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CROWDBOT

Safe Robot Navigation in Dense Crowds

http://www.crowdbot.org

Technical Report
D 6.3: Proceedings of ESAB Workshops & Report on Ethical Protocols

Work Package 6 (WP 6)

Ethics & Safety

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Executive Summary

This report reports on the ethical protocols developed and followed during the CROWDBOT project and on all ethical and safety advisory board (ESAB) meetings held throughout the project. The ESAB served as a committee. We report here on the opinions of several experts as a group. After these meetings, we organized an international workshop to convey to a broader audience the ethical and safety challenges of robots in crowds.

The first section of this report details the ethical protocols at EPFL for driving reactive control experiments with the robot Qolo at different locations on the EPFL campus; at UCL, for the different experiments involving wheelchair users for shared control navigation indoor and outdoor settings; at ETHZ, for navigation and interaction modalities with the robot Pepper, and finally, at Locomotec for testing and evaluation of the developed algorithms with Locomotec's different robotic products.

The second section gives a detailed summary of the discussions held during each ESAB meeting presenting the topics addressed, opinions, suggestions, and concerns raised throughout the project. Each meeting was summarized in a table of questions/concerns, and responses/actions from the Crowdbot project. Finally, we have included a roundtable with wheelchair end-users organized between the team at UCL and EPFL for gaining feedback regarding the ethical questions raised during the design of shared-control strategies for wheelchair driving support, this meeting concluded that each user's different needs shown be address and consider when designing a driving support system, as not every user would need or want assistance.

In section three, we present the proceeding of the Workshop entitled: *"Robots from Pathways to Crowds: Ethical, Legal and Safety Concerns of Robots Navigating Human Environments."*, which was held within the IEEE ROMAN-2020 conference in a virtual format. In this workshop, we targeted a broad audience that could relate the issues raised over the Crowdbot project around the ethical and safety concerns of having robots navigating around people, therefore, invited talks addressed several aspects from the technical challenges, social, ethical and safety concerns, and legal frameworks required to achieve these types of robots.

Finally, section four reports on our current work to address safety and ethical concerns that are not covered in current standards on mobile service robots (ISO13482). Indeed, the latter still lacks the appropriate set of metrics and perspectives to assess a robot in the broad context of human-robot interaction with stakeholders involved in a robot navigating on open human environments.

1. Ethical Protocols

In this section, we present the experimental protocols used by each of the partners performing experimental evaluations:

1.1. EPFL

At EPFL, we evaluate the two reactive navigation control systems developed as part of the work package 3, task on “Reactive Control for CrowdBot Navigation”. We used as a testbed the standing mobility vehicle - Qolo - designed for mobility of people with spinal cord injury and already tested with uninjured and injured participants [Paez-Granados et al. 2018, Kadone et al. 2019].

In total, we have submitted one ethics proposal and one amendment to the Human Research Ethics Board of EPFL (HREC). They have been approved with ID: **HREC-032-2019** and **HRECH-089-2020.** The original application was approved on **May 27th, 2019** with experiments carried out until Feb. 2020 when the pandemic halted this evaluation, as described in section 1.1.5.

The amendment was approved on **February 19, 2021,** made to include two include sites at the city of Lausanne for encountering real crowds and real-life evaluation. Plans for the current period are set in section 1.1.6.

Objectives:

We investigate whether semi-autonomous and autonomous behaviours for Qolo can improve its ability to navigate around people, while achieving safe control in dynamic environments. We further aim at verifying in a real-life environment the performance of our reactive controllers and to assess if they can act as safety mechanisms in variable situations and when faced with naive pedestrians.

Specifically, we aim at assessing that the robot can navigate from one point to another autonomously and without entering in contact with pedestrians. To ensure safety, the robot will be in a semi-autonomous control mode with the human able to take over control at all times.

Robot Sensors and specifications:

The experiment envisioned is shown in Figure 1 with a user (hereafter the driver) accompanied by a task supervisor. The driver has full operational control of the device via an embedded force/pressure array as a motion control interface, and the supervisor has an emergency switch via wireless remote control, for ensuring the safety of the task.

- Protective fence: made of semi-deformable material (PLA) is located at each side of the robot structure covering frontal and rear wheels. Attached to force/torque sensors (Botasys Rokubi 2.0), so that any possible contact with feet or legs of the surrounding pedestrians can be sensed. Perception ranges from 1N at 500Hz, and up to 1000N.
- Obstacles information for decision making in the control algorithm will be compiled from a set of two commercial range sensors located in front and rear of the driver - Velodyne VLP-16 LIDAR (light detection and ranging). With a sensing range of 0.4 to 100 m, FoV 360x30 degrees sensing at 20 Hz, with a set of 16 lasers, human eye safe standard 905nm class-1 laser (IEC: 60825-1 2014).
- Proximity: a set of four commercial stereo depth cameras (RGB-D) Intel RealSense D435 for further depth and full body information in proximity from 0.1 to 10 m at 180 Hz.

