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

Minutes of the milestone review consortium meeting (focus: final validation TOSS, BOX, and GRAB scenarios)

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Control sheet

Version history			
Version	**Date**	**Modified by**	**Summary of changes**
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Peer reviewers		
	Reviewer name	**Date**
Reviewer 1	Alessandro SACCON	27/10/2023
Reviewer 2	Michael BOMBILE	27/10/2023
Reviewer 3	James RUSSEL HERMUS	20/10/2023

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ABBREVIATIONS

Abbreviation	Definition
EC	European Commission
PU	Public
WP	Work Package

1 INTRODUCTION

1.1 I.AM. 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 modeling, 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 close 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.

1.2 Purpose of the deliverable

Deliverable D6.9 is a document summarizing the reflections and decisions of the whole consortium taken during the final consortium meeting, taking place 9 & 10 October 2023 at Algoryx, Umeå, Sweden (and online in hybrid fashion), to ensure reaching all milestones up to M45 (in particular, the final validation of the TOSS, BOX and GRAB scenarios). This deliverable is a follow-up of the deliverables D6.4, D6.7 and D6.8 delivered in M1, M18 and M30 respectively. Originally the due date of this deliverable was 30 September 2023, but since the consortium meeting was scheduled later (9 & 10 October 2023), the actual submission date was postponed till 16 October 2023.

1.3 Intended audience

The dissemination level of D6.9 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 its scientific and exploitation boards.

2 Participants

The following participants were attending to present their progress in the project and discuss the final steps on validation of TOSS, BOX and GRAB scenarios.

Name	Initials	Affiliation
Alessandro Saccon	ASa	TU/e
Jos den Ouden	JdO	TU/e
Maarten Jongeneel	MJo	TU/e
Jari van Steen	JvS	TU/e
Alexander Oliva	AOl	TU/e
Aude Billard (online)	ABi	EPFL
Michael Bombile	MBo	EPFL
Harshit Khurana	HKu	EPFL
James Hermus Russel (online)	JHe	EPFL
Elise Jeandupeux (online)	EJe	EPFL
Stephen Monnet (online)	SMo	EPFL
Alessandro Melone	AMe	TUM
Ali Baradaran	ABa	TUM
Abderrahmane Kheddar	AKh	CNRS
Ahmed Zermane	AZe	CNRS
Léo Moussafir (online)	LMo	CNRS
Claude L'acoursiere	CLa	Algoryx (AGX)
Fredrik Nordfeldth	FNo	Algoryx (AGX)
Heico Sandee (online)	HSa	Smart Robotics (SR)
Ricardo Duarte	RDu	Smart Robotics (SR)
Steven Eisinger	SEi	Smart Robotics (SR)
Marco Morganti (online)	MMo	Franka Emika (FE)
Chee Hung Koo (online)	CHK	Franka Emika (FE)
Bas Coenen	BCo	Vanderlande (Vdlande)
Stijn de Looijer	SdL	Vanderlande (Vdlande)

3 Agenda

3.1 9 October - General Assembly

The agenda for 9 October was as follows:

DAY 1 - General Assembly - 9 October 2023		
Time slot (CET)	**Topic**	**Lead**
09:00 - 09:15	**Welcome and general intro**	TU/e
09:15 - 09:45	**Exploitation of I.AM. technology and scenarios (WP7+WP5)**	Vdlande
09:45 - 10:00	*Ques ons and discussion*	all
10:00 - 10:30	**WP1 – modeling**	TU/e
10:30 - 10:45	*Ques ons and discussion*	all
10:45 - 11:00	BREAK	all
11:00 - 11:30	**WP2 – Learning**	EPFL
11:30 - 11:45	*Ques ons and discussion*	all
11:45 - 12:15	**WP3 – Sensing**	TUM
12:15 - 12:30	*Ques ons and discussion*	all
12:30 - 14:00	LUNCH BREAK	
14:00 - 14:30	**WP4 – Control**	CNRS
14:30 - 14:45	*Ques ons and discussion*	all
14:45 - 15:15	**WP5 – Integration and Scenario Validations** - TOSS: completed (status resubmission D5.3) - BOX: TU/e update - GRAB: EPFL (quick overview, further details on day 2: 10 October)	SR
15:15 - 15:30	*Ques ons and discussion*	all
15:30 - 15:45	**WP7 – Dissemination**	TU/e
15:45 - 16:00	**WP6 – Management & WP8 – Ethics**	TU/e
16:00 - 16:15	*Ques ons and discussion*	all
16:15 - 16:30	BREAK	
16:30 - 17:45	**Discussion** - Franka Emika preliminary insolvency and D7.2 due 29 feb 2024 - BOX scenario plan and D5.4 due 29 feb 2024 - Roadmap and business cases D7.3 due 31 dec 2023	all

3.2 10 October - Discussion scenarios

For 10 October, the program was split into two parallel sessions, discussing in detail for the final demonstrators and deliverables for both GRAB (see Table 3.2.1) and BOX (see Table 3.2.2) scenarios as part of tasks T5.4 and T5.3, respectively, as well as their respective deliverables D5.5 and D5.4.

3.2.1 10 October - Discussion on GRAB scenario

DAY 2 - GRAB scenario - 10 October 2023		
Time slot (CET)	**Topic**	**Lead**
9:00 - 9:30	**GRAB concrete scenario (on KUKA and Franka Emika robots)**	EPFL
9:30 - 10:00	**GRAB modeling, simulation, validation status**	TU/e + AGX
10:00 - 10:30	**GRAB learning DS**	EPFL
10:30 - 11:00	BREAK	
11:00 - 11:30	**GRAB planning posture planner**	CNRS
11:30 - 12:00	**GRAB sensing**	TUM
12:00 - 12:30	**GRAB control**	CNRS + TU/e
12:30 - 13:00	**GRAB agreements towards demo and D5.5 due 31 mar 2024**	all
13:00	Lunch @ Algoryx	

3.2.2 10 October - Discussion on BOX scenario

DAY 2 - BOX scenario - 10 October 2023		
Time slot (CET)	**Topic**	**Lead**
9:00 - 10:30	**BOX concrete scenario**	TU/e + AGX + SR + Vdlande
10:30 - 11:00	BREAK	
11:00 - 13:00	**BOX agreements towards demo and D5.4 due 29 Feb. 2024**	TU/e + AGX + Smart Robotics + Vanderlande
13:00	Lunch @ Algoryx	

4 Minutes - DAY 1 - 9 October 2023

4.1 Meeting goal

General update of the work done by all the partners since 1 January 2023 (and most specifically last EC Review meeting) and discuss upcoming 6 months of work till the end of the project by 31 March 2024.

4.2 Organizational changes

- Marco Morganti (FE) joining online, Chee Hung Koo (also FE) joining online and for first time in the project
- Aude Billard (EPFL) joined online
- James Hermus, Elise Jeandupeux and Stephen Monnet (all from EPFL) joining the consortium meeting (online) for the first time in the project
- Steven Eisinger and Ricardo Duarte (bot SR) joining the consortium meeting for the first time in the project
- Teun Bosch and Sjouke de Zwart (both SR) left the project
- Léo Moussafir (CNRS) joining the consortium meeting (online) for the first time in the project

All presentations from the consortium meeting are to be shared on the I.AM. Teams environment under `/01_Consortiummeetings/20231009-20231010-MIDYEARconsortiummeetingatAlgoryx`. References to those slides are also made in this deliverable.

4.3 General introduction

A summary of the goals and roadmap of the I.AM. Project was provided. The key suggestions after the 2nd review meeting were summarized. The positive points are that I.AM. is considered an innovative project, that is likely to provide results with significant immediate impact. The areas of improvement regarding reporting include paying more attention to description of engineering aspects and better highlighting the role of simulations in impact-aware robotics. Regarding future work, see slide 21. It was highlighted that the TOSS report was rejected because of a lack of statistically relevant data in the demonstrator.

4.4 Exploitation of I.AM. technology and scenarios (WP7+WP5)

Vanderlande highlights the industrial context or each of the three scenarios (TOSS, BOX, GRAB), highlighting new drivers that are pushing innovatioin (in particular, changing landspace in packaging for GRAB scenario to reduce plastic and waste). Franka Emika showed progress on D7.2 on the business case and roadmaps for torque controlled robots in a logistics context. Higher payload and reach required.

4.5 WP1

Task T1.1 Specifications for the impact motion database, including Taxonomy of Contact Transitions; Already finished, no news to report. **Task T1.2** Data Collection of Robot-Object-Environment Contact Transitions for Robotic Manipulation; Data has been collected for the three scenarios (TOSS, BOX, GRAB) as well as generic impact and release motions. Currently, on three different setups (two at TU/e, one at Franka Emika). Other partners (EPFL, TUM, CNRS) have collected data but data is not yet uploaded. EPFL is taking clear step in this direction in the last months, in collaboration with the TU/e. The front-end of the website that contains the datasets was updated and the current contents are shown, including instructions on how to use the data and how to contribute with new data. **Task T1.3** Physics engine interface; Algoryx and TU/e further developed the GLUE framework (Algoryx employees visited TU/e during summer 2023). The structure of the GLUE application was improved during this visit. The GLUE Git project is now hosted on the I.AM. Gitlab hosted at the TU/e (see D1.2). Employees by Algoryx and CNRS are and have been involved in mirroring the repo. The GLUE framework can currently be used for synchronous communication between a physics engine (currently AGX Dynamics) and controller (currently mc_rtc) using the CLICK communication protocol, and for batch simulations using a physics engine (currently AGX Dynamics) without controller in the loop. HKu mentioned EPFL (EJe) also has already implemented controller with GLUE as well. GLUE will become openly available, and as agreed is not developed to work specifically just with AGX Dynamics or mc_rtc controller. An AGX Dynamics license is provided for three years to every member of the consortium. An interactive demo that can be used to understand the BRICK code was created and shown. **Task T1.4** Validation and identification of model-based Impact laws. Robot-surface impacts, continuation of a TU/e publication from 2017, showing that impact effects on the robot joint can be predicted accurately, if one knows the robot joint gains (torque controlled) sufficiently accurately (confidential information, in this case). Work has been submitted to IEEE R-AL. For the GRAB scenario, there is a collaboration ongoing between TU/e (MJo) and EPFL (HKu). An effort is made to predict the velocity jump at impact, measuring accuracy of prediction in terms of feedback in experiments. **Task T1.5** modeling benchmarks; overview of all the work done in the other tasks.

4.5.1 Questions

Update was clear, only minor questions. (**SdL**): How difficult would it be to redo some of this work on non-rigid objects (not boxes)? (**ASa**): Pushing objects would still be feasible. (**CLa**): Flexible bodies are also under evaluation from AGX point of view, bit more difficult. (**BCo**): From industrial point of view, we can also still adapt the environment to ensure more accuracy in for example tossing scenario; you can add an edge on the conveyor, for the object to land against, to ensure position/orientation accuracy. (**SdL**): Perhaps accuracy is not the correct measure, rather repeatability. At ERF 2022 we already showed that repeatability is something our toss robot is good at, even better then human.

4.6 WP2

Task T2.1 focuses on learning uncertainty models on impact. As a result of this task, two papers have been published. The first publication focuses on learning the release dynamics from motion capture systems for different masses in a one-dimensional case. The second publication focuses on filtering noisy rotational data (as, for example, obtained from motion capture systems). The approach here is to extend the Savitzky-Golay filtering to SO(3). This allows for estimation of velocity and acceleration of objects from motion capture systems, that can be used to validate models. Both these publications have been published in IEEE IROS 2022.

