
- Preparation for finalizing 1st period in June 2021.
- Discuss European robotics workshop to show what I.AM. project is about.
- Discussion about the IROS conference (does it make sense for the I.AM. consortium to organize a workshop already?).

5.2. Organizational changes

New people have joined the consortium, some have left:

- Smart Robotics:
    - Sjouke de Zwart and Teun Bosch joined as robotics engineers
- Franka Emika:
    - Marco Morganti has taken over role of PI from Andreas Spenninger
    - Kamal Mohy is new member from FE
    - Andreas Spenninger (FE) has left FE in March 2021
- Vanderlande:
    - Jalte Norder (Vanderlande) will be temporarily replaced by new Program Manager Jesse Scholtes
- EPFL:
    - Harshit Khurana (EPFL) has joined the consortium as a new PhD member

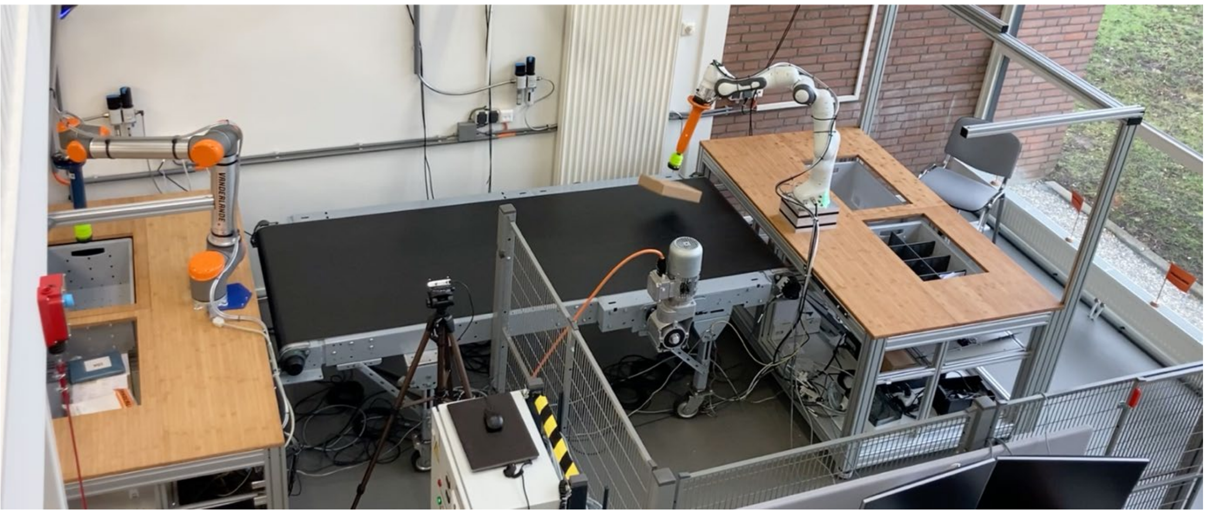
5.3. General introduction

The key points of the presentation by Alessandro Saccon were the following:

- The main goal of the I.AM. project is tackling the challenge of speeding up cycle times in logistics by exploiting intentional impacts between robots and its environment. In short: I.AM. enhances traditional pick-and-place with human-like grab-and-toss.
- The project is divided into 5 objectives (I.Model, I.Learn, I.Sense, I.Control, and I.AM) matching with corresponding challenges in impact aware manipulation.
- Three validation scenarios are defined for impact aware manipulation:
    - TOSS: Tossing an item on a conveyor belt

- BOX: Boxing items using impacts to more efficiently stack pallets
- GRAB: Grabbing swiftly boxes/cases from a pallet (non-zero contact speed)

- I.AM. focuses on existing robots (UR10, FE Panda, KUKA iiwa/LWR) to assess possibilities and limitations.
- I.AM. has now a fully functional setup for TOSS and BOX scenarios, available at Vanderlande Innovation lab at TU/e campus, shown in the picture below:



5.4. WP6 (Management) & WP8 (Ethics)

5.4.1. WP6 - Management

The key points of the presentation by Jos den Ouden were the following:

- An overview of the procedures, processes within the project is presented and status on deliverables is given. All deliverables so far have been uploaded. No questions from partners on processes.
- Three periodic reports should be completed including technical and financial reporting, RP1 regarding M1-M18 (1st report period finishes on **June 30, 2020**), RP2 regarding M19-M36 and RP3 regarding M37-M48. Review meetings will be aligned with the reporting periods. Input is required from **all partners** for Continuous reporting (EC Portal), Technical part of the periodic report, and the Financial Statements. 1st deadline for reports is end of August 2021. TU/e will coordinate.
- The environment for collaboration (file sharing, communication, meetings) is MS Teams, for which everyone has received and accepted invites. Gitlab is used as a software repository, which also contains LaTeX templates for writing deliverables if this is preferred over MS Word. Currently this is working properly, and all partners contribute.
- Two Gitlab groups are currently used: TU/e Gitlab (on TU/e server) and Algoryx Gitlab (on Algoryx server). Algoryx would prefer to move all their applications to TU/e Gitlab

(in view of making all developed software eventually open). Ongoing discussion about setting up pipeline for continuous integration and continuous delivery (CI/CD). Updates will be given later.