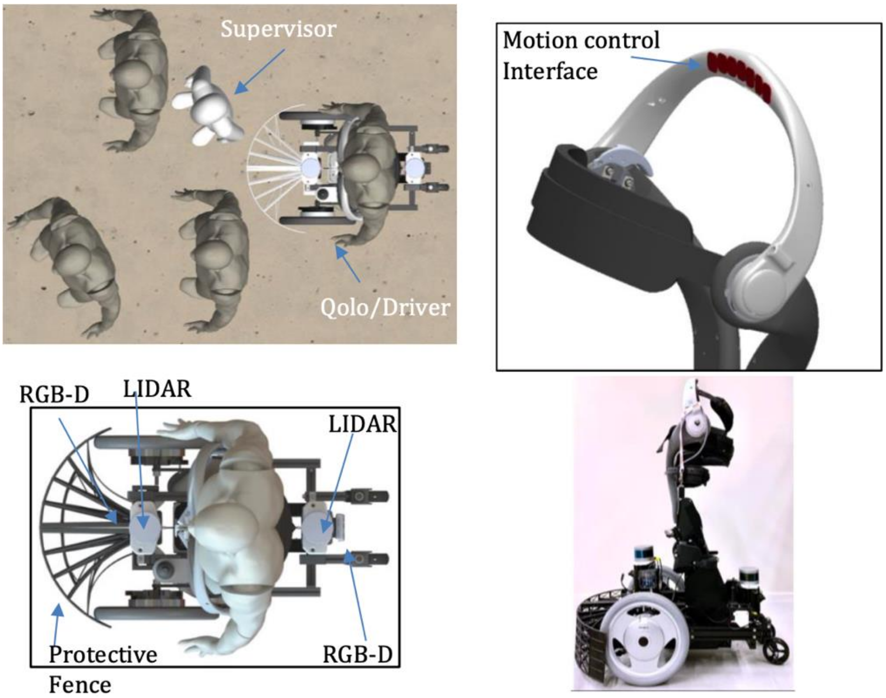

Figure 1: Robot Qolo's experimental setup and sensor placement.

Study hypotheses for shared control:

In this context, shared control refers to the semi-autonomous control of the powered wheelchair sharing decisions between the user driver giving commands through a control interface and the robot based on sensor information [7-11].

These studies have evaluated multiple control interfaces from joysticks, headrest, and spit interfaces [9,10] and developed control algorithms for static environments with motion tasks, crossing doorways tasks, or obstacle avoidance. Although some performance metrics show fewer workloads when some form of shared-control is implemented [7-9], the different shared-control algorithms and the level of autonomy of such presented little difference [9,10], concluding that user's preference is highly variable regarding the desired autonomy or support of the robotic wheelchairs.

In the case of the Qolo device, we will study the performance of the following shared control scheme. The human will be in charge of giving direction of motion via the embodied control interface for hands-free motion control. The interface could also be used to increase or decrease speed at run time. Qolo autonomy will use on-board detection of obstacles, combined with the user's set direction of motion and maximum velocity, to execute the steering of the non-holonomic platform in a smooth manner (controlled acceleration) avoiding any collision while satisfying human commands.

1.1.1. Research Protocol

As initial preparation all participants will learn the manual control of the embodied interface and follow a protocol of evaluation of powered wheelchair skills test (WST) 5.0 from point 1 through 9, which covers directional operation, start/stop and lateral maneuvers.

The participants will then join at different dates the three scenarios below displacing between a start point and a goal point for approximately 50m moving around other pedestrians in the determined area. While driving they should pay attention to surrounding people and obstacles for commanding the device.

Timewise, the experiment will require around one-hour and 15 minutes for each participant. First 15 minutes for preparations, filling the consent form and reading the experiment protocol. Second, around 20 minutes for driving 3 times round trips from the start point to the goal in one operation mode and subsequently filling the evaluation questionnaires. Followed by a short pause of 5 minutes.

Third, around 20 minutes again for repeating 3 times round trips from the start point to the goal in the other control mode and filling the evaluation questionnaires.

The previous test by each participant will be performed in three scenarios in a progressive manner, that is, after completing all volunteers' tests in scenario 1, we will start testing of scenario 2 and subsequently scenario 3.

Scenario 1: It will be performed in the evening after 6pm (after classes are over) on weekdays along a corridor of the campus, an hour when it is known to be of little congruence of people.
Scenario 2: It will be performed during the non-rush hours of the weekdays (mid-morning 9-11 am, or mid-afternoon 2-5 pm) around a corridor of the campus, hours where pedestrians are expected to walk around without great affluence.
Scenario 3: It will be performed during rush hours of the weekdays (mid-day 11:30 to 12:30 and afternoon 5:00 pm) around a corridor of the campus when classes are finishing.

Any volunteer is free to stop, rest or retreat themselves from the test whenever they consider it necessary.

Measurements taken during one trial encompass:

- Motion information in the form of points cloud of all surrounding people and obstacles.
- Force/Torque information gathered by the contact sensors at the robot’s fences.
- Recordings of the interface input given by the user/driver of the robot.
- Motion data gather from the robot inertia sensors and velocity sensors.
- Video recording of the scene from the robot’s perspective without personal identification recording, all faces will be blurred out of the images.
- Video recording of the participant-robot driving in a scenario, with no personal identification, all faces will be blurred out.