Task T2.2 focuses on the Impact Posture Generator for Dynamic Manipulation. The work presented here is an extension of the work that EPFL (HKu) has done before, that has been published in IROS 2021. The current work presented has been accepted as a publication in T-RO, which now includes an extension to have the desired inertia (hitting flux) reference included for the impact posture.
The second work related to this task focuses on unstructured environments. The goal here is to understand how to deal with unstructured environments in a factory. In the situations that are considered, the positions of the objects on a conveyor (here only boxes are considered) can vary, they can fall off from the conveyor, or the desired box position can be far away from the robot. The goal here is to position the robots to minimize the amount of robots while at the same time the goal is to maximize the workspace of these robots. There is an optimization that gives the optimal placement and orientation of these robots to achieve an optimal sequence of movements to reach a given point of the object. The approach includes modeling the reachable spaces of where the robot can go (robot workspace), and the object reachable space of where the object can be moved to by hitting. They learn the hitting function from experiments that gives the object reachable space via Gaussian Mixture Models (GMM). Using that, EPFL does an optimization problem. They either do a full optimization, where they maximize the likelihood of reaching a final position of the object, or a so-called "golf optimization". This golf optimization is inspired from the sport golf. So, EPFL focuses on the maximum likelihood in last hit, and using this information and solve for the first hit, which is less important. Both of these approaches work, but in current form, uncertainty is not yet taken into account. The second approach gives better results in terms of reaching the desired position of the box.

Next is to understand what the difference is between physics (numerical solvers) of PyBullet and Algoryx, depending on contact parameters. EPFL uses an air hockey setup for data collection where two robots are pushing an object from one robot to another. The next step is to understand how to hit and slide an object after being hit the first time.

CNRS update on T2.2. Goal: provide impact-driven posture generator. Work of former member Niels has been integrated. Goal is to create a planner for tossing. The approach has modular plugins. CNRS links model-based plugin to planning. Other tasks focus on performing dual arm grabbing motions as fast as possible. CNRS did an estimating on what is the necessary velocity/force to flip a box, to see what boxes can be rotated or are not "flippable". This was mainly shown in Deliverable D2.1. CNRS also submitted a journal publication at the end of September 2023, of which the details are also given in deliverable D2.2. In the coming months, CNRS will focus on investigating optimization based planning and other possible impact-tasks.

T2.3 EPFL presentation starts with brief summaries of previous work focusing on the coordinated control of a dual-arm robotic system for dynamic grabbing (with impact) and release of objects. So far two journal papers have been published out of this work. The first publication deals mainly with coordination control of motion and forces that allow a dual-arm system not only to grab but also to toss objects using a dynamical system-based approach developed by EPFL. The key concepts such as the coordinated dual-arm dynamical system's vector field and the dual-arm grabbing forces distribution under frictional unilateral contact constraints were illustrated. The main experimental results that validated the approach under various task perturbations were also recalled. MBo indicated that this work was also presented at ICRA 2023. The second paper extends the dynamic capabilities of the first paper by allowing the dual-arm system to grab and toss objects onto a moving target. EPFL (MBo) briefly recalled the main achievements, in particular: a mixed learning-optimization algorithm to compute kinematically feasible dual-arm tossing release states, an approach to learn the tossable workspace of a dual-arm system, and an adaptation algorithm to compensate for changes in the moving target's motion. Experiments of dual-arm successfully tossing objects onto moving targets with and without perturbation were presented.

In another work related to T2.3, EPFL presented ongoing research that focuses on the question of optimal feasible impact postural state in grabbing tasks. The work addresses the problem of determining the dual-arm impact posture, direction, and speed that will lead to the desired post-impact state or will favor the most post-grabbing task while satisfying the robot-object hardware constraints. The goal is to find what is the best configuration, as there are multiple possible solutions.
To address this problem, EPFL presented an optimization-based approach that, given the desired grabbing points and the desired post-impact state of the object, computes the corresponding dual-arm optimal impact postural state (robot posture, minimal pre-impact velocity) that satisfies the robot's joint limits. The presented method uses collision dynamics between bodies and the robot's impact map, and it assumes an inelastic impact between the two robots and the object taken in a sandwich. It also accounts for the object's effective force distribution between the two robots under unilateral frictional contact constraints. It is an iterative approach as it updates at each iteration the robot's posture and associated impact state by optimizing the directional inertia until convergence (no change in impact directions). Preliminary results of computed optimal feasible pre-impact velocities and forces corresponding to desired post-impact velocities of the object were shown.

In relation to the grabbing scenario, EPFL (MBo) also presented dual-arm pre-grabbing and re-grabbing maneuvers. On the one hand, the pre-grabbing maneuvers aim at extracting objects from a tightly packed pallet. They mainly consist of tilting the object to free part of the occluded object's surface for grabbing purposes. While such maneuvers could be quasi-static, EPFL focused on a dynamic approach which is faster. The presented approach consists of tilting the object using the two end-effectors until the object starts falling and then catching it through dynamic grabbing. Videos of this simulated dynamic pre-grabbing maneuver where the tilted object falls and is grabbed again by the dual-arm robot were shown. On the other hand, the re-grabbing maneuvers aim at enhancing the dual-arm grasp stability of a poorly grabbed object through "in-hand" re-position and re-orientation of the object. Such strategies can also be used to deliberately change the relative position and orientation of a grabbed object with respect to the dual-arm end-effectors. Hence, this results in a dexterous dual-arm in-hand manipulation. To achieve this, EPFL exploited the analogy between bimanual in-hand manipulation and bipedal locomotion and presented a bimanual in-hand gaiting strategy that generates appropriate sequences of relative End-effector contact steps. Currently, the gaiting controller formulation is based on MPC. Videos of simulation results showing dual-arm in-hand re-orientation and re-position of the object through hand gaiting were shown. Future work on these topics will focus on validating the proposed approaches on real robots, extending the re-grabbing controller toward a DS-based formulation, and including the impact awareness in the presented dexterous in-hand manipulation.
So far, the dissemination of this work package consists of six different publications (both journal and conference) and Deliverable D2.2.

4.6.1 Questions

- (**ASa**:) Are the simulations that are shown done using PyBullet? Or Algoryx? (**MBo**): The simulations are done using Matlab simulations and Gazebo, it has not yet been done in Algoryx or other physics engine, but EPFL plans on doing this in the near future.
- (**ASa**:) Is there any experimental work done related to the last work presented? (**MBo**): No, for the work done on hand gaiting, not yet. This is something EPFL plans on doing in the future months.
- (**SdL**:) It is interesting to see the link to industrial usecase, where we need to push, do you think what has been developed now can be transferred to practical use cases? (**HKu**:) Yes, we can for sure do this. We explore scenarios where different boxes can go to same place, but we also explore scenarios where objects can end up at different places. There will be a further discussion on this later during the meeting.
- (**ASa**:) EPFL is aware of what TU/e has done on control (reference spreading). Has EPFL used this in the current framework that is presented today? (**Harhist**:) That has not been done here yet, but would be interesting to do in the future. (**ASa**:) Would be good to implement this also in the future, as TU/e clearly sees an increase in performance, it would be a missed opportunity if this would not be done. (**HKu**:) Agreed, EPFL will consider this in near future.
- (**ASa**:) The terminology used by CNRS in the presentation might be confusing, it would be better to use a different term (referring to "Boxing"). (**AKh**): Indeed, the "Boxing" terminology was confusion from the CNRS side. But it is anyway important to show that what CNRS promised has been done. Furthermore, the work at EPFL is really impressive, for them to have a first step in MATLAB is good (as Algoryx has not been implemented yet). (**ASa**:) For the moment it is really good. Later, it would be nice to also have experiments and the implementation of Algorxy into their framework. I see a lot of potential to show that the integration of all the different parts work together. (**AKh**:) The breakthrough is really to implement what has been done on real systems. Current missing link is a fast identification of the inertia parameters, would be a very nice addition. (**ASa**:) I'm not sure if we have the resources and time to do this, this also depends on TUM and Smart Robotics. (**AKh**:) All the work we do we assume we know the parameters, we show we can plan and control, but if we do not know what we are holding, we cannot do anything. For certain tasks, you can do an offline parameter identification procedure. But for other tasks, we have to do an online identification of the object parameters (such as mass, inertia) via a motion that does not necessarily is part of the tasks. This is also part of the work done at TUM. (**ABi**:) Would be nice to have a discussion on this, as we have also been thinking about how to grab objects that have a changing inertia (e.g., objects that have a moving mass inside).

4.7 WP3

Task 3.1 is presented by TUM (AMe): RA-L publication on classification pipeline as collaboration between TUM and TU/e based on work of TU/e student, classifying whether an impact is expected based on a given intention. Unexpected behavior implies there is no guarantee the task at hand is completed successfully, implying that a corrective reaction (reflex) might be required. Classification is done based on a comparison between a physics engine (AGX Dynamics) and the sensor output of a real robot system.

AGX Dynamics is used to predict impact time + configuration, and a prediction of the post-impact joint velocities during 200 ms after the impact. Training of the classifier is done based on a small number of impacts (10-20) and configurations (2-3), and should be generalizable to a large number of scenarios.
Presentation by TUM continued by ABa. Collaboration between TUM and CNRS on robust Cartesian kinematics estimation for task-space control systems. Paper on evaluation of robot-manipulator link velocity and acceleration observer presented at IFAC WC 2023. Extension of this work to a journal paper is currently in progress, resubmission was asked.
Stable adaptive extended Kalman filter for estimating robot link velocity and acceleration submitted to IROS 2023.

4.7.1 Questions and discussion

Does the classifier generalize to different tasks? **(AMe:)**: it is not expected that the transient period directly after the impact can be properly predicted, but the velocity after a given time can be predicted accurately by AGX Dynamics, so this should generalize to different applications. Perception of unexpected behaviour in humans is around 0.3-0.5 seconds (perception to actuation, on trained individuals), similar reaction time desired for robotic applications, sooner not required. TUM setup is not very robust yet, but will be improved for integration with other I.AM. works.
To integrate the momentum observer on the KUKA, external force estimation is required. Force estimation through momentum observer by Franka Emika is currently used in classification. Measurements with Force/Torque sensor at TU/e reveal this estimation is very inaccurate, A force/torque sensor is more accurate, so might be better to implement for the KUKA. This is to be discussed in further detail later.
Model-based impact classification depends on the model parameters of the Franka Emika, which are confidential. Tuning based on the uncertainties in these parameters is hence required at the moment. This is possible since uncertainty to e.g. a few grams is OK, only big discrepancies between the expected and real scenario need to be classified.

4.8 WP4

Introduction: CNRS (AKh) introduces WP4. The objective is to extend robot controllers for impacts, integrate contact awareness, enhance the constraints with impact resilience bounce, and robustness in impact location and some modeling parameters. Enhance control with short-time horizon model preview control, swift manipulation exploiting deformable contacts in the beginning, and started to look into MPC governor to see if it can handle problems that are beyond the problem of impact. Last objective is control theory to assess the stability and robustness of the controller with adaptive stiffness, eventually coupled with knowledge developed in I-learn via closed-loop constraint feasibility and stability assessment. CNRS has a deliverable D4.1 that covers all the knowledge.