- 10 deliverables have been submitted so far. Next two deliverables coming up: D6.7 (TU/e) **June 2021**, linked to this consortium meeting, and D5.2 (FE) December **2021.**
- Peer reviewing process of deliverables can be improved. Proposal to send the version to peer reviewers **three weeks** before the deadline and set clearly beforehand who will be peer reviewers for what deliverable. Partners agreed on this.
- 18 milestones are defined to be achieved, 2 reports (MS1 and MS2), were both due in M12. More milestones coming up: MS3-MS8 until the end of this year, December 2021. These are input to the TOSS Scenario.
- Website has been up and running through. http://www.i-am-project.eu, described in D6.1, since February 2020. New people to the consortium should send a picture, name, and social media to **TU/e** such that this can be shown on the website. "Scenario" section and "About" section, "vlogs" and "videos" will be added to the website soon.
- Twitter, YouTube, and LinkedIn are up and running. Partners are asked to use this more actively for dissemination of the project.

ESAB (External Scientific Advisory Board)

- A meeting with the External Scientific Advisory Board was held on February 2, 2021. Invited external people: Oussama Khatib, Aaron Ames, Vincent Acary.
- 2 meetings with the End –User Advisory Board are to be planned for 2021 and 2023. First meeting being scheduled for April-May 2021 (lead: Vanderlande).

5.4.2. WP8 - Ethics

Regarding WP8, the following points were discussed during the presentation of Jos den Ouden:

- Objective: ensure compliance with the 'ethics requirements' in WP8.
- This is required for every partner. It is a continuous effort through the entire project.
- There are 4 deliverables regarding human participants in testing (D8.1, March 2020), personal data collection (D8.2, June 2020), participation of non-EU countries (D8.3, March 2020), and experimental safety (D8.4, June 2020). All deliverables have been submitted by TU/e and written with support of project partners. Information is shared within the consortium via presentations and deliverables.

5.5. WP1 – Modeling (I.Model)

Main updates for WP1 are the following:

- Objective WP1: The objectives of WP1 are the collection and (public) storage of recorded impact motions, identification of parameters for model-based impact laws and implementation of these impact laws in a commercial nonsmooth dynamics solver.
- Deliverables: There are 4 deliverables: D1.1 (Publication of I.AM. dataset), completed in September 2020. Deliverable D1.2 (Physics Engine API), due in June 2023. Deliverable D1.3 (I.Model), due in June 2023, D1.4 (Publication of I.AM. dataset), due in December 2022.
- Tasks: There are 5 tasks: T1.1 (database specification), T1.2 (impact data collection), T1.3 (implementation impact laws in nonsmooth dynamics solver), T1.4 (identification parameters model-based impact laws) and T1.5 (Modeling Benchmarks and Progress Definition)

5.5.1. Presentation T1.1 and T1.2

The following summarizes the results and discussion during the presentation of Alessandro Saccon.

Results:

T1.1 Specifications for the impact motion database:

- Deliverable D1.1 was submitted and the first version of the I.AM. Archive (HDF5 format) was uploaded. The taxonomy described in D1.1 will be mainly used to ease the search within the database.
- The first I.AM. archive provides the raw data from experiments but also contains lots of metadata to understand the experiments and allow for reproduction of the data (to comply with FAIR data structure).

T1.2 Data Collection of Robot-Object-Environment Contact Transitions for Robot Manipulation:

- TU/e now focusses on data acquisition of a bellows suction cup for holding and release phase of the package.
- TU/e also focuses on experimental work (on Panda robot): robot-environment impacts for the BOX scenario as well as collaboration with TUM on impact-detection and classification (unexpected/expected impacts).

Discussion:

- TU/e found it a bit cumbersome to program by hand trajectories for the Panda for recording impact experiments and it is therefore exploring the use of VR controllers for this to ease data acquisition in different impact configuration. Input from the consortium is welcome. Impact predictions however show promising results (as was experience in the past with KUKA LWR arm, before starting of I.AM).
- TU/e is developing visual tracking for impacting objects, to see if the tossing is successful (side-project to I.AM.).