Participant recruitment:

Volunteer participants for driving the robot will be recruited inside the project’s host university EPFL, through open call for healthy participants within the age range of 20 – 50 years old. Subjects will be restricted to adults no shorter/taller than: 160 cm - 190 cm, and with weight ranging: 50 Kg - 80 Kg to match the specifications of the standing mobility device Qolo. Care will be taken to have a gender-balance cohort of subjects for balanced user assessment.

1.1.2. Subjects and Informed Consent

- In this project voluntary healthy adults will take part in the study.
- The participants will be free to withdraw from the experiments at any time and any phase without being subject to any disadvantage or penalty.
- The participants will be informed about the procedure with an "Information Sheet for Participants" and they will be asked to read and sign an "Informed Consent Form". Both documents are attached to this application.
- All data is anonymized. The videos of subjects focus mainly on the torso and feet of the subject and are never linked to the subject’s identity, where the faces are recorded this will be blurred out. Also, the participant is shown a preview and asked if it is ok to record video in that position.

- During video recording the face of the pedestrians might become visible. In this case, blurring of the video will be performed as an additional processing step.
- The surrounding areas covered in the video range will be marked by signs with information of the experiment and a link (QR code) to a website for detailed information of the experiment for the pedestrian's benefit.
- An alternative route parallel to the experiment area will be described in the signs for people desiring to avoid the indirect participation in the experiment.
- Neither the sensor data, nor the video recordings will ever be linked to the subject's identity.

1.1.3. Expected risks and corresponding precautionary measures

The study involves the use of standard, commercially available and certified equipment for video recording, force/torque/acceleration, proximity sensors (LIDAR and RGBD). The use of these devices does not bring any particular risk to humans.

We have designed the experimental set-up to ensure that no harm may be caused to any person:

- The presented device will be driven by a user with passable ability tested in the lab for start, stop and directional control.
- The driver has full control for starting and stopping the device in the form of hands-free pressure sensing array.
- There is an emergency button at the side of the robot for the driver to use if consider that a collision is imminent.
- A companion person monitoring the device motion at all times with a wireless remote controller as a fail-safe control of the motion in case of unforeseen obstacles, or unexpected pedestrians coming in proximity.
- A surrounding fence with semi-soft material (plastic with 3500 MPa of elasticity) will cover wheels and all protuberant parts of the device so that the risk of overrun or colliding with any part of the device is minimized to the fences.
- The fences are equipped with force/torque sensors for detecting and collision and stopping in accordance.
- A safe area will be demarcated, posting signs informing of the experiment being performed.
- Signs in the area of the study will be posted specifying that a robotic powered wheelchair-like device will be navigating the area.
- In cases of children, pregnant women, elderly or other pedestrians requiring special attention come in the area of the study this will be stopped and resumed after the pedestrian is out of the area.

1.1.4. Experimental Location (Protocol HREC-032-2019)

Initially, the study will take place in the robot room of the Learning Algorithms and Systems Laboratory (LASA), STI, EPFL located at the ME A3 455 EPFL, Station 9, CH-1015, Lausanne.
The experiments of crowd navigation will be performed in either of the following locations of open spaces with flat surfaces at corridors of the CM and AN building.

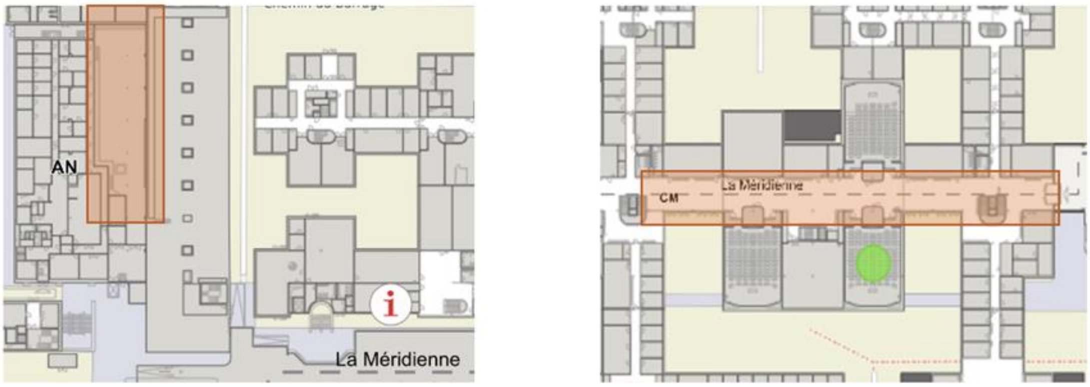

Figure 2. Building scheme

1.1.5. Performed Experiments: period 2019-2020

During the period September 2019 to February 2020 several experiments were performed as detailed in the deliverable **D1.4 1st Round Test Evaluation Report.**

During this phase of the project shared-control navigation was evaluated:

1. Several, in lab evaluations for algorithm assessment.
2. 3 in lab testing with volunteer users.
3. 3 days of recordings on campus at the set locations with a single user.
4. Online Demo at EPFL with Crowdbot consortium (Jan. 2020).