Task T4.1 (CNRS): control problems regarding dynamic contact transition. CNRS has incorporated task-space reference-spreading as a QP-formulation. The metric for evaluation is handling complex contact modalities and error in contact positions. At the start of the project CNRS has developed a task-space QP-controller called mc-rtc. Lot of things have been improved during the project, such as tossing, dual-arm grabbing, several modules associated with Algoryx, and it is made open source. Recently, CNRS integrated move-it as a planner in the whole framework as partners have asked for this to plan trajectories. Planner is now available (earlier with Niels no complete planner was available yet). One of the major contributions is to consider an approach to not change the structure of the QP-control while being resilient to impacts. Main issue with impact is that there can occur a jump in some states, most of these constraints are usually mathematical constraints in tasks space, in these dynamics models you sometimes have limitations in joint velocities. CNRS looks how to make the QP forward invariant such that it is feasible for forward steps. If there is an impact they have a model of the impact and can predict what will happen such that to make sure that next iteration the QP is still feasible. This has been done by Y.Wang and published in Journal of robotics research. Take off message: CNRS maintains the same structure of the QP but just add top-level constraints that are aware of impacts to make sure QP is still feasible for next iterations. For that CNRS did experiments to see how good they are in predicting post-impact impulses. This work resulted in 2 RAL papers, with the focus on models that are suitable for QP control. This is the reason why CNRS did experiments quickly and did not store this experimental data in the database, as this was a request from reviewers, and it needed to be done fast. The results would be too big for 1 paper, so they split it into 2 papers. CNRS wanted to be able to predict the post-impact velocity. It is written in a way that they are compatible with QP control and performed experiments with different impact velocities. Friction is taken into account into the modeling for the QP control and you can put constraints on doing impacts while being inside the friction cone. CNRS also did dual arm grabbing with humanoids to show this can also be implemented on different systems. They also use the same control to do the posture generation of the planning for the tossing scenario. The planning was done in WP2, but the control was done in this work-package. The planning needs the models of the objects (mass, inertia) and the model of the suction cup. Without it, sometimes you do not end up on the right spots, you need to take it into account in the planning. Two scenarios: lower impact imposed on the object (landing impact) or one where it does not matter. The planning part for dual grabbing was also done at the begin of the project, but now this is also completed. Furthermore, CNRS had a research focus on tilting boxes to allow for dual arm grabbing. The issue of rotating a box is that there is no single impact that makes all object rotate. Rotation of the box depends on the mass, inertia, etc. This work is also in line with the work of Brogliato of the rocking block.

Task T4.1 (EPFL): At EPFL, controllers have been developed for inertia-based dual arm grabbing. This depends on the configuration of the robot. The idea is to have a desired directional inertia and desired hitting speed. EPFL has developed a velocity tracker to understand how this can be done. Afterward, they move in the direction of inertia gradient regulated by a desired inertia exploiting redundancy (given one free DOF). Different approaches are compared, results in aligning the robot configuration in the direction of hitting. This has been published in a T-RO paper. Using KUKA iiwa 7, EPFL 1) achieve max flux for different objects, 2) achieve similar distance for different objects for collection, and 3) achieve similar distance for different objects. EPFL also does human to robot handovers. This leads to specific symmetric positive definite matrix of the inertia matrix. Provides inertia values in different directions (see slide 37). EPFL uses Stein Distance between SPD matrices, which shows how to get a desired inertia. However, this is not fully used in hitting. EPFL performs inertia reference generation using IK and motion manifold, an educated guess of the direction inertia. Minimizing joint velocities norm subject to the fact desired joint velocity and position and these have certain limits. With this, they can influence the desired inertia that is needed.

Task T4.2 (CNRS): For impact model preview, the approach CNRS took was to take one step QP control with constrains and tasks. Beyond the problem of impact there is the problem of understanding when the constrains conflict. There has been approaches in literature s.a. exponential barrier function such that the constrains are forward invariance, but no one has solved the problem of when the constraints conflict. If you want to do MCP, it becomes nonlinear. CNRS tried to use an approach that is not finished.

Ideally, one would have more time on the QP control, as on the fly you can add constrains to make sure it is feasible. If it conflicts in the future, the QP controller can be aware in that in a few iterations it can be conflicting, which allows to take action before. To solve this, one option would be to use MPC on whole body control, what CNRS still investigates. The first time they approached this was with grabbing experiments with former member Niels, where the MPC was really local. This is part of a paper that is currently published already. By using MPC on the pads that predict deformation, you can grab faster with higher impacts. If ones does not take into account deformation it is not possible to do do the impact without triggering the Franka Emika Robot violations. There is also new work in progress, but the people that were working on this have left CNRS.

Task T4.2 (EPFL). A small introduction to the new team members: JHe is a post-doc, EJe is working on Algoryx simulations, and Stephen is working on time optimal trajectory. The first work presented is that of Farshad. The problem is that QP-based controllers require precise models, where the solution contains a self-correcting QP using adaptive control law and a learned residual inverse dynamics model. EPFL shows a demonstration with adding unknown mass to the system, and with the adapted system, they can compensate for this. EPFL also did bimanual manipulation with unexpected mass added, and with the new approach, they can solve this problem. EPFL also did a few more tasks like pick-and place and with humanoids. The ongoing work focuses on bimanual throwing, and making the contact motion of the tasks. Given the end-effector's final position and velocity, they will determine the joint configuration of the robot which minimizes the inertia in the control direction. Next, EPFL will train a dynamical system from time-optimal trajectories generated with polyMPC. These trajectories are beneficial, as they are within torque, position, and velocity limits. Finally, EPFL will learn the optimal matrix $D(x)$ which minimize the kinetic energy of the system subject to dynamic constraints, stable contact dynamics, initial robot state, and final robot state.

Task T4.3 (CNRS). The focus here is on stability robustness performance. The first publication was an extension of a paper published in 2018 before the project started, at that time CNRS did not take into account the constraints. The metric of evaluation on this task contains formal proofs of convergence and stability, where the approach involves a method using computed torque control. CNRS started with a single toy example as presented in the paper, and noticed even without anything the QP controller can be unstable. So, CNRS focused on kinematic control, to understand what is the problem if one closes the loop, which is prone to instability due to non-robustness to non-modeled dynamics. This is shown on experiments with humanoid experiments. These experiments show that given external perturbation, the oscillations keep increasing. CNRS now has two papers: one closing the loop on the constraints to show how you should be careful to choose the constraints (RA-L) and the second published in T-RO notices if one adds integral terms in the cost function, it is possible to stabilize the QP in the closed loop. For the work on robust feedback QP for kinematic controlled robots, CNRS shows that by increasing the gains, at some point the QP will start to oscillate. By adding integral terms on constraints and the tasks of the cost function, by increasing the gains (there is a limit of course) allows to reduce the error faster, which allows one to move faster while maintaining stability. No further work will be done on this in the future, as CNRS has achieved what was wanted to show on making the QP robust. Furthermore, CNRS performed many experiments with humanoids. In these experiments, there is no specific focus on the impacts, as it is stressed that impacts in general are no different than other constraints for the QP solver. This does not depend on the nature of the tasks or the constraints. The take-away message is that if one designs a stable QP, it will also work for impacts.

Task T4.3 (TU/e). The topic of T4.3 covers the addition of robustness to QP control for impacts via extension of the reference spreading framework. TU/e shows experimental results in a T-RO paper currently submitted. The idea is to obtain a reference that includes the impacts via teleoperation, that allows to create references that include the jump in velocity. Then, the references are extended beyond the impacts and as a control approach, a switch is made from ante-impact mode to interim mode. In practice one will see not a single impact for dual arm manipulation, but rather multiple impacts, where in between the states, there is an interim mode that initially removes velocity feedback and slowly transitions to post-impact mode without seeing peeks in input signals. Compare the proposed approach to an approach without reference spreading or no interim modes, one can observe high input signals, while with the proposed method, these input signals are deminished. With no velocity feedback, one will get poor control performance. For future work, TU/e plans on extending this idea to not rely on actual experiments, but instead the idea is to use Algoryx to understand what the impact map looks like. Furthermore, TU/e also focuses on time invariant reference spreading, where instead vector fields are used that are coupled via the impact map.

Task T4.4 (CNRS). Task 4.4. includes a presentation of work focusing on control and benchmark of progress definition. The proposed control framework is used on all robots in the project, providing inputs for sensors and simulations. To support this, different interfaces have been developed for the I.AM project, including mc_click with Algoryx, mc_rtc_ros_control for UR, mc_franca for the Franka robot, mc_kuka_fri for the Kuka robot, and mc_iam provides hardware software integration. Ongoing work on I.Control from CNRS includes investigating a strict-hierarchy approach, a full planning pipeline, and sequencing impact pushing. CNRS is also doing work on fast computation by taking into account hessian, and CNRS is revising paper that is very theoretical on how to compute this, that goes beyond impact, where the authors consider QP as general framework of tasks and constraints. CNRS stresses that it would be nice to use optimal control, but also makes clear that this is not tested yet in scenarios of I.AM. This comes from a discussion that CNRS internally had with colleagues, who state that optimal control can solve part of these problems. On a dissemination level, CNRS shows that there are already many publications connected to WP4.

4.8.1 Questions

- (**AKh**:) Are we going to show the final integration of I.AM. by work package or by demonstrators? (**ASa**:) Something to discuss later on. We might merge work package and demonstrate final results on the different scenarios.

- (**ASa**:) one comment on "similar vector fields to DS", there is no vector field in intermediate mode, there is therefore a hybrid approach there (DS and trajectory tracking). The slides may have been confusing on this. (ABi mentioned that vector fields are not similar to DS, but are the same).

- (**CLa**:) how did you do the transfer from simulation to the lab, was there simulation before experiments? Did it work well? (**AKh**:) there are things we can and cannot simulate. For the moment, the titling of the box was from experiments directly. We did simulations with Simscape. (**CLa**:) question is if it is easy to go from simulations to hardware, also holds for Simscape. (**AKh**:) people use different tools for simulations, Simscape has a lot of libraries, but then if you want to do experiment where you need to test your controller, whether is robust or not, I think the simulation of AGX would be the right tool. Before going to experiment, I think people do simulations first to test certain variations first. In the lastest work, we first used Simscape, then MuJoCo, and if it works there CNRS goes to the real experiments. (**CLa**:) gap between results from simulations, how relevant is this for experiments, there is always a gap. (**AKh**:) big trend of differentiable simulations. If you want to simulate you have to inject noise, so how to solve this.

4.9 WP5

New members from Smart Robotics (SEi and RDu) introduced themselves.

4.9.1 TOSS: completed (status resubmission D5.3)

It is shown through integration on the Franka Emika robot tossing is 10% faster than placement. The D5.3 deliverable on the final integration of the TOSS scenario was submitted and rejected. To improve based on the reviewers' comments, a chapter on tossing repeatability has been added to the D5.3 report. The report is to be reviewed internally by TU/e. TU/e will contact SR again of follow-up if anything needs to be changed still. Otherwise, TU/e will resubmit the deliverable as soon as possible.