5.5.2. Presentation T1.3

The following summarizes the results and discussion during the presentation of Fredrik Nordfeldth

Results:

T1.3 Physics Engine Interface and impact laws implementation for learning, planning, sensing, and control

- Algoryx will provide application suited for analyzing I.AM. dataset, parameter identification and validation.
- A Python application has been created for parameter identification (used by TU/e)
- Plan towards deadline in June:
    - Setting up CI/CD pipeline for code testing.
    - Use configuration files (BRICK) to improve usage of the application. With reusable models, hierarchical environment composition, parameter models, and application configuration.
    - New features: parameter identification and validation application (to be used by TU/e, to substitute what developed in MATLAB already by TU/e); start discussion about flexible suction cup model in Algoryx Dynamics for holding and release phase; Reset of the controller within mc_rtc and in the simulation scene of Algoryx Dynamics (allows to restart from new configurations at run-time).

Discussion

The current challenges we are facing are the following:

- What size of timestep to use? Impacts occur over a few recorded frames, while simulation time step is a single timestep (nonsmooth dynamics assumption).
- Conveyor belt model: maybe it should be modeled as a deformable object, including stiffness and damping of the contact surface.

- Suction cup model should be included.
- Might have to run in Docker (investigation still ongoing).
- Resetting for mc_rtc (CNRS) needs to be investigated.

Q(ABi): is it doable to model the conveyor?
A(FNo): we have several other projects where we did this, but we need to investigate it to see whether this is good enough/necessary, comparing to real data.

5.5.3. Presentation T1.4 and T1.5

The following summarizes the results and discussion during the presentation of Alessandro Saccon

Results:

T1.4: Validation and Identification of model-based impact laws:

- Toss scenario: Focus now on performing least squares identification for **holding** phase of the suction cup. Discussion on how to implement the model in Algoryx Dynamics has been discussed with Algoryx already and does not pose any significant challenge. Modeling of **release** phase is more complicated: due to fluid-structure coupling, made also more complex due to the **blow-off** (air injection in the suction cup gripper to speed up parcel detachment, typical in real applications). Fully model-based approach might not be ideal, discussion with EPFL is planned to further discuss this. TU/e can measure pressure inside the gripper and positions of all the components using motion capture system.
- Using a full rigid robot model with nonsmooth impact laws to predict gross velocity jump in a real robot. TU/e wants to use full rigid model (as the one implemented in mc_rtc) for prediction. Impact model predictions are being verified on the real Panda, discussions with Franka Emika are ongoing to get a better understanding of the experimental results. So far there are promising results, the main trend of the flexible system is captured by the rigid model. This means we can use nonsmooth models to predict the post-impact state, interesting for planning and sensing, as we wrote in the proposal.

T1.5 Modeling Benchmarks and Progress Definition and Evaluation:

- TU/e is currently comparing numerical impact simulations done with Algoryx Dynamics against TU/e MATLAB implementation of the same impact laws. TU/e also wants to perform model parameter identification on new box-conveyor impact data by using Algoryx Dynamics, in place of the MATLAB implementation: this will pave the way for the development of parameter identification software for the more challenging BOX and GRAB scenarios.

5.6. WP2 – Learning (I.Learn)

WP2 contains 4 tasks, regarding learning uncertainty models at impact (T2.1), an impact posture generator (T2.2), learning of impedance and dynamical systems for control with impacts (T2.3), and Learning of QP control weights, gains & impedance (T2.4)

5.6.1. Presentation WP2, T2.1, T2.2, T2.3 and T2.4

The following was presented by Aude Billard (EPFL):

- Tasks to focus this period: Learning of robot motions with intentional impacts and bimanual grabbing.
- EPFL has a dual iiwa setup and motion capture system from OptiTrack: HKh will present the progress on the single arm; MBo will show progress on the dual arm.

5.6.2. Presentation single arm setup

The following was presented by Harshit Khurana.

Results:

- Concept: Starting from simple manipulation tasks, pushing a box. Compute the optimal hitting velocity, having high velocity impacts.
- Create a dynamical system, linear combination of linear systems. The end effector must go to second attractor before going to the first attractor, where the first attractor is where the object should go.
- They demonstrate this in simulation in Gazebo. The auxiliary attractors are used to steer the end effector.
- An experimental setup is used to obtain results on real objects and learn what the object is doing after impact from data. An end-effector velocity of 1.1 m/s is now used. Running with different initial conditions, they collect data.
- A saturation of 1.1 m/s by the end-effector is reached, even though higher velocities are commanded.
- Try to get a probabilistic model from the experimental data.
- Given the desired final position of the box, now try to predict how one should impact the box.

Discussion

Q(NvdW): is there enough information to build the model? Configuration is not affected by the light weighted box, it is likely that heavier boxes would influence the configuration, how do you view this?