Subsequently, from March 2020 through July 2020 the COVID-19 pandemic forced all experiments in crowds to be halted, and we moved to indoor testing and simulation evaluation of the system integration as described in **D5.3 - Updated and Extended Robot Systems.**

From August 2020 through December 2020, several new recordings on campus were performed for evaluation of the reactive navigation control with the results published in [Gonon. D, et al. 2021], as well, new control for post-collision compliance was tested with artificial crowds (crowds of volunteers) and described as well in deliverable **D3.4-Reactive Motion Planning.**

During this last period, we encountered very few crowds on-campus overall, furthermore in November 2020, new restrictions for the pandemic crisis set to EPFL students and staff meant less people on campus.
This motivated us to propose an amendment to the research protocol (**HREC-089-2020**) to extend for outdoor places in the city of Lausanne where crowds are still prevalent and will allow us to assess the algorithms and integration in real-life situations. In the next section, we detail the current plans for 2020 with the amended protocols.

1.1.6. Extended Experimental Location (Protocol HREC-089-2020)

Extended Sites on to the City of Lausanne:

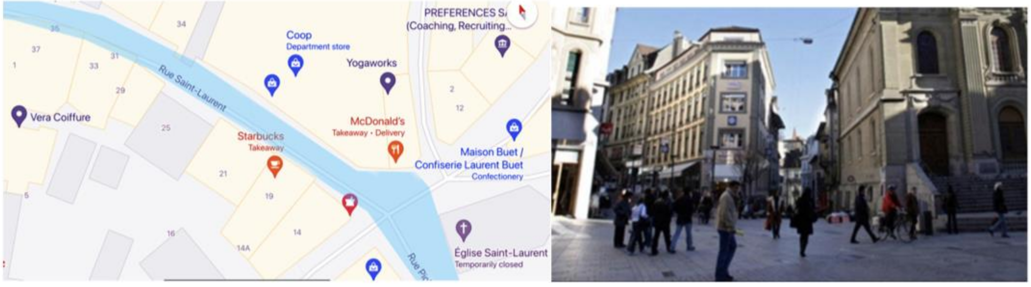

Figure 3. Rue de Saint Laurent

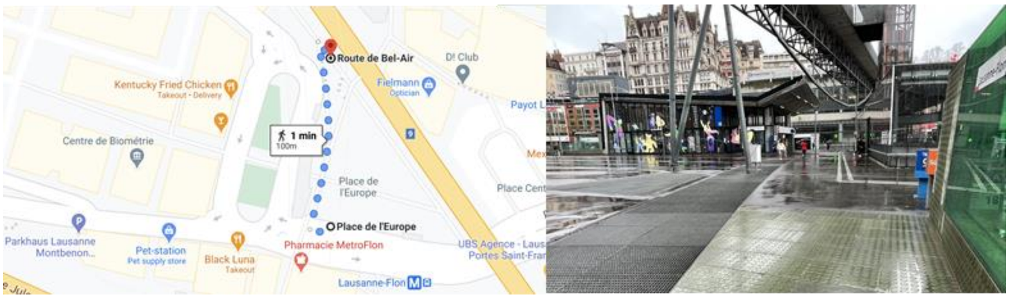

Figure 4. Place de l'Europe

Extended Sites on EPFL Campus:

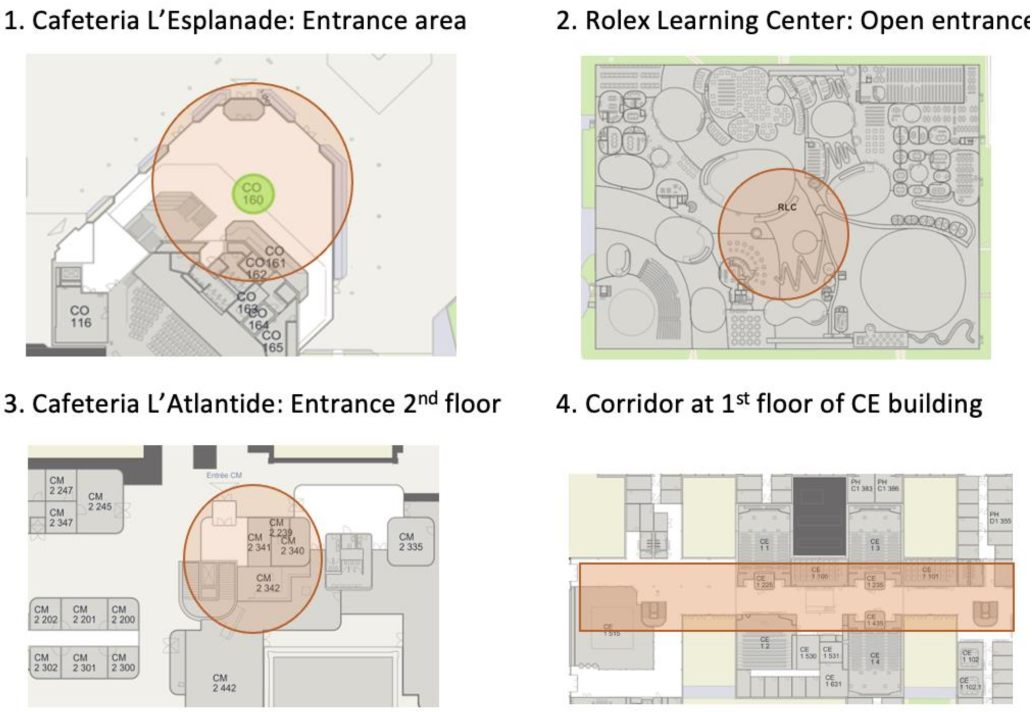

Figure 5. Scheme of 4 extended sites

1.1.7. COVID-19 related health and safety protocol

1. Prior to all tests the robot will be thoroughly cleaned and disinfected.
2. During the whole duration of experiments the “driver” of the robot, the supervisor and the assistant in the experiment will follow the physical distance recommendations of 1.5m and wear masks.
3. For riding on the robot, the driver will need assistance, thus, both the driver and the assistant will disinfect their hands prior and post riding on and off the robot.
4. When changing driver on the robot the robot will be disinfected in all surfaces in contact with the drivers.

1.1.8. Experimental plans for 2020

- At the set locations on the city of Lausanne we will run experiments in 2 sets of scenarios from the set requirements on **D1.3 Specification of Scenarios Requirements Update,** following the protocol set in point 1.1.1 of travelling 50m from a start location to a given goal at different times of the day for achieving different crowd densities:
    - A 1D flow navigation: At the street of "Rue de Saint-Laurent", we expect to find several pedestrians moving in both given directions and the robot will follow the given flow to arrive at a given goal location.
    - Sparse crowd navigation: throughout the pedestrian street of "Voie du Chariot", we expect to find several quasi-static pedestrians in the surrounding areas of the stores on each side of the street.
- The experiments are expected to be carried out during the months of March through May 2020 given all permissions are obtained and pandemic restrictions allow it.

1.2. UCL

1.2.1. Research Protocols

Existing prototype robotic wheelchairs are able to safely navigate uncrowded areas, however dense crowds still pose a challenge to navigation systems. Such situations can result in the “robot freezing problem”, where the robotic wheelchair may stop and be unable to plan a safe route through the crowd.

This study aims to develop a “shared-controlled" wheelchair with a navigation strategy that overcomes the robot freezing problem and helps the potential users navigate safely and effectively in crowded environments. Different from a fully autonomous system, human factors must be considered when designing a shared-controlled system. In order to study the interaction between the wheelchair user and the system, as well as the interaction between the entire system and the surrounding pedestrians (the crowd), we need to conduct a few experiments and interviews.

In total, we have submitted one ethics proposal and two amendments. They have been approved with ID: **UCLIC/1819/011/StaffHollowayCarlsonZhang** (Original application was approved on 25/7/2019 and the amendment was approved on 25/8/2020) and **UCLIC/1617/024/StaffHolloway/Herrera** (Original application was submitted for another project and was approved on 05/9/2017, one amendment was made for the CROWDBOT project and was approved on 08/3/2019).

Experimental results using the protocol here described were reported in **D1.4 1st Round Test Evaluation Report**, and we will report the final results on **D6.3 Proceedings of ESAB Workshops & Report on Ethical Protocols** and **D1.5 Second Round Test Evaluation Report.**

1.2.2. Indoor experiment

Participant safety:

This experiment will involve 28 healthy participants walking together with a robotic wheelchair or a humanoid robot Pepper. The wheelchair will be fully controlled by a trained member of the research team who follows standard safety precautions. The driver will stop the wheelchair immediately with the emergency button if something unexpected happened. Similarly, Pepper will be controlled remotely by a trained operator. In addition, a researcher will walk around the robot and observe the situation in case anything happened.

Consent:

Printed information sheets will be distributed among the present and an oral explanation of the study and its implications will be provided. Consent forms will be handed to those indicating willingness to volunteer.

Privacy:

Video recording of the experiment will only start based on all participants’ consent. It will be post-processed to guarantee pseudonymizing. It will only be used for person detection and trajectory extraction.

1.2.3. Outdoor data collection

Pedestrian safety:

The wheelchair will be driven through naturally occurring crowds at various UCL campus sites (including but not limited to Stanmore, Bloomsbury, Here East, and PAMELA campuses) by an experienced driver with other researchers close-by, thus limiting the chances of any collisions with pedestrians/participants.

Consent:

Natural crowds are not recruited explicitly, however notices will be posted before and during the experiments to alert pedestrians that data collection will be taking place. If any pedestrians would not like to be recorded, they could take alternative routes as marked.

Privacy:

As we will only record videos of crowds, there is no personal data being collected as they will not be identifiable. This is in line with the UCL guidance note on capturing images/videos of crowds in relation to data protection law, available here:

https://www.ucl.ac.uk/legal-services/ucl-general-data-protection-regulation-gdpr/guidance-notices-ucl-staff/guidance-note-capturing.

The original recording will be post processed to blur pedestrian's face (if they can be seen), thus pseudonymizing the personal data (if any). It will not involve any new technology such as facial recognition.

1.2.4. Interviews

The series of interviews studies will involve the general public, wheelchair users, building managers, experts from wheelchair/robot/vehicle manufacturers, policy makers, cares and occupational therapists.

***Participant safety**:*

During Covid time, all interviews will be conducted remotely. If an in-person interview is required, the researcher will conduct structured interviews in a quiet room in one of the UCL campuses. We will make sure no other people will hear the interviews and the participant feels comfortable. In addition, we will follow the social distancing rule.