4.9.2 BOX: TU/e update

Work has been done on modeling of the suction cup, an overview of the mathematical model that uses only 5 independent parameters was presented by TU/e (AO). Given the high torsional stiffness, the corresponding stiffness cannot be properly identified for the considered types of motions. Hence, this parameter can be removed from the model without major consequences, leaving only 4 parameters. Results show the holding behavior is well-captured. The suction cup model can be used in the planner by CNRS, AKh agrees it is a good time to bring things together.
Regarding reality gap assessment for the BOX scenario, there are issues with sudo rights that are required to control the suction cup. CNRS might be able to help resolve this issue.
The friction model is also assessed for pushing boxes in the BOX scenario. In AGX dynamics, the friction model is anisotropic, leading to incorrect behavior is a box is pushed under an angle that is not equal to 90 degrees (but this depends on the specific solver setting used). TU/e is obtaining good results indeed with different settings.
Joint friction is not yet modeled in AGX Dynamics, which also creates a discrepancy between simulations and real experiments when torque control is used. AGX Dynamics can be used to also including joint friction. To be discussed further.
Comparison of estimated external force using a momentum observer versus measured external force with a force torque sensor show the momentum observer is highly inaccurate.

Questions:
(AKh:) what is needed to transfer the suction cup such that it can be used by CNRS. To transfer the suction cup model, three parameters, which are identified for the model, build a stiffness matrix plus a potential function. This model can be used by other partners. The model is more than the stiffness matrix, but the stiffness matrix is a part of the model that contains the parameters that need to be identified, it also depends on inertia and rotation matrix terms. The stiffness matrix in this model is constant. AKh is assuming the model with constant stiffness will be inaccurate for large deformations. TU/e explains this is not necessary the case. Discussions will be continued at a later state.
(BCo:) what is the sensitivity of the model on parameters that are affected by e.g. manufacturing? Parameters need to be re-identified when a different suction cup is used, but this is not expected to be a problem given that only three parameters need to be identified. Previously, cases like identifying the

inertia were not possible without a suction cup model. While inertia identification for the BOX scenario will likely not be done within I.AM., it is now possible with the presented suction cup model.
(AZe:) what force sensor is used? An ATI force sensor? Is the force sensor used for identification of the suction cup? Answer: no, the force sensor (a 6D Bota system SensOne) is only used for estimation of contact forces, the suction cup does not use any contact forces.

4.9.3 GRAB: EPFL (quick overview, further details on day 2: 10 October)

Setup at EPFL consists of a pair of KUKA IIWA lbr 7 and KUKA IIWA lbr 14 robots. Grabbing and tossing onto a moving target was shown using this setup. Integrations with AGX Dynamics, mc_rtc and ROS made. ROS has now been replaced with the integration with AGX Dynamics. Single-arm hitting and dual-arm grabbing in AGX Dynamics is successfully implemented.

The intended final demo includes hitting a box into the shared workspace of two robots, quickly grasping the box and tossing the box on an intended target. Integration of the full scenario is currently WIP.

CNRS has helped with an integration mc_rtc with the EPFL control framework. Sensing integration based on the results from TUM will be integrated in January.

The GRAB scenario has also been researched at TU/e, with the setup replicated at TUM. The silicone end effectors created at the TU/e are shared both with EPFL and with TUM. Integration with mc_rtc and AGX Dynamics has also been established. TUM and TU/e contributed on a demo shown at Automatica 2023, highlighting the potential for the GRAB scenario and showcasing its repeatability.

Discussion: **SdL**: for the BOX scenario, it is important to agree on the final demonstrator, which should be connected closely to the industrial use case, to prevent the issues that were there for the demonstrator of the TOSS use case. **Jos** agrees and says TUE and AGX (main organizers of this consortium meeting) was already planning to have a parallel session on 10 October (instead of the initially only set GRAB scenario) with both BOX and GRAB scenarios to come to concrete demonstrators for both scenarios.

4.10 WP7

WP7 was not presented anymore, due to time constraints. For new I.AM. members **JdO** made note that the slides can be found in the consortium meeting folder mentioned earlier in this document (see 4.3).

4.11 WP6 & WP8

WP6 is a management work package. Since the end of the project is getting close, only D6.9 the meeting minutes of this meeting is missing. After that, all WP6 deliverables are finished. AGX had a separate Git in the beginning of the project, but all relevant parts for the project and software have been moved now to TU/e IAM Gitlab. By the end of project, the final technical report is to be written, for which we will use the TU/e Gitlab as well. Overview of all the deliverables so far in the project: till end of 2022 20 deliverables were submitted, of which D5.3 was rejected by the reviewers. This year we already submitted 3 deliverables; there are 5 deliverables that still need to be finished (original deadline was 30 September, 2 weeks ago), of which 3 will be submitted next week. The official deadline was the end of September, taking already the new timeline of the project extension with 3 months into account. D6.9 was for obvious reasons postponed till after this meeting, because we have the meeting only 9-10

October. We had also 5 milestones that were due last week. MS14-MS18, MS14 for TU/e, MS15 and MS18 for EPFL, MS16 for TUM, and MS17 by CNRS.
The innovation radar for period 2 report: since 2020, the commission is also expecting us to provide input on innovation and patents (not just publications). A few innovations were already submitted at period 1 and period 2 reporting. If new innovations are developed by any of the partners, they should be shared. Innovation itself is vaguely defined: but should be directly applicable in innovation.
AKh: As a rule, companies typically take the lead in this innovation, as they are the one that are using it.
ASa: As an example, GLUE framework could also be an example of the innovation
AKh: Can also be software, also software can be patented. The companies should indicate if and how they will exploit the innovation. For instance for AGX, could be brick or GLUE.
Jos: Innovation, does not mean it should be a patent. From project point of view, we need to indicate which technologies we have developed, could be taken up into an innovation by industry (either within the project's time line and/or partners, or after project end / by other interested parties).
ASa: The Innovation Radar, is linked to a website where these things are shared (5 items on the innovation radar list for the I.AM. project). This Innovation Radar acts as a search engine for innovation. It is not only for IPs.
We have an external scientific advisory board (ESAB) and end-user advisory board (EAB); The EAB has been organised twice now, and the output of the EAB is to be incorporated into D7.2 and D7.3. Originally only 2 meetings were to be planned, but will aim to have a final one in November/December 2023, if time allows. Would be nice to have some people from Smart Robotics again as well. On Scientific advisory board (ESAB) we already organised this twice as well. We aim to organise a 3rd and final meeting online, just before end of project to provide the complete outcome to the ESAB on scientific side.
Further deliverabes on this WP, are all the meeting notes from other consortium meetings.
For this last deliverable, all partners should provide their slides to the Teams environment (see 4.3). Other deliverables were to tasks that were submitted early on in the project. Third and final submission on data management plan was done earlier this year.

4.11.1 Open topics

The three months extension that was proposed earlier by the PIs, was approved by project officer. Most (not all) deliverables were extended with 3 months accordingly and processed into current amendment AMD-871998-9. This amendment is still open and needs to be signed. However, in latest discussion with the project officer (mr. Baldyga), this amendment was kept open, because of the new situation with Franka Emkika filing for preliminary insolvency. Further follow-up is to be discussed with all PI's today. We need to decide if we need to continue or discontinue with Franka Emika as a partner in the project. FE is asked to provide the consoritum with more background information.
Franka Emika discusses current situation of the company. The consortium discusses how to continue. There is the possibility of terminating the participation of the company as partner in the I.AM. project. Franka Emika is doing all possible to complete deliverable D7.2 anyway.

4.12 Discussion

4.12.1 Franka Emika insolvency and D7.2 due 29 feb 2024

Franka Emika has filed for preliminary insolvency. However they are actively working on finishing their final deliverable. MMo is working on finishing this deliverable by end of October and is requesting now input from industrial partners. SdL (Vanderlande) and HSa (Smart Robotics) committed in reviewing this deliverable. SdL mentioned to focus on making the payload more concrete (which is bit unclear in the current version of the deliverable).

4.12.2 BOX scenario plan and D5.4 due 29 feb 2024

Q: Is it required to include the suction cup model in AGX? A: Yes, this would be preferable for an evaluation of the model and should be done as soon as possible.
Regarding the final demonstrator of the BOX scenario, Smart Robotics should take the lead, so we will discuss after the new members (RDu and SEi) come up with a proposal.

4.12.3 Online seminar on GLUE/RACK for dissemination to robotics community

Proposal to disseminate software by ASa: create an online event that is advertised in advance, expected to have good attendance and shows engagement with the community. Can be organized by TU/e and/or Algoryx.
AKh mentions there are problems in organizing a tutorial online, given that there are problems regarding time zones. Two events can be set up, one in the morning and one in the evening, to circumvent this issue. Estimated to be a minimum of 20 people that are interested.
The online event won't be a tutorial, instead it should include pre-recorded videos and a presentation on the software framework. Interested attendees can then download the GLUE software, which is publicly available, and use the software afterwards by using the three year AGX Dynamics license.
A paper is to be created out of the D1.2 deliverable by TU/e, Algoryx and CNRS that also can be used to disseminate the software to the community. Ideally, this paper should also be finished before the online event, if not possible, the D1.2 deliverable is publicly available and should be mentioned in the online event.

4.12.4 Roadmap and business cases D7.3 due 31 dec 2023

No need to be further discussed. TU/e and Vanderlande aligned to involve input from EAB (to be planned November/December 2023 still).
BCo suggests to make a gap analysis based on the original table from paragraph 2.1 table from the original Grant Agreement (page 29). Could be a paper exercise.
Based on Vanderlande data on different specific human GRAB motions (e.g. grasping box from a corner or from the side), we could compare quantitatively with the time it takes a robotic system to execute the same type of motions.
BOX integration will be a combined effort between TU/e, Smart Robotics, Vanderlande and Algoryx. SEi and RDu are going to familiarize with the setup used for the final demonstrator. The contents of the demonstrator will be further discussed in a session tomorrow, in parallel with a session describing the GRAB integration.

5 Minutes - DAY 2 - GRAB scenario - 10 October 2023

5.1 Meeting goal

Discuss and agree on the BOX and GRAB scenario.

5.2 General announcements

JvS joins online from the hotel due to illness. The consortium will be split into two meeting groups, one group discussing GRAB (ASa, JvS, AKe, AZe, ABi, MBo, HKu, JH, EJe, SMo, AMe, SvL, CLa) and one discussing BOX (MJo, AOl, JdO, BCo, SEi, RDu, FNo, LMo).

5.3 Presentation

Presentation by MBo on Grab scenario to guide the discussion. The key points of the presentation were:

Task requirements or expectations as per the proposal

- perform fast depalletizing motions with an average cycle time of 6 s
- demonstrate fast-moving grabbing motions involving impact events such as:
  - hit to push,
  - hit to tilt,
  - catch a falling case,
- showcase of robustness to various disturbances (moving or tilting the object unexpectedly, generating impact at unexpected locations).
- generate nominal and contingency motions with intentional impacts and matching impedance

Technology readiness level
Scenario 3 (GRAB) targets TRL 4 with a primary strong impact on feasibility demonstration in a lab environment and science advancement.

Integration requirement of the different I.AM modules
This task integrates and validates level 3 of the four objectives (I.Model, I.Learn, I.Sense, I.Control).