A(HKh): This is indeed something to investigate. Learning model can be developed to hit the object a bit below the COM of the object to make sure it will slide instead of tumble.

Q(NvdW): What are the uncertainties that you want to learn? Like coefficient of restitution, friction, are these the dominant uncertainties you try to capture?
A(HKh): These are indeed the main ones.

5.6.3. Presentation dual arm setup

The following was presented by Michael Bombile.
Results so far:

- Focus on dual arm grabbing and depalletizing.
- Tasks for grabbing and for lifting. This was achieved in the past, but now they want to speed up the process by making impacts. This means that after the impact the object should be stabilized.
- Implementation in simulation in Gazebo. Hitting velocity around 0.4 m/s, which is higher than what is set for I.AM. They are able to repeat the tasks multiple times.
- They demonstrate in simulation it is possible to pick up two objects at the same time for depalletizing.
- Demonstration shown of tossing with the dual arm robot a box into different totes, placed at different locations. Focus is to learn the "throwing parameters" (release position and orientation) to toss at a certain place. Currently, this is done from synthetic data.

Discussion:

Q(NDe): How to reach the desired release configuration and velocity?
A(MBo): Given the desired end position, they learn it from data what is required. Then they can be used to generate the trajectories to achieve this.

Q(NDe): are joint limits considered?
A(MBo): Yes of course, these are considered.

Q(FNo): Do you take dynamics of the object into account?
A(MBo): We use flying object dynamics, like drag, gravity.

Q(FNo): What about the impacts?
A(MBo): We focus on where the object lands, not where it comes to rest. What is now developed in WP1 will be used later, taking the impacts into account.

Q(FNo): The Python application from Algoryx can be used for this.
A(ABi): Yes, this will be used in the future. Communication with CNRS will also be established in the future.

5.7. WP3 – Sensing (I.Sense)

The following was presented by Sami Haddadin.

- The objectives of WP3 are:
  - Impact-aware estimation robot-object position/velocity/forces/contact states (T3.1).
  - Accurate estimation velocity and force estimation right after impact (10% velocity and force error).
  - Providing a fault recovery framework for dealing with contingencies (T3.2).
  - Improve robustness in the execution of intended manipulation tasks.

- A collision event pipeline is presented (T3.1) putting WP1, WP2, WP3, and WP4 into perspective, and presents a more detailed overview of the challenges related to WP3, including T3.1 (Validated impact models) and T3.2 (Reflex Activations for Fault Recovery).

Results so far:

- Four publications are pending (submitted and/or published) for T3.1, T3.2, and T5.5.
- Multiple methods exist regarding the isolation and identification of collisions, the momentum observer is the best and most used so far, but a new method, the observer-extended direct method (Recent method in joint-space, Birjandi 2019/20), is considered right now. There is also a new method in Cartesian space, the "Cartesian Direct Method".
- TUM has been building a framework to measure contact problems. So far, the accuracy of force measurements of UR robots is not sufficient. There is also high thermal drift in the UR systems, but very constant in the Panda system.
- Observer extended direct method: Accurate estimations of the joint variables by extending direct methods by an observer, therefore eliminate modeling errors.
- Setup: IMU for one joint, force plate as reference measurement. The momentum observer is a low-pass filter and limited by link-side position measurement bandwidth. The observer-extend direct method has the highest bandwidth due to multi sensor fusion and highest accuracy.
- Modeling errors are rejected via model-adaptive collision detection.
- Now, transform robot dynamics equation in operational space at IMU location and use the direct method with 6D IMU measurement to calculate external wrench.
- Still some problems with IMU noise, data not yet full verified against ground truth data. Results so far are quite promising.
- Research questions to consider in upcoming period: How to provide information for classification? Where to place the IMU's? (Not necessary with Cartesian direct method).
- TUM is also working on evaluation of human safety in impact aware manipulation.

Discussion

Q(YWa): We want to implement the detection of impact at CNRS, now happening at force measurements which is problematic.
A(SHa): What can we implement is the question. We want to make sure the methods work well for high frequency impact. We can then implement this on other systems, but it depends on the system, as it has some requirements. We can plan on that in the future.

Q(YWa): In the future would be possible on Panda?
A(ASa): Yes possible, also TU/e is in discussion to implement this.

5.8. WP4 – Robot Control (I.Control)

WP4 has four tasks: T4.1 Impact aware QP robot control. T4.2 impact model preview and adaptive control for QP control. T4.3 Stability, robustness, performance study of the impact QP control framework and gain tuning. T4.4 Control benchmarks and progress definition and evaluation.