Privacy:

Upon the approval of the participant, video and/or audio will be recorded. We will make sure no other people's talk will be recorded. The information sheet explains to participants that they will be able to indicate their choice through the consent form.

Consent:

Consent form and information sheet will be shared with participants prior to the interviews and will be verbally explained on the day before obtaining written consent.

Others:

We will not ask sensitive questions, but wheelchair users may feel uncomfortable sharing their stories. If that happens, we will give them time to calm down and stop the interview if they wish.

For all the activities, the collected data will be handled and processed according to GDPR and the guidance provided by UCL Data Protection Office. The data will be kept strictly confidential and will not be able to be identified in any ensuing reports or research publications.

1.3. ETHZ

1.3.1. Research plan

Design behaviours for a humanoid robot under three main modalities:

Robot behaviours are parameterized according to low level control commands that can be sent directly to the robot for execution, for example, forward velocity of the base, angular velocity of the joints, etc. A basic set of behaviours is outlined in Table 1; this set was defined from observed human behaviours for navigating through crowds.

We aim to iterate on the individual behaviour definitions (parameters) through in situ evaluation of the robot navigation performance. Our ultimate goal is to design a control policy that can adjust the optimal behaviour parameters online given the response of the crowd to the robot actions, rather than using hand-tuned parameters.

In total, we have submitted one ethics proposal and one amendment to the Human Research Ethics Board of ETHZ (ETAPPO). They have been approved with ID: **EK-2020-03**. Original application was approved on Feb 17, 2020 to run experiments from March 2020 to December 2020 which were detailed in **D1.4 1st Round Test Evaluation Report** and **D3.3 Local Interaction Aware Motion Planning**, and the amendment provided an extension for experiments until December 2021. Final experimental results will be reported in **D1.5 Second Round Test Evaluation Report.**

Table 1: Description of Pepper robot behaviors for initial testing

Behavior name	**Description**
Intend	The robot base follows the planned path to goal with a strict tolerance on the allowed path deviation. The robot will travel with a forward velocity inversely proportional to the density of obstacles around it to facilitate smooth acceleration. The maximum commanded velocity in this mode $v_{move\,,max}$ is equal to the top speed of the robot base. The robot will stop if no movement command will allow it to make forward progress along the path without (i) coming within a specified radius r_{move} of an obstacle and/or (ii) violating the path deviation constraint.
Crawl	Similar to the “Intend” behavior except that $v_{crawl,\,max} << v_{move,\,max}$ and $r_{crawl} << r_{move}$. The resulting behavior allows the robot to slowly move closer towards nearby obstacles.
Say	The robot executes a verbal utterance such as “hello” or “excuse me”, which is commonly used to get a person’s attention. This can be accompanied by a corresponding arm motion.
Nudge	From a neutral pose, the robot raises and points its arm in the direction of intended motion before returning to a neural pose.

Formalize a high-level behaviour-based planning framework for selecting between behaviours to reach a goal position:

We have based our planning framework on Monte Carlo Tree Search, which expands and searches through possible outcomes of executing behaviours according to the sensed robot state and the state transition probabilities. Given sensor information specifying the relative location, orientation and movement of pedestrians, the planner outputs a sequence of behaviours to execute. The planner must also generate new plans in cases where the observed state changes or when commanded behaviours fail, e.g. the “Intend” behaviour terminated prematurely due to newly observed obstacles, or pedestrians do not make room for the robot to pass after a “Say” action.

The main performance metrics for the planner are related to the computational and memory complexity of the solver. In addition, we are also interested in the navigational performance of the robot, i.e. time to reach goal, travel distance, deviation from shortest path, etc. Initial testing in a simulation environment has shown that the planner is capable of discovering behaviour sequences that allow the robot to reach to goal in scenarios where tradition motion planners fail and that real time re-planning is possible even in reasonably complex environments. The high-level behaviour planner takes as input the perceived crowdedness of the environment and searches for the sequence of behaviours that result in the lowest path cost for reaching the goal.

Evaluate the behaviour-based planner on a humanoid robot in natural human crowds:

Following our simulation evaluations, we will conduct field experiments using the Pepper robot to navigate in natural human crowds. Existing crowd and pedestrian simulators are unable to capture the complex human-robot interactions that occur in realistic pedestrian scenarios. For example, in our prior work, we noted during our experiments that people tend to interact very differently with a robot compared to how they interact with other people in the crowd. Reactions we observed range from those that give the robot a wide berth to people who actively block or follow the robot. Furthermore, natural crowd dynamics that arise from social norms, e.g. moving in groups, passing on the right, overtaking on the left, etc., are also not captured by existing crowd simulators. Our goal is to compare the performance of our behaviour-based navigation to traditional motion planning methods (which only command the motion of the robot base) under the kinds of scenarios that occur organically in natural human crowds. We expect that the additional behaviour modalities that we provide to the robot will enable faster goal reaching while ensuring safe navigation through the crowd.

Figure 6: The humanoid robot Pepper, including custom LIDAR and RGBD and safety guard.

1.3.2. Research Protocol

We focus the discussion in this section on the practical details of our proposed field experiments which target objective 3 of our research plans.