Description of a proposed concrete scenario
We envision a scenario where a dual-arm robotic system performs dynamic object grabbing in a depalletizing task of a tightly packed pallet. The dual-arm robot is expected to empty the pallet by successively grabbing and tossing (placing) objects onto a conveyor belt. For objects located in one robot's workspace but not in the shared workspace of the two robots, one arm is expected to hit the object to bring it into the shared workspace for dual-arm grabbing.

The task implies grabbing non-isolated boxes from a pallet and its main challenges come from:

- the restricted access to stable grabbing points (boxes too close to each other);

- the reduced collision-free workspace (due to the number of objects).

The Solution will involve **pre-grabbing maneuvers** to ensure access to stable grabbing points on the target object. These maneuvers thereby will allow the extraction of the object from the pack of boxes before its actual dual-arm grabbing. As pre-grabbing maneuvers, we will consider tilting the object around horizontal axes. Hitting and sliding the object will also be considered.
The solution will also involve contingency motions to allow **dual-arm re-grasping** of poorly grabbed objects to improve their grasp quality. In the same vein, dual-arm in-hand manipulation to give to the tilted or rotated object an in-hand desired relative pose will also be considered. Finally, once an object is grabbed, the dual-arm system will either place it or toss it onto the conveyor belt.
A block diagram summarizing the above steps is given in Figure 1.

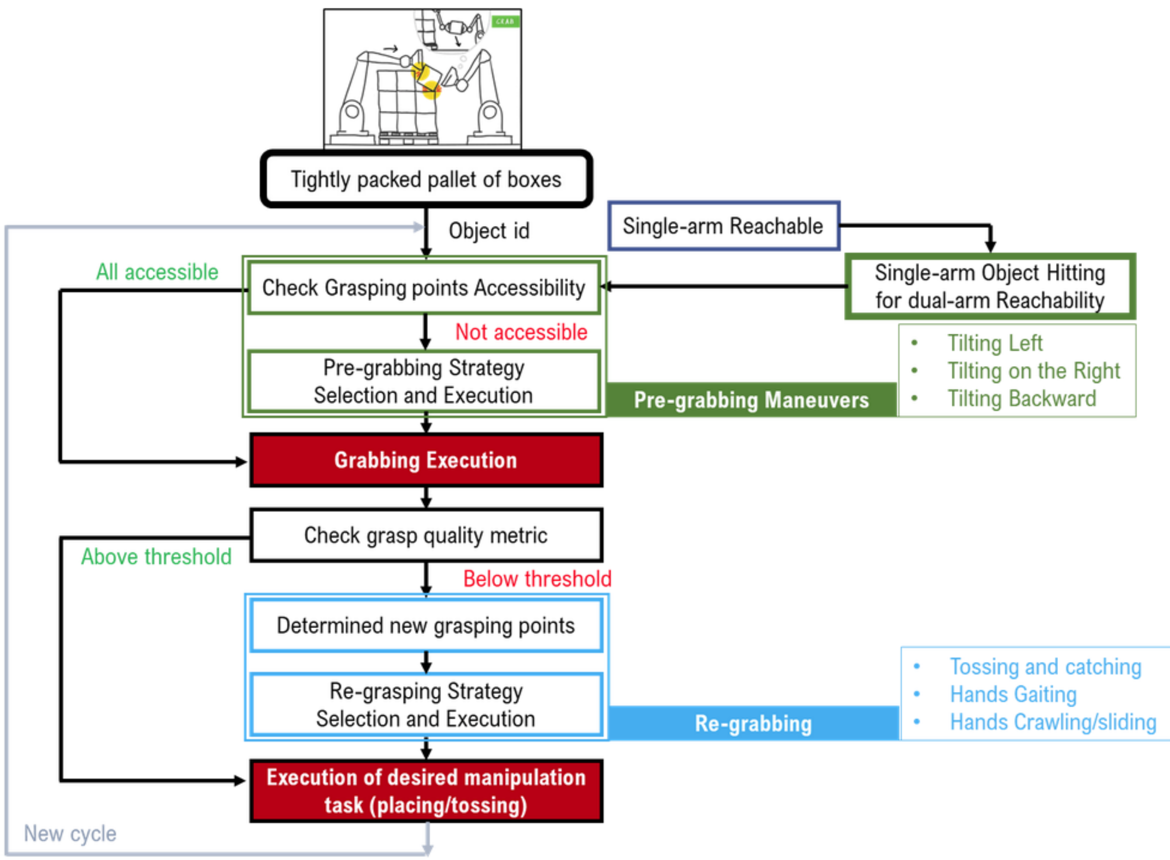

Figure 1: Block diagram summarizing the integrated steps for the grab scenario

5.4 Discussion

This section covers the main points of the discussions that took place during and after the presentation (MBo) described above. They have been grouped according to topics.

5.4.1 GRAB Scenario Setup

MBo: Regarding the grab scenario already implemented, we see that four institutions have already implemented the scenario. We have ours (EPFL), CNRS, TU/e, and there is also TUM I think now they have replicated the the dual Franka grabbing. As per the proposal, the idea for a scenario is to have a depalletizing of fully or tightly packed pallet. So we have a pallet with multiple boxes. And the goal is to have the dual-arm robot to fully remove all the boxes from the pallet. Our idea is to grab then and toss them, because it may be difficult to place them depending on the available free workspace. We can pick the boxes from the pallet and then toss then unto a conveyor belt that carry them until the palette is empty. This means that the robot need to successively go, extract and pick each and every box. Those that are free are grabbed directly, but for those that are occluded, we have to extract them first and then grab and toss them. In the process, if any box fall off the pallet but it is still reachable by one of the robot, then it possible to push or hit the object to bring it back in the joint workspace of the two arms so that it can be grabbed. This is illustrated by the simulation that EJe showed and we can show it again if necessary.

ASa:We also have this discussion. I fully understand that this is interesting, and we need to to showing that you can push things around, you can move them around. Operators typically do this type of motion. Also, sometimes you don't always lift things, you also push them. Sometimes it's just placing them. Nobody has been looking at, you know, placing it with impact.

SdL: I like that you put a tightly packed pallet because depalletizing that is exactly the scenario where you also need this tilting motions. So that's good. What you see in depalletizing is that you also have a lot of shifting. So you're not necessarily lifting object, but you're also shifting it. The tray is stationary there. You also use moving trays. So that's something to discuss there. We don't typically see operators doing a lot of tossing because it's quite confined space. And you typically use one to four objects in it. So it has to be quite precise. But this also triggered, for me, the truck unloading scenario that I also showed yesterday.

MBo: In fact, the tossing was also inspired by the truck unloading where we have a dynamic manipulation not only in terms of picking but also the way [the operator] was putting on a conveyor belt in a more dynamic way. Of course, the human was much more elaborate because he is able to rotate the objects, sometimes change their orientation, and put them. But the dynamic aspect, not only in picking and also in releasing is an interesting component that can also be shown.

ASa: Clear. But we should be careful to not mix different scenarios (truck unloading and depalletization) from industry. But, in any case, very good if we can demonstrate different types of manipulation motions

SdL :Everything is in an ergonomically designed workstation. And the pallet is on the same level as the sliding table for the operators. And that is also on the same level as this tray because the bottom of the tray moves up when it's loaded. So it's all on the same level. You can also slide objects.

AKh: What you are showing there, I mean the workspace wouldn't allow the two arms to rotate. So that's the reason why I think having the grab and tossing it is much more easier to do than rotating, which is likely impossible. The workspace of the dual-arm is not the sum of the workspaces. If you take the box out, it's even less. Don't see it like a human arm. It's far from it. Frankly speaking, I don't know how much you can rotate, but if you have a palette where there are several boxes, it's already complicated to grab all the boxes. I'm not sure that they will be able to do them because of this workspace.

HKu: I understand we need to have a tightly packed pallet, but what changes is the fact that how many part of the object is available for you to actually work on. There might be another object on it, or it might be on the top layer. It might have just one face available or two faces available for us to grab. So potentially we can just create that scenario with 2 or 3 boxes together that we are basically saying that right now, this is representing a scenario where you only have these faces available. And what would you do in such scenario? We don't need to utilize 10 boxes so that the entire space is too crowded. We just need to show that this is part of this particular tightly packed. It could be in the corner., it could be in the middle or the top layer. So if that basically is a valide representation of a tightly packed pallet, we just need [the boxes] on one side and just take and put [them] on the other side.

5.4.2 Presentation format of the demonstrator

ABi: We should step back a little bit because I'm a little worried that we are going into an incredible level of details, but that project is called impact. And I want us to go back to science. What do we want to show? So I'd like us to rather think in terms of what is the complexity of the manipulation that we want to showcase, and the level of complexity of the type of manipulation we can do, as opposed to know whether we have a conveyor belt or small workspace. To not losing track, we are not developing a robot arm that can depalletize in industry. We are developing a set of algorithms that can then be possibly deployed. And also, I am worried about us not going into the discussion of how do we showcase the complementarity of the different themes, especially between CNRS and EPFL?

ASa: For me this is also research innovation action. So the innovation for me is also important. If this would be an ERC grant, I would fully agree with you. I fully understand that we should not just build a robot aiming at depalletizing. But to me, we should not only stress on the scientific part, showing that this technology can have a potential is also important.

AKh: First of all, it's not a binary choice. The most important thing is that you can showcase the science. This is the reason why I wanted to know at the beginning, how are we going to present this? Because this is very important in the European project to say, what are we going to present and how, for which purpose? So in the video we can relate the story of the the ingredients of each demo, how they started, what is the science behind and then showcase at the end. What is the outcome in an ideal spectrum? So I tend to agree with both. In fact, because it's true that it is an innovation action, and it's also true that we have to show what is the science behind.

ABi: What I wanted to say is if I were to present this scenario, I will really go by challenges. What is difficult when you pick up an object and you depalletize it? And then we have to really spell out. What difficulties could be solved by traditional engineering and what needed to be developed in order to tackle this challenge. And this is the way that I would present every single application and then showcasing the different contributions of the different partners. Even if it's innovation.

ASa: So we were talking about challenges. We can discuss those challenges first. I think what JvS showed yesterday is an example where you can see that there is a problem with trying to execute these motions when simultaneous impacts are occurring. That is for me one challenge that is clear. And then all the motions you showed yesterday is also another challenge. So I think those challenges are clear. We can of course make a list. But I'm a little confused of why we have to discuss the challenges now.

ABi: Because if you know what you want to show, the challenge that you want to display, it doesn't matter if you have a conveyor belt or if you're putting it from a rotating or not rotating the object, because this is not the core of what you want to show. I just want to ask what the challenges are when you depalletize. To me, the first challenge is perception of the stack of boxes which all look alike and it is hard to tell which one is where, we're not solving that in the consortium. Another challenge is the adaptation to the unexpected changes of the object inertia or mass distribution (box with object moving inside) when tilting, picking or tossing. It is important to be able to immediately identify some of the physical properties of the object as we go. This is novel and very different from engineering.

ASa: I fully agree, of course, we have to say and this is also in the proposal that vision was not part of what we wrote. The part of the adaptation was a dream that we discussed with TUM. While this is interesting indeed, we have only six months to go and and the idea that we want to do other research and then try to stitch things together at the last moment is less realistic. For me, can we take whatever we have developed and try to put them together?

HKu: But for now, whatever we have on the Grab scenario, how can we combine them together to show a demo? So first we discuss whatever research we potentially possess. And we also see currently what those researches are actually tackling. And those tackled problems should be in the grab scenario.