5.8.1. Presentation T4.1 and T4.2

The following task updates were presented by Abderrahmane Kheddar, Niels Dehio, and Yuquan Wang:

- **T4.1**: Enhancing mc_rtc with impact awareness.
- **T4.2**: no results to show yet (starts M19 – July 2021).

More in details, the following was presented.
Results:

- CNRS to start with EPFL an impact-aware motion planning.
- At impact, a QP can become unfeasible at the next iteration because of the jump of state + feedback. Idea: Assume impact in the next iteration, use impact model to predict jump velocity and forces, rewrite constraint for QP, no additional decision variables required, add impact resilience constraints very easily, generate max velocity for desired impacts.
- CNRS submitted a paper for making impact with a humanoid robot, but received a lot of feedback, specifically about the impact models and friction models. They are revising it now.
- Presentation (YWa):
    - Integrate impact and friction awareness in the QP controller. The existence and uniqueness of the solution and the speed of convergence is a problem now (of the contact problem).
    - So far robot dynamics are not considered in state of the art.
    - Papers that do consider robot dynamics do not take impacts and friction into account, or only very simple models.
    - Good impact and friction models are needed.
    - So far achieved experimental validation from open-source C++/MATLAB code.
    - Future work: validate 3D frictional impact dynamics model on the Panda to obtain better post-impact state prediction.
- Presentation (NDe):
    - Investigation of how to safely impact a deformable object with the maximum impact velocity.
    - Core idea: Model-predictive control in task-space with mapped joint-space limits.

- Start with collecting data from force and velocity measurements.
- Challenging tasks: mapping the constraints from task-space to end-effector-space.
- Next: planning for tossing scenario in I.AM.

5.8.2. Presentation T4.3 and T4.4

The following task activity, main collaboration between CNRS and TU/e, was presented by Jari van Steen (T4.3) and Abderrahmane Kheddar (T4.4):

T4.3 Stability, robustness, performance study of the impact QP control

Results:

- A common view of the challenges in control with impact is important.
- A document highlighting these challenges will be shared.
- Current research focusses on extension of reference spreading ideas with QP control.
- Due to uncertainty in contact state, feedback information from joint velocities cannot be trusted.
- Possibly integrate ideas with dynamical systems approach using time-invariant vector fields as reference.

T4.4 Control Benchmarks and Progress Definition and Evaluation

Results:

- Panda interface for mc_rtc has been provided. TU/e and TUM are already working on it.
- At CNRS several end-effectors are being used.
- System is used with one mc_rtc controller, controlling two Panda robots at the same time.
- All sources and code are available (see slides for links).
- One of the main feedbacks so far: why does one need to use nonsmooth models instead of smooth models? Demonstration of this is very important.

5.9. WP5 – Integration and Scenario validations

The following was presented by Sjouke de Zwart and Teun Bosch (Smart Robotics):

WP5 has 6 tasks:

- T5.1 I.AM. Software Integration and Development,
- T5.2 Take-up and Deployment of Scenario 1 (Robot Tossing),
- T5.3 Take-up and Deployment of Scenario 2 (Robot Boxing),
- T5.4 Take up and Deployment of Scenario 3 (Robot Grabbing),
- T5.5 Evaluation of human safety in impact aware manipulation,
- T5.6 Scenarios Benchmarks and Progress Definition and Evaluation.

5.9.1. Presentation T5.1 and T5.6

Results:

Two milestone documents were produced, based on discussions between partners:

MS1 – Scenarios specification and interfacing architecture agreed (for T5.6):

- Compare the impact of I.AM. technology on the current industry.
- Key Performance Indicators used as quantification for comparison.
    - Current industry (bold is to be used for comparison *toss* in I.AM.) – **average cycle time, pick&place time**, mean time to failure/recovery, retry rate, **success rate.**
        - *Question: will only successful tosses be included in the pick and place/cycle times or also failed ones?*
    - *Box*: **average cycle time**, average pick and place time, **average mean time to failure**, retry rate/pickability, **filling degree.**
    - *Grab* (currently not applied in industry): **average cycle time, pick&place time**, mean time to failure/recovery, retry rate, **success rate, arms synchronization.**
- Test setups bin-to-belt and bin-to-bin created with UR10/Panda and conveyor.
- TU/e currently working with mc_rtc for scenario validation.
    - Currently, some issues with torque control in mc_rtc, discussions with CNRS ongoing.
    - Familiarization with AGX/mc_rtc URDF application.
- KPI's compared using Grafana dashboard. Jaeger tracing will be used for more detail in time breakdown.
- Success rate to be measured via Optitrack cameras.
- Filling degree can be measured with camera vision, which is not developed yet.

- Test setup for Grab scenario consists of 2 KUKA iiwa arms/FE Panda arms.