Figure 7 shows an example environment in which we would test our robot. The space contains several columns and plants that partition the environment and cause pedestrian traffic to flow along different trajectories depending on the start and goal locations of each person entering the space. In addition, we can use furniture in the environment (e.g. benches) to specifically generate bottleneck regions and divert the flow of pedestrians.

To test the robot's navigation performance, we will command the robot to move continuously up and down the corridor between two or more fixed goal points. Given the current goal location and inputs from the sensors, the high-level planner will output a sequence of behaviours, which are then passed to the low-level controllers for online execution. The mission will be terminated if manual control is activated by the robot operator.

Each experiment will last for approximately 2-3 hours and we expect each round of experiments to only take one or two days to complete.

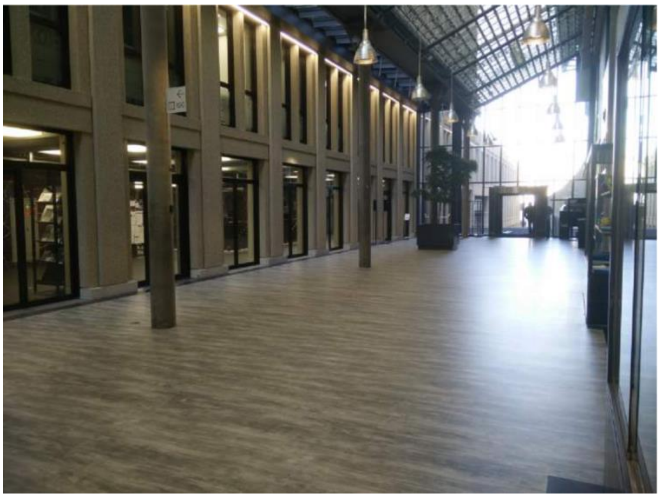

Figure 7: Example test environment, CLA hall D floor. The space is approximately 35m long by 8m wide.

1.3.3. Data collection

During test time, data from the robot's RGBD camera and 2D planar LIDARS will be used to perform online pedestrian detection and tracking. The robot will also use a visual inertial sensor for localization. The visual inertial sensor uses two greyscale cameras which are mounted to face the ceiling. These raw data will be logged for post processing. Image streams from the RGB cameras built into Pepper's forehead and chin will not be recorded. Anonymity is preserved with the raw LIDAR and depth data; however, the greyscale and color images will capture facial data.

In additional to the onboard sensors, we will also set up external cameras to record the full experiment scene. The recorded videos will be used in post processing to obtain annotations and metrics related to crowd density and motion. We expect that this footage will also contain visible faces of crowd participants. All identifiable faces in the recorded camera images and video footage will be blurred for reporting purposes.

1.3.4. Timeframe and Place

We aimed to do several rounds of testing and algorithm iteration during the 2020 Spring and Autumn semesters while there are more people on campus at ETH Zürich. Nevertheless, it. Has been extended to perform new experiments during 2021.

1.3.5. Questionnaires/surveys if required

No surveys or questionnaires will be required for our proposed studies. Only metrics related to robot navigation will be recorded and reported, e.g. robot travel time, travel distance, computation time, number of re-planning events, distance to nearest obstacle, etc.

1.3.6. Expected risks and corresponding precautionary measures

The main operational risk involves the safety of humans in the crowd. The possibility of contact and collision with the robot depends on the density of the crowd and the properties of the tested navigation algorithm. To mitigate this risk, an operator will be on hand at all times during the experiment and will be able to take over control of the robot at any time to avoid collisions with people. This is the main mechanism by which we will ensure the safety of humans in the crowd.

Additional hardware and software features are also in place to prevent injury in case of contact. The maximum speed of Pepper is 0.83m/s (3km/h) with a maximum acceleration of 0.93m/s2. Note that the average walking pace of a human is 1.38m/s (5km/h). Furthermore, following an earlier study on the risks of operating robots in crowds, which was conducted as part of the CROWDBOT project7, we included a safety guard on the base of the robot to reduce the risk of injury if contact with the base occurs (see Figure 6).

1.3.7. Data protection

As described in Section 2C, we will collect data from the robot sensors (2D LIDAR scans, color and depth camera (RGBD) images, greyscale cameras) as well as video from external cameras of the test scene. During the experiment, raw outputs from the RGBD camera will be processed online onboard the robot to perform person detection and tracking and will not be transmitted to an external computation source. Similarly, the greyscale camera images will be processed online for robot localization. The obtained data will be stored safely and reported in an anonymous form. That is, faces and other potentially identifying data in camera images and video will be blurred. Only the responsible investigators will have access to the original data, which will be stored in a secure data repository hosted by ETHZ under strictly observed rules of confidentiality.

1.4. INRIA

Section below details the information we have communicated to our Internal Ethical Board COERLE for authorization of robot-humans interactions studies in VR. We had positive feedback from this board, they only asked for translations of the informed consent to be signed by participants that we gave. Since then, the planned experiments concerned by this approval have been postponed without a new date in view. For this reason, formal approval by the board is still pending.

Objective:

The CrowdBot project aims at improving the navigation capacity of mobile robots in crowded places. This requires experimenting robot motion capabilities in close proximity with humans, especially in scenarios of near collision. Given the obvious risks raised by such experiments, the project plans to perform them in Virtual Reality.