AKh: I kind of agree with what ABi have said. Let's list what is difficult, what is challenging and how we want to show it. Then once this is listed, then we take what you are asking. So what are the technology that are already available inside the partners that you could integrate.

5.4.3 GRAB Demonstrator Description

MBo: In this demonstration, we want to start with a tightly packed pallet and assume the vision problem is solved. First, we need to identify if it's possible to grab the box. If not we need to execute a pregrabbing strategy. Once the box is isolated we can move forward to the intended task. An example of this could be a tilt to grab or a hit to grab. These are examples that were discussed previously. We would like the final demo to exploit combinations of these types of behaviors as explained in the flow chart in the slides.

SdL: Have you also tested already grabbing multiple boxes at once?

MBo: At least for pre-grabbing maneuvers, we have solutions. For instance, when there are three boxes to be grabbed and tossed, we could employ a variety of techniques. We pick one, extract it, and leave two behind. Then we simultaneously pick those two, followed by flipping and grabbing the last box. The goal is to showcase diverse challenges and the solutions devised through the system. This will, of course, necessitate seamless integration of solutions from different partners.

ASa: We're addressing challenges in teleoperation, particularly in managing simultaneous motions and their potential discrepancies. Our goal is to develop more efficient motion control methods and compare their success rates. We've summarized this research in a paper presented by JvS and submitted to

IEEE T-RO. We'd like to share the paper with EPFL and CNRS for feedback and to discuss potential integration. This paper represents a decade of research at TU/E, emphasizing a dynamic system approach before and after motion execution.

MBo: The idea behind this initiative is to leverage existing solutions and add new components within the next six months. We aim to create a scenario that not only highlights the technical and scientific challenges but also addresses industrial aspects, as some reviewers have an industry background. Our approach involves highlighting the scientific problem, presenting a solution, and showcasing integration.

In our process, we introduce a pre-grabbing level and, after grabbing, assess the object's stability. Typically, if an object is easily accessible and stable, we proceed with our tasks such as placing it on a conveyor belt, lifting, or tossing. However, if the object is not securely grasped, we need to adjust our approach dynamically, ensuring stability throughout the task. This means that the algorithm must assess stability on the fly and, if necessary, execute a re-grasping maneuver.

ASa: Indeed, AMe's work aligns with this. If we merely label something as successful or not, it's a limited classifier, as it only signals issues when things go wrong. The real challenge lies in identifying what specifically failed. In the upcoming months, ASa will be tackling this problem, which includes cases like unexpected weight, a glued box, or immovable objects.

AMe: Regarding this matter, we initially began with binary classification. However, as we move forward, it's essential to determine what precisely we aim to classify, as it extends beyond a simple binary choice and encompasses multiple categories. The main issue is what we intend to classify and whether both have reflex actions to be classified. These aspects are related, or else it wouldn't be logical.

ASa: It circles back to what I mentioned earlier. The challenge is to classify effectively while considering the relevant reflex actions. We can't classify everything; it's an engineering matter. However, demonstrating a specific classification like this is relatively uncharted territory.

ASa: I'm perfectly fine to keep it that way. We just have to be reasonable given the 6 month timeline.

MBo: I recommend specifying particular failure types for the demonstration, keeping it simple. Research can later explore more complex failures. This way, we'll have a manageable scenario for the demo.

ASa: Your clear schematics are highly beneficial. One suggestion is that similar functionality could apply to this maneuver. The aim of the collision monitor they're developing is continuous operation, usable in various stages like grasping and pre-grasping, helping us make informed decisions.

5.4.4 GRAB Scenario Benchmarks

MBo: Various KPIs were determined, and a preliminary report on Grab specification exists. This report outlines the tasks and the associated KPIs. In summary, it includes metrics such as the average cycle time, average peak and place time, and the mean intersection. The intersection, which I believe is linked to single-arm tossing, is not yet covered.

SdL: Can we compare not only toss but also toss and grab?

ASa: We only have six months. So I think it's important to be practical. I think it's important to decide on the benchmarks. In addition, is there any science that is important to do at this point?

ABi: Overall, those metrics are fine. But again, bringing us back to the very title of this consortium, we need to have metrics that measure impact.

JvS: In terms of global impact metrics, speed is a key factor. The speed of operation and task execution are crucial components of our overall impact assessment.

ABi: No, I had in mind rather the force of contact. We wanted to neither damage the object nor damage the robot. So it would be interesting and also energy efficiency, which is related. So essentially we're talking about the energy or the forces at the impact. So if you could have metrics that do measure that, we are achieving what we wanted in a better way than traditional pure position control for instance.

JvS: I do agree energy efficiency might be a nice addition. If we can show that what we do is more energy efficient. However, I would still say that if you are able to execute a motion faster without damaging anything then time is quite a good measure of successful manipulation.

ABi: I agree. If we design the depalletizing task with various types of items—some fragile, some very heavy, and others solid—we can combine different impact prediction algorithms to determine how to handle each item. Our goal is to ensure that we don't damage either the robot or the items.

For instance, consider a very heavy and rigid box that we shouldn't handle at full speed to avoid robot damage. On the other hand, there's a light, fragile box where full speed is also not suitable to prevent item damage. Then there's a box in between, highly deformable and capable of absorbing impacts. The challenge is to demonstrate that we can handle all three at the same speed without causing harm, which would be a valuable achievement, especially in a collaborative effort between the three teams.

ASa: One additional challenge is the control of robots with torque or velocity. As I understand it EPFL does torque control and CNRS does velocity control. Is that correct?

ABi: Yes, Alessandro you are touching on a point which we should discuss. We must either compare the two approaches or merge them. If we keep both, a comparison with both methods would be quite useful.

5.4.5 Grabbing Impact

ABi: So, do we aim to create a comparative system for loads, position, and tracking control? If we use jumping velocity as a metric, we need to exercise caution, especially when jumping back onto a hard surface. The key question is whether we can bounce in a way that avoids harming both the robots and the objects, considering that there will always be some degree of jump.

This leads us to the crucial aspect of how to prepare for impact. If we can prepare effectively, we can demonstrate not only that we can limit this impact to an acceptable level but also determine what ”acceptable” means. This is where it gets interesting. We can define what’s acceptable, considering factors like package damage. If our preparation for impact proves incorrect, we need to adjust it while maintaining our desired average cycle time.

MBo: I want to address ABi’s concern about grabbing various objects without causing damage. Our existing components include Yuquan’s work on bounding acceptable impact. I think there are two other works from Nails in this area.

Parameters like the coefficient of restitution and friction are object-dependent, with friction being a major consideration in our grabbing scenario. Additionally, we need to account for the robot’s torque limits. The object parameters, including friction, guide how we set acceptable impact limits for each object. This leads to the question of optimizing impact utilization. While people often assume that impacting the box’s normal direction speeds up the process, this isn’t always the case. The box might not be picked up unless a post-impact motion aligns with the desired motion.

Hence, there is an ideal impact direction influenced by the box’s properties. For a fragile box with known properties, we can establish an acceptable force threshold. The next challenge is adapting the Quadratic Programming (QP) formulation based on the box’s parameters, ensuring it doesn’t generate excessive force for that specific box. In summary, the box’s parameters are key in this process.

AKh: The problem is to define requirements for each object, and this information is currently unknown. For example, some boxes are fragile and require gentle handling, while others may need rotation before grabbing. The question is: What level of impact is acceptable for each box?

ASa: The force application direction matters a great deal. Factors such as friction cones are very important.

MBo: Yes, the questions are how should we choose the component that favors the upcoming task and what is the optimal configuration for impact? The usual impact during approach primarily relies on motion speed for its energy. Comparatively, a traditional approach moving at around 20 centimeters per second with a similar fast acceleration during picking can yield almost identical results. Nevertheless, when the impact aligns with the desired motion, it leverages the existing kinetic energy, providing a distinct advantage.

ABi: In this context, it’s essential to consider the robots’ posture and how it can influence the energy impact on the robots themselves. It would be interesting to explore how we generate robot postures, as this is crucial to the overall concept.

Returning to the example of picking up a very rigid object, the core concern is risk mitigation for the robot. We should aim to showcase a scenario where both the posture generation and the approach strategy are different from the traditional method. Instead of moving slowly and approaching the box perpendicularly, we opt for a faster approach. We may even adjust the approach vector when sweeping the box out of view. Furthermore, we should adopt a posture that minimizes the risk of joint breakage. This approach would indeed be a powerful demonstration.

5.4.6 Uncertainties in object and task

AKh: I was impressed by the ability to grab objects and adjust to their weight during the lifting process; it's truly remarkable. However, the challenge we face is the real-time estimation of certain parameters, which is crucial for our progress. We're eager for TUM to assist us in providing these estimations. We've already prepared everything from the CNRS side in terms of system integration, but the key question is whether your team can handle online parameter estimation, which is the core of our objective. The initial focus was on detecting unexpected impacts or contacts, and while it's important, I believe the primary purpose lies in real-time parameter estimation, which is our critical need.

AMe: Yes, there was research in this field, which AOl initially pursued. After his departure, I quickly transitioned to impact-related research. In the first stage, we focused on real-time parameter detection, particularly by shaking objects to understand their initial parameters.

ABi: Returning to the topic I just mentioned, it appears that many of the cases defined in the logistics scenario involve situations where the object's mass is heavier than expected, its center of mass is slightly off, or two packages are colliding.
Now, if we revisit the idea of tilting the box as we pick it up, we could potentially gain more insights through sensing, beyond just video, enabling two classifications. It can either indicate that the mass and center of mass are as expected or, if not, it could provide information about how much they deviate from expectations. This way, we could recover from the situation.
CNRS has already demonstrated their capability in this area, and they employ an estimate of the friction cone. Extending your sensors' capabilities to provide information on such deviations would be highly beneficial.

AMe: Yes, this is the next step we aim to pursue after binary classification. As you rightly pointed out, the challenge lies in estimating the mass difference and having an estimate in that regard. We intend to explore this direction.

Additionally, a straightforward yet valuable aspect is to determine the mass of the object and understand the location of its center of mass. This should be relatively easier and provide us with essential information, including an estimate of the object's mass.

MBo: At this point, based on our requests and the desired components, given the current situation where these components are not available, I'm uncertain whether they can be delivered by the timeframe from now until January.

Additionally, I'm wondering if we could consider using external force sensors mounted, perhaps on the end-effector, to expedite the resolution of some of these issues.

AMe: Having force sensing capabilities could potentially improve the situation, but it needs to be integrated by Algorix because I require a one-to-one simulation. I'm unsure if your sensors are supported in that physical engine.

Certainly, the work I was doing was at the core of the classification problem, particularly addressing the vibrations that occur after impact. It was more of a foundational issue. However, as I aim to achieve high-level results more quickly, I've found the need to balance working on the core problem while also investigating details incrementally, given our time constraints. This decision revolves around priorities and what's necessary to showcase.

MBo: While I was working on this, there were several aspects that have been mentioned today that we need to consider. Specifically, we could focus on reducing the number of failures. The first type of failure could involve a loss of contact or poorly estimated mass, meaning that after the initial grab, we recognize that we can't perform the intended task.

If we detect such a failure, and we categorize it as a type where the object is likely to fall soon, we can opt for a re-grasp. The other scenario is losing contact, where we need to re-grab. In this aspect, your system uses motion capture from Optitrack for perception, while we employ vision.When it comes to re-grabbing after losing contact, it's not a significant issue because the Dynamical system already handles it.