MS2 - Software policy agreed and shared repository put in place (for T5.1):

- Software should be accessible as there are novice and experienced programmers
  - Integration policies:
    - Gitlab set up at TU/e, integration with AGX Git to be still discussed
    - Minimize time taken for installation via install script on Ubuntu 20.04
    - No use of Python2 / MATLAB code (Python3 should be used)
    - Use of continuous integration (CI/CD) to continuously test code
    - License should be chosen for shared components
  - Architecture
    - Software should be modular
    - Components should be easily interchangeable
    - Hierarchy: one master configuration that can override all other configuration
  - Interfaces between AGX/mc_rtc, the two processes communicate over UDP/IP
    - **R(CLa):** also communication via ROS available, which EPFL is currently using

- Video shown for test setup at Vanderlande Innovation lab with Panda tossing box and UR10 placing item in box

Timeline

- Upcoming milestones:

  - June 2021 – Scenario 1 (Toss) performed in simulation + attempted on UR10
  - December 2021 – Scenario 1 (Toss) demonstrated on UR10 robot and on FE Panda

5.10. WP7 – Dissemination

The following overview was provide by Bas Coenen and Stijn de Looijer (Vanderlande):
Relevant tasks of WP7 are

- T7.1 - Requirements and recommendations for Exploitation
- T7.2 - Dissemination of the Project Results

5.10.1. Presentation T7.1 and T7.2

Main discussion points:

- Typical industry use cases shown for TOSS, BOX and GRAB scenarios
- Goal T7.1 - *decrease toss cycle time from 5 to 4.5 seconds*
    - Typical customers for toss scenario shown, e.g., DHL
    - Box types: regulars, smalls, irregulars, non-conveyables.
      Smalls are to be used in I.AM.
        - Handling process smalls: debagging, sorting, bagging
        - Parcel smalls types: 2/3 are regular carton boxes, others include envelopes, pack plastic, jiffy mailer carton/plastic
    - Applications toss scenario:
        - Infeed (pos accuracy: +/- 300 mm lateral direction, rot accuracy: barcode not down, short edge leading)
        - Low-speed sorter (pos accuracy: 400/600x400 mm, rot accuracy: barcode not down)
        - High-speed sorter (pos accuracy: 427x700 mm, rot accuracy: barcode not down)
        - Question Heico: would it be possible to toss in such a way that the barcode faces up?
          Answer Alessandro: yes, this is possible and in line with I.AM.
- Goal T7.2
    - Dissemination to industry and business/academia/research community
        - Vlog idea
            - Vlog made about I.AM. for internal use at Vanderlande shown
            - Show what we are doing in I.AM. project and share on social media
            - Write a script for the vlog for each of the main contributors to show what they are doing
        - Preparation of ERF 2021
            - Registered for a 90 minute workshop
            - Content to be discussed in this meeting
        - IROS 2021
            - TU/e is trying to organize a scientific workshop on I.AM. with involvement of TUM, EPFL, CNRS and AGX

        - The deadline for submission of the proposal is March 21
    - Communication to tax payers and general public
        - LinkedIn, twitter, website
        - It is requested to every partner to check whether they are following/sharing stuff on the LinkedIn channel

- **Q(AKu)**: is there a possible source regarding the data in the box types? Currently, information from master thesis Luuk Poort is used, but this is not a complete/exhaustive source.
- **A(SdL)**: The data currently shown is that of a customer, which cannot be used as citation. Will investigate if Vanderlande can share other data for this.

5.11. General discussion

5.11.1. Agenda

In brief:

- Preparation for EC review meeting (September 2021):
    - Financial and technical reports
    - Rehearsal of review meeting (2-3 days)
- Integration for Toss scenario
- ERF 2021 I.AM. workshop (13/14 April 2021)
    - Agenda & contents
    - Demonstrators (design freeze): time frame for video recording/vlog
- IROS 2021 I.AM. Workshop (28 March 2021 submission proposal)
    - Organizers/speakers
- Software integration status
    - Sharing overview and software architecture to consortium; setting up CI/CD
- Document review process

5.11.2. Preparations for EC review meeting

Main discussion points:

- Timeline up until EC review meeting shared
- Reporting period 1: (M1 till M18)
    - Each partner will receive a notification from EC Portal to complete:
        - Their own financial statement (and if applicable of their Third Party)
            - Each partner: update financial contacts on EC portal
            - Each partner: start preparing person month and budget expenditure for period 1
        - Their contribution to the technical part of the periodic report
            - TU/e will provide template and coordinate with WP leads
            - WP leads to coordinate and provide update of WPs
                - All partners provide contributions to WP lead
- Date to be set with Project Officer and external reviewers
    - Proposal dates
        - 2nd half of September (after 15 September because of ICRA submission deadline)
        - Not 23 September for SR
        - Doodle will be created
    - TU/e will contact PO to start process