5.4.7 Summary of Discussions

HKu: We can proceed with this approach, but there are a few additional discussions required. One key point is that MBo will liaise with JvS and TUe to understand the inertia changes resulting from the joint motors and their gains.

ASa: MBo primarily focused on control alignment. We can perceive these aspects because we don't employ that model in our control and force generation.

EPFL seems to be working on impact posture planning, particularly for dual-arm grabbing. We have experience with the kind of inertia and related elements required to improve post-impact velocity estimation. The information is available and has already been shared, especially in the paper authored in collaboration with Franka Emika. You can reach out to me, or we can connect you with relevant people if needed.

HKu: If I recall correctly, we are also moving in the direction of a qualitative comparison between the velocity-controlled dual-arm system in grabbing and the torque-controlled dual-arm grabbing. Both involve force generation but differ in control methods. Is that correct?

AKh: We might consider comparisons in terms of robustness and resilience. Generally, torque-based robots tend to avoid high impacts due to the torque sensors they use. But I believe it's equally important to make comparisons regarding rigidity, particularly the presence of flexible or soft components. These aspects could also be of interest.

ASa: Why don't we do this? For example, use Optitrack to detect sliding and then demonstrate hand gaitting.

HKu: In this scenario, we plan to conduct comprehensive comparisons of different grasping approaches. Our focus is on the robot's motion when picking up boxes and placing them on a table, either by tossing or through a smooth pick-and-place motion. To assess the efficiency of these methods, we will evaluate various Key Performance Indicators (KPIs) and compare them to a baseline scenario where a robot per-

forms non-impactful pick-and-place operations or rapid grab-and-displace maneuvers. We'll investigate the results of these approaches, considering aspects like object placement speed and the impact on the system.
Expanding beyond simple tabletop scenarios, we intend to examine slightly semi structured environments, such as sorting objects into different locations. We'll explore the implications of these grasping techniques on various metrics and potentially include a classification system for detecting slippage. If we end up getting something from Munich that would be great and could be integrated later. However, in the meantime, the integration of a motion capture system can help in identifying slippage events and making real-time adjustments to enhance performance.
Regarding the other base of grasping like hit to tilt, developed by CNRS, we will also be in contact. EJe is working on mc_kuka_fri so that we have a similar system working on the Kuka as well. That will also be part of the integration.

- Consortium agrees it is best to compare robotic motion with impacts with a motion without impacts as main evaluation, rather than human-robot comparison. Placing the object with an impact can be an interesting case study, but it is suggested by ASa to focus on the grasp with impact. Success rate of GRAB motions (e.g. under uncertainties) is also a possible benchmark as used in the most recent work of JvS.

- It is important to decide on a specific use case for the demonstrator. Figure 2 shows a demonstrator description suggested by HKu. It is suggested a demonstrator with pre-grabbing motion, grabbing motion, re-grabbing motion and placing motion that should include all research into a single scenario.

- TUM is suggested (**ABi**) to provide a timeline for when it will be possible to have the sensing (estimating) of mass and inertia discrepancy. **AKh** reiterates it is important to determine inertia parameters on the fly to properly do so. However, there is no time at CNRS to do so, and **AMe** is focused on the classification + reflexes. **AMe** should discuss with supervisors at TUM to inform whether this is possible before the end of the project, since it was agreed on.

- It is suggested that we classify successful grabbing for at least one specific pre-determined failure scenario, such as unexpected loss of contact. This can be caused by a mismatch between expected and actual mass/inertia of the object, or between expected and actual position. Some forms of reflexes are already implemented in the EPFL approach given that they use Optitrack measurements which ineherently tell when the box is not grabbed successfully. To make this more realistic, **ASa** suggested that it would be good to show robustness to vision with cameras by adding noise. He also mentioned that TU/e has this noise data, with uncertainty regarding a few centimeters, available. Box slipping as an unexpected scenario will be tackled by EPFL, using Optitrack as a replacement proprioceptive sensing. TUM will instead focus on classification regarding a mismatch between the weight of the object (over 10-20%).

- Regarding the I.Model, it is agreed that **MBo** will align with TU/e on the inclusion of the motor inertia, low-level torque control model to improve the prediction of the impact map. **JvS** and **MBo** will discuss to implement the reference spreading technology with the dynamical systems approach. **ABi** underlined the importance of showing the influence of an impact model on the successful execution of the grasp motion.

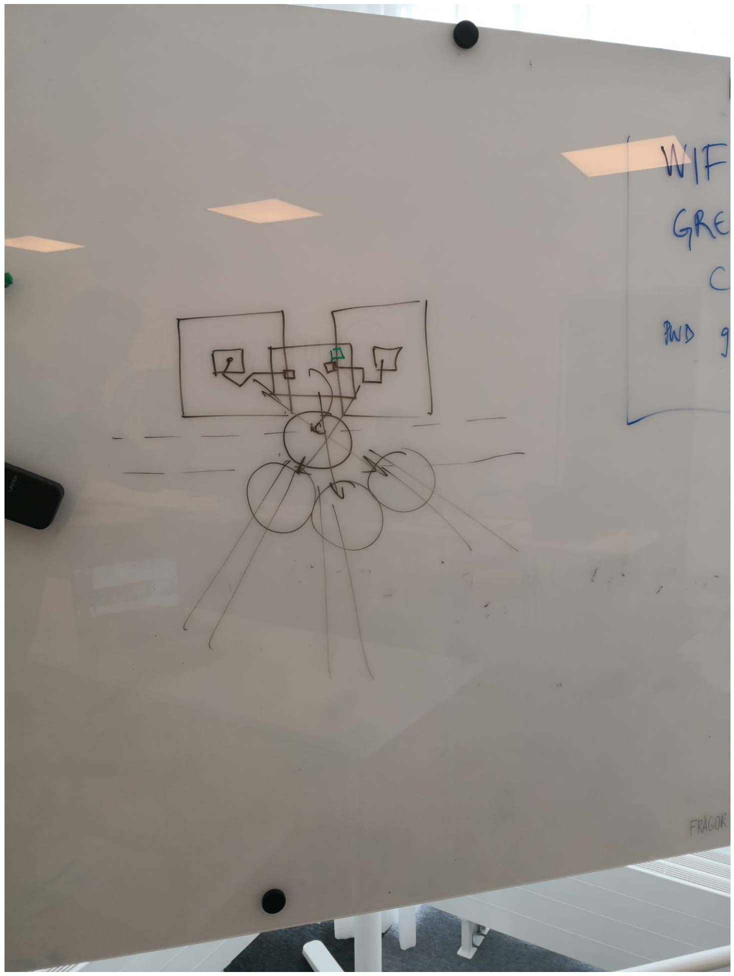

Figure 2: GRAB scenario layout

5.5 Summary of the agreed GRAB demonstrator

Types of objects to grab

- Rigid objects/boxes (mainly);
- Rigid and fragile objects;
- Objects with moving mass inside (EPFL)

Tasks to be executed

Pre-grabbing Maneuvers & Grabbing Tasks

- Pre-grabbing maneuvers: tilting and grabbing (EPFL/TUe)
- Grabbing with impact (EPFL/TUe/CNRS)
- Grabbing a layer of two to three objects (CNRS/EPFL)

- Hitting to flip and grabbing (CNRS)
- Hitting and grabbing (EPFL)

Post-Grabbing Tasks

- Placing/Tossing objects on a conveyor belt (EPFL)
- Placing objects into a tote box on a table and pushing the tote box (see Figure 2)
- Grabbing then hitting (EPFL)

Contact Sensing

- Identify expected/unexpected contact (impact)
- Identify possible grabbing task failures
  - loss of contact
  - contact slippage
  - poorly estimated mass/ inertia (TUM)

Contingency Motions

- Re-grabbing after loss of contact
- Re-grabbing to enhance grasp stability

Evaluation

- Comparison between grabbing with and without Impact-aware technology.
  During benchmarking, we will measure:
  - *Average cycle me [s]* (average time it takes from one grab to the next grab)
  - *Average pick and place me [s]* (average time it takes from grab to place)
  - *Retry rate /pickability [items]* (average amount of grabbing attempts needed before an item is successfully grabbed)
- Comparison between impact-aware manipulation control without and with mitigation of effects of speed jump on control (JvS TU/e)
- Comparison between impact control with velocity-controlled vs. torque-controlled robots

Timeline

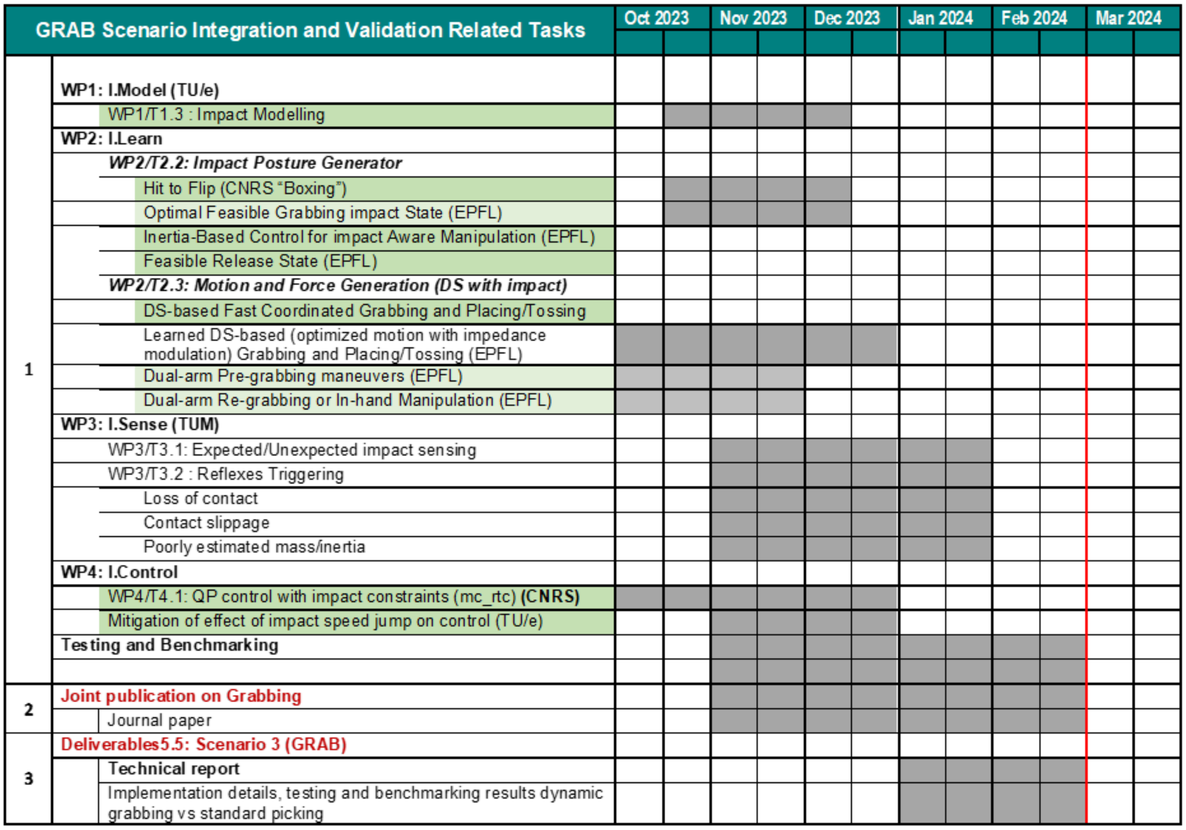

Figure 3: GRAB Scenario Integration timeline

6 Minutes - DAY 2 - BOX scenario - 10 October 2023

6.1 Meeting goal

Discuss and agree on the BOX scenario demonstrator, Task T5.2.