5.11.3. Integration for TOSS scenario

Main discussion during the gathering:

- Goal: prepare integration of MS3-MS6 into MS7: software integration and numerical testing
- Organize an integration week in March/April (likely April)
    - Ideally this would be a physical get-together, but this is not likely to be possible with COVID-19 measures
        - EPFL already knows this won't be possible due to travel restrictions up till June 2021
    - According to AKe, physical get-together is not necessary for integration for simulations, ABi agrees
    - CLa does prefer physical get-together as the format for video conferences is limiting
    - Concrete goal for integration: have pipeline containing model for holding + release phase, and planning and control software to perform toss that is specified by a user in simulation.
    - This does not include parameter identification
    - No physical experiments before June
    - SHa: we should be paying attention not to integrate software too early. There are multiple levels of integration.
    - AKe: integration consists of agreeing of the methodology of the architecture, without necessarily having each component itself completed.
    - No full week required for integration; question is more posed by Alessandro whether this is integration week is necessary.
    - Concrete software: data collection on real experiments, not necessary according to Abder for the review meeting if you show that all the software bricks are in place, such that it is easy to show that it is possible to eventually achieve what we want.
    - The integration between AGX and CNRS is already implemented.
    - Architecture discussion with partners to set up first draft of architecture.
    - SHa: use the bottom-up approach for the implementation of the software architecture – both for simulation to real and vice versa
        - We must agree what the right quality of code is before integration (partially already described in MS2)
    - Issue with CNRS/AGX interface – attempt to understand each other, but this was initially difficult as partners generally lack understanding of the work of other partners, eventually, we did manage.
    - AKe: Image shown by TU/e might not be representative for other partners, as a detailed understanding of mc_rtc + AGX was desired for further tweaking

- Three partners (TU/e + Algoryx + CNRS) are well aware of the software integration, question is how to get EPFL and TUM more in the loop
- TUM is currently already using mc_rtc for control
- Integration should be an effort from the start, not in hindsight
- Good to understand what the ultimate purpose of integration is to understand what the priorities are.
- Q(Ake) to TUM: do we need estimators in the simulator/planning? A(ASa): not for June, but eventually yes
- R(SHa): divide and conquer the integration – focus on bilateral integration
- TU/e is to create a document regarding software integration, which will then circulate among partners
    - High level architecture integration
    - Toss scenario integration

5.11.4. ERF 2021 Workshop (13/14 April)

- 90-minute workshop
- Agenda & contents
    - Introduction of I.AM. project and goals of impact aware manipulation for robotics applications
    - Live video demonstration of the scenarios from Vanderlande Innovation Lab with help of TU/e and SR
        - Vibration measurements
        - Toss/box in conventional way and new way
    - Live demonstration from CNRS
        - Later discussions internally to determine what would be nice to show
        - Potentially grabbing box with 2 Panda's, tossing
    - Live demonstration from EPFL
    - Live demonstration from TUM
    - Discussion/poll leaded by SR on:
        - Current technology implementation
        - Possible other application areas
- Time schedule demos: 5-10 minutes each
- Purpose: mix of what is achieved already, and have an open discussion
- BCo will make a document with an outline + timeline

5.11.5. IROS 2021 Workshop

The I.AM. consortium has been discussing the possibility to organize a workshop about the I.AM. project (or, in general, impact-aware manipulation). Main point of discussions were the following:

- Agreed last consortium meeting to organize a workshop at IROS 2021 (instead of ICRA 2021)
- Proposed structure
  - Whole day workshop
  - 5 sections, 10 speakers
  - Poster and videos section open for external contributions (where we can also advertise I.AM. project)
  - 1.5-hour panel discussion
- Final deadline proposal March 21, 2021
- **Q(CLa):** Is workshop more application or research driven? If research, no need in Algoryx presenting.
- Advice ABi: dissemination via tutorials instead of via workshop
  - Tutorial might be too early for 2021
  - Workshop: should mainly be with external speakers
  - Poster highlight session / small slot for I.AM.
  - Do not have organizers and speakers both from I.AM in workshop
- Have speakers to inform Consortium instead of the other way around
  - Invite young researchers to present their work
- The methodology of impact-aware manipulation should be disseminated as this should be the main takeaway from the I.AM. project
  - Target for 2/3 tutorials
  - I.AM. consortium members can organize, but we should not call the workshop I.AM.
  - Whoever organizes, means they will not be speakers
  - The list of organizers is less important than the list of speakers according to Aude
- **R(AKe)**: if the workshop is not about promoting I.AM, the organizers should not necessarily be from the I.AM. consortium.
- Follow-up: Discussions will be proceeded via e-mails the coming days.

ANNEX 1: PARTNERS IN I.AM. CONSORTIUM

Table 2: I.AM. beneficiaries

#	ID #	Short name	Beneficiary name	Country
1	1	TU/e	TECHNISCHE UNIVERSITEIT EINDHOVEN	NL
2	2	EPFL	ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE	CH
3	3	TUM	TECHNISCHE UNIVERSITAET MUENCHEN	DE
4	4	CNRS	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	FR
5	5	AGX	ALGORYX SIMULATION	SE
6	6	FRANKA	FRANKA EMIKA GmbH	DE
7	7	SR	SMART ROBOTICS BV	NL
8	8	VDLANDE	VANDERLANDE INDUSTRIES BV	NL

ANNEX 2: STATUS ACTIONS FROM D6.4

5.12. Actions

#	Description	Who	Added	Due	Status
1	Check the interactions between WP & tasks and set-up bilat/telcos with the WP leads.	TU/e (ASa/JdO)	30-01-2020	February 2020	done
2	All partners to upload the presentations to the shared folder for internal use. The PowerPoint slides will be uploaded in the I.AM. website, once online (M3), for future reference (password protected).	all	30-01-2020	29-01-2020	done
3	AGX will develop an importer of URDF (eventually, SDF and SRDF) files for AGX dynamics. Furthermore, AGX will create an URDF file for Panda by FRANKA, containing estimated inertia and mass.	AGX	30-01-2020	01-03-2020	Panda available at TU/e with URDF
4	AGX will provide the partners with free licences of AGX dynamics, under the condition that they will be solely used for the scope of the I.AM. project.	AGX	30-01-2020	15-02-2020	Provided to TU/e. Can be provided on request to AGX.
5	Detailed specifications of Panda: FRANKA will provide missing details about some of the components of Panda (e.g., inertia, motor gear ratios, ...) to allow	FRANKA	30-01-2020	15-02-2020	done

	the creation of a detailed URDF (or similar) format of the robot for dynamic simulation under impact. Andreas Spenninger (FE) will discuss internally what the possibilities are and will report to the consortium.				
6	SR will inform the interested partners about the possibility of obtaining a bellowed suction cup for internal testing. This type of end effector will be used in the TOSS scenario validation.	SR	30-01-2020	15-02-2020	done
7	Study feasibility of mounting FRANKA Panda in existing SIR system (due to the different reach compared to UR10).	SR + FRANKA	30-01-2020	01-04-2020	done
8	Make available to the interested partners the impact data obtained on a tossing UR robot and recorded with an Optitrack Prime 17W 360FPS mocap.	TU/e	30-01-2020	01-03-2020	done
9	Contact the EAB, possibly enlarging its original composition to include other potentially relevant interested businesses. Set up a meeting to introduce the I.AM. project and collect feedback.	VDLANDE	30-01-2020	15-02-2020	Delayed due to shifting of priorities within Vanderlande. Date agreed: 29 June 2021
10	Contact the ESAB. Set up a meeting (ICRA	TU/e	30-01-2020	15-02-2020	Done, first ESAB held 2

	Paris?) to introduce the I.AM. project and collect feedback.				February 2021
11	TUM will share recent results on combining momentum-based observer (accurate/slow) with direct method observe (noisy/fast), to obtain accurate/fast external torque estimation.	TUM	30-01-2020	15-02-2020	done
12	TU/e will manage WP8 – Ethics and will provide 2 deliverables D8.1 & D8.3	TU/e	30-01-2020	31-01-2020	done
13	TU/e will manage WP8 – Ethics and will provide 2 deliverables D8.2 & D8.4	TU/e	30-01-2020	31-03-2020	done
14	All partners will check (use checklist provided in D8.1, D8.2, D8.3 & D8.4) and follow the guidelines of these 4 ethics deliverables.	all	30-01-2020	28-02-2020	Deliverables discussed and provided to partners via June 2020 consortium meeting.

5.13. Decision / open issues

ID	Decision	Described in:	Remarks
1	ICRA 2020 in Paris will be the venue for the next consortium meeting. To be confirmed via email in early February by each partner.	D6.4 (31/01/2020)	Due to COVID-19 no longer possible. Currently online consortium meetings.
2	Open-source software framework to be developed – type of open-source license to be agreed upon.	D6.4 (31/01/2020)	Ongoing
3	EPFL will explore further grabbing experiments, based on the DS approach when dealing with heavy objects	D6.4 (31/01/2020)	done

	and higher speed of motion of objects and robot. Data will be made available to the consortium as this could be already of interest for the I.AM. impact motion database.		