6.2 What is required?

In the original proposal is written that for each of the scenarios, we promise a speed up of execution in cycle time of 10%. However, for box scenario, the key selling point is that we can increase the fill rate by exploiting impacts, as it allows us to place boxes in a way that is not possible without I.AM. technology. The final review will focus on the content of Figure 1.3.2 of the proposal. This is what they expect us to do.

As an overview, the different TRL levels are defined as:
TRL4: The technology is demonstrated in the lab
TRL5: The technology is validated in a relevant environment
TRL6: The technology is demonstrated in a relevant environment

For the boxing scenario, we have promised (aimed) to deliver TRL5, so validating the technology in a relevant environment. For that, a demonstration in the lab is sufficient.

6.3 What do we practically deliver?

We have agreed to deliver a video and a report. We (practically) can only upload a PDF file to the EC Portal, but we will put the video on the I.AM. YouTube page and put a hyperlink in the PDF file as a way of demonstrating our efforts.

6.4 What is the idea of the demonstrator?

The story:
With current state-of-the-art, humans determine the upper limit of the fill rate. The systems at Smart-Robotics will be used to benchmark the state-of-the-art robotic solutions with 5 different orders, that will be determined by Vanderlande and Smart-Robotics, where we use rigid-body uniformly filled carton boxes of different weights. The boxes used here can be the ones in the lab, but if more are needed, we'll have to make more. These same orders are used also in the Vanderlande lab to show the maximum fill rate (determined by human operator) and to show what I.AM. technology can do. This last point we will do by (manually) creating a planner and stacking algorithm to fill the objects in the tote, which we will then execute with mc_rtc and record with OptiTrack. In Algoryx, we will use the same controller to mimic this experiment in the simulation environment. We then show a comparison between the simulation and the actual experiment. With that, we can show that, due to accurate simulation results, we can create planners that can now fill the totes by exploiting impacts. This will lead to higher stacking density. The higher stacking density will lead to higher utilization. By exploiting impacts, we can also place the objects faster in the totes. It would also be good to show a difference between using and not using IAM technology, show what would be happening now.

Discussion on the type of order we should use:
BCo: Should we focus on food order? There is min, average, and max items of orders. Probably showing 3-5 different orders would be good. We can do something with the different weights such that we can stress limits of the model.
MJo: Can we still use carton boxes? This would be desirable, as it will simplify other aspects.
SEi: Yes we should, because that is that what we currently have. SR says there are customers that have these type of orders (totes with carton boxes), in retail. We can make a story around this.
BCo: How many items do satisfy rigid body constraint? And if we would extend to non-rigid body. Yes, this would still all be relevant.
Conclusion: we can use carton boxes, we can make a story around it related to customers in retail industry.
Conclusion: We will use UR10 with velocity control in the demonstrator, as Smart-Robotics guys know how to do this. Then we can also directly compare this with benchmark at Smart-Robotics, as this is also done with UR10.

The Vision:
We showcase the difference between current industry and the potential of the fill rate when we use I.AM. technology. The focus then should be on comparing the motions of the objects with the simulator, as the simulator in the future will be an enabler for creating these type of motions. Key point is that this technology allows to make planners. You could do online pose estimation of to know where the

object is, but you cannot create a planner on this. It's online feedback basically. So the technology we develop will make the planner possible.

Assumptions:
For the demonstrator we will use no vision and no planner. We asume this can be done and making this for the demonstrator is out of scope. The orders we use are assumed to be representative. The objects we will use are uniformly filled and rigid.

Practical points:
We do not necessarily have to show the demonstrator with the Franka Emika panda, using it torque controlled. From a time frame point of view, it is best to focus on what we have. Furthermore, the benchmarking at Smart-Robotics will be done with the UR10. So, to make a fair comparison, we will do the demonstrator also with the UR10. **Leo** (CNRS): for boxing scenario there is no relevance from CNRS point of view.

6.5 What is still missing to do this, what are the steps we need?

1. Implementation of Suction cup model in Algoryx (priority one) (CLa says is possible, time and resources are there) For validation of the implementation of suction cup, UR10 is not needed yet. (**Algoryx + TU/e**)

2. Implementation of UR10 in Algoryx for the final demonstrator. (**Algoryx**)

3. Define the item sets (orders): We'll do preferably 5 orders, if time does not allow for this, we will do less (but at least 3 would be needed). We will define these orders keeping in mind the objects that we already have in the lab. Orders should reach a fill rate of 80/90 percent. We agree on staying with objects that are uniformly filled to validate the models (if the inertia is clearly incorrect, there will be a large mismatch between simulation and reality, for sure). The point is that the envision inertia estimation component using suction cups has not yet been developed by TUM, also due to various people leaving the project and it is unlikely this will be done in the remaining part of the project given resources are mostly allocated to develop the aim-aware contact monitoring pipeline useful for the GRAB scenario. If new objects are needed, TU/e will take the lead on making new ones. If time permits, we can do a sensitivity analysis on the inertia: how well does the simulator predict what will happen if the estimation of the inertia is off? (**Vanderlande** + **SR** + **TU/e** (on creating objects))

4. Benchmarking the 5 orders with current industry standards (using vision, planning, stacking). This will be done at Smart-Robotics. Time-wise, it is best to video record the benchmarking progress at Smart-Robotics directly. It will not be a problem in the comparison later, once we show this comparison on different setups. We will use the same objects for the benchmarking as we will use for the demonstrator. (State of the art is not Panda Robot, can be used as argument) (**Smart robotics**).

5. Creating, demonstrating, and recording the new box scenario. This means getting the real world data. We will use mc_rtc for this. This is because then we use all the componetns of I.AM., and we can also reproduce this controller in Algoryx. An approach could be to use teach pendant first and then copy paste these waypoints to mc_rtc in a finite state machine. (**Smart robotics + TU/e**)

6 Comparison of real world data obtained in step 5 (demonstrator) with simulation data coming from Algoryx. This step therefore involves getting data from Algoryx. Compare the data from Algoryx with Real world data. (**TU/e**, with support of **Algoryx**)

7 Making and publishing on YouTube the video for the deliverable. People at TU/e have the most expertice in this (MJo, Alexander) (**TU/e**.)

8 Writing the report (**Smart Robotics**)

Due date: 29th of February for both PDF of report and video.
1 and 2 in parallel with 3 and 4. Names of partners here indicate who is taking the lead. They should reach out to other partners in case help is needed.

6.6 BOX integration timeline

In the table below, we give a high-level overview of when the tasks that are described above should be executed. In the Figure below, we show a picture of the draft of this timeline.

Date	Task
12-10-2023	Start of Smart Robotics and Tu/e on **Task 3** and **Task 4** with support of Vanderlande. Keep in mind: • Making new boxes will take quite some time (Sander in the past spend 3 days full time on 10 boxes). So this should be determined in the first week after 12th of October. • Smart Robotics will benchmark the different orders. This will likely take them a few days. And can only be done once the orders are clear and well defined.
24-10-2023	Start of Algoryx on **Tasks 1** and **Task 2** with support of TU/e
01-12-2023	**Task 3** and **Task 4** finished. Start of **Task 5**. Note: • Task 5 will likely be most efficient by having an integration week of Smart Robotics and TU/e to create and record the motions of the demonstrator in the Vanderlande Innovation lab. **We should plan this in December before the Christmas break.**
15-12-2023	**Tasks 1**, **Task 2**, and **Tasks 5** finished. Two weeks holidays will mean no further work in December.
01-01-2024	Start of TU/e on **Tasks 6**. Start on **Task 8** from Smart Robotics
22-01-2024	**Task 6** finished. Start on **Task 7** by TU/e.
15-02-2024	**Task 7** and **Task 8** finished. Report and video ready for review
29-02-2024	Due date of deliverable D5.4 Scenario 2 (BOX) report

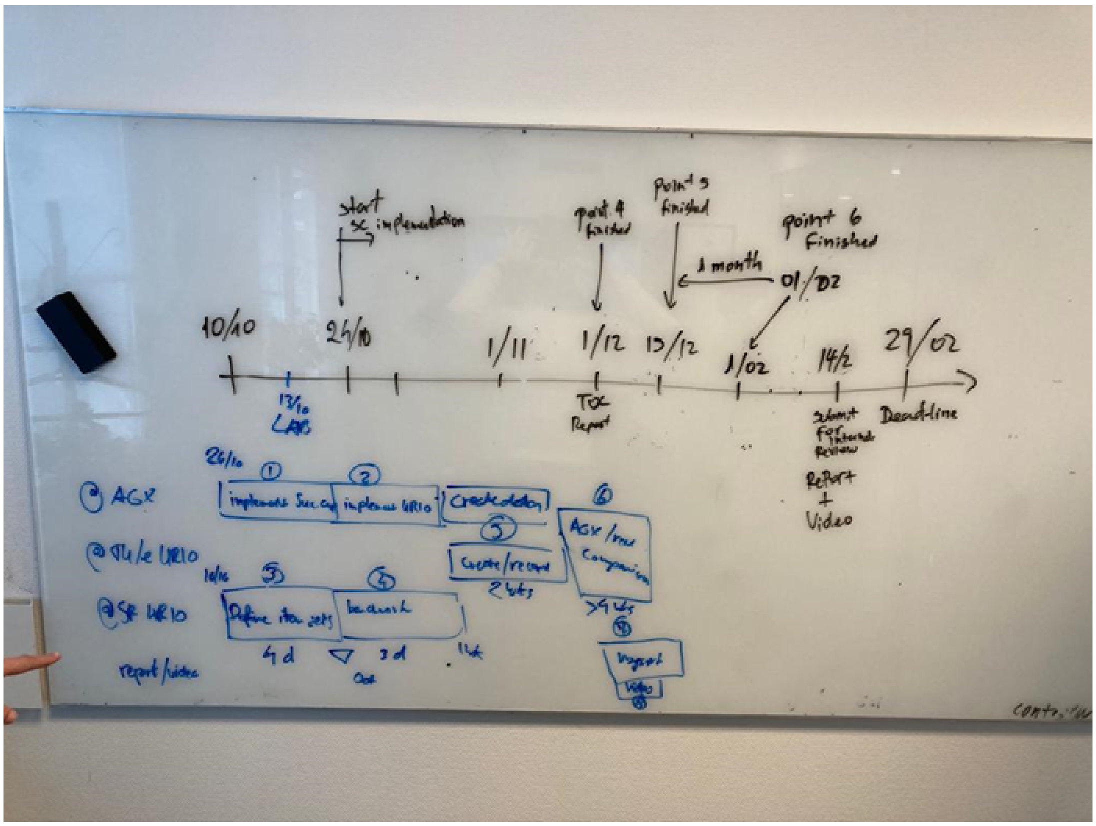

Figure 4: Picture of the draft of the timeline for completing the box demonstrator.