This means that Robot and Humans remain in remote places, cancelling the risk of collision between them. The robot perceives the human through a simulation of its sensors, whilst the human perceives the robot actions through a graphics representation of them displayed through Virtual Reality devices.

Thus, the objective of the study is to twofold:

- Evaluate the realism of interactions between a robot and a human performed through Virtual Reality (this will allow us validating the use of Virtual Reality in such scenarios).
- Evaluate robot capabilities in moving (virtually) close to humans (this will allow us improving robot motion capabilities).

Protocol:

We present here a generic protocol, where the specific procedures for each experiment will be introduced in joint "instances". However, all the following items correspond to a general framework:

- Participants:

We will recruit healthy participants over 18 of age for most of the experiments. We will also recruit disabled adult that use powered wheelchair every day. Recruitments will be done through institutional e-mails or personal/professional networks. Experiments can last for one or several sessions (around 30min to 2h00 long each). Participants will not be paid.

- Ethics:

All the experimental procedures will follow the guidelines of the Declaration of Helsinki: participants will be provided a letter of information and an informed consent form (that will be submitted to the COERLE together with the "instances" if different from the enclosed generic consent form), and this consent form will be signed by both the participant and the experimenter for the experiment to take place.

- Apparatus:

Our experiments can involve several types of devices, mostly falling in the following five categories: Virtual Reality apparatus (head mounted & stereoscopic displays), Motion Capture Systems, Eyetracking systems, Haptic devices, Non-invasive Physiological Devices (e.g., galvanic skin response, electrodermal response, heart rate), autonomous and semi- autonomous mobile robots(e.g. Pepper robot or sensor equipped powered wheelchair).

- Virtual Reality apparatus:

For experiments involving virtual reality, participants will be either equipped with a Head-Mounted Display (HMD), or will wear 3D stereoscopic glasses while being immersed in a CAVE (Cave Automatic Virtual Environment). The time of exposition will be reduced to 1h maximum per session and per day with several breaks to minimize any potential side effects, such as disorientation or vertigo.

- Motion Capture Systems:

For experiments requiring to track the trajectory or motions of participants, we will use motion capture systems equipped on the participants. For instance, HTC Vive trackers or a few reflective markers (e.g., vicon system) will be used to track the global position and orientation of the participant when only their global trajectory is necessary. When full body motion is required, we will either use an optoelectronic motion capture (e.g., vicon system) in which case participants will wear a set of reflective markers attached to the subject using double-sided hypoallergenic tape, or IMU-based motion capture suits (e.g., xsens system).

- Eyetracking Systems:

When necessary for the experiment, we will record participants' gaze activity using an eyetracker. Such recording can be conducted either in virtual reality stereoscopic situations (e.g., using eyetracking glasses such as Tobii Pro Glasses), when using Head Mounted Displays (e.g., FOVE eyetracking HMD), or using desktop screens (e.g., the Eyetribe eyetracker). In all cases, eyetrackers are simple cameras attached to eyetracking glasses, mounted in HMDs, or mounted on tripods below screens, that record where participants look at.

- Haptic devices:

To improve the participant immersion in virtual reality, non-invasive, safe, haptic devices might be used. We can distinguish wearable devices, useful when the participant touch something with his hand for instance, and non-wearable haptic device, such as stewart plateforms or similar, useful when the participant is virtually immersed in a vehicle, such as a powered wheelchair.

- Non-invasive Physiological Devices:

In addition, when required for the experiment we will record physiological information of the participants' activities using non-invasive wearable devices (e.g., galvanic skin response, electrodermal response, heart rate).

- Mobile robots:

Studying human-robot interaction require the presence of a robot in the experiment. The robot pepper from the company Softbank robotics might be used, as well as a powered Wheelchair developped in INSA Rennes, and the robot Cuybot developed by the company Locomotec in the context of CrowdBot.

- Experimental procedures:

Once equipped with the apparatus required for the experiment, and placed either in real or virtual environments depending on the study, participants will be asked to perform a number of taks, highly similar to daily activities. Participants will be provided with frequent breaks and can ask for additional breaks or to stop the experiment whenever they want.

- Risks:

The research procedures will be the least risky that can be performed consistent with sound research designs.

- Debriefing:

At the end of the experiment, the investigators will be at the participants' disposal to answer any question they have.

- Questionnaires:

At the end of the experiment, participants will be asked to fill questionnaires, e.g., about cybersickness, the quality of the immersion, and to provide feedback about the experiment.

- Data analyses and publications:

Data will be analysed and published anonymously.

Target population:

- People without any specific classification on vulnerable populations.
- Adult users of electric wheelchairs.

We will recruit healthy participants over 18 of age. Recruitments will be done through institutional e-mails or personal/professional networks. In general, there is no a priori about the gender and ethnic background of the participant population being recruited. However, some instances might require to restrict the recruited population, which will be precise in the instance description. For instance, because of the general influence of high-gaming experience on people's gaze behaviours (e.g., "gamers" typically display non-habitual searching gaze patterns), we will typically recruit non-gamer participants (i.e., playing video games on average less than 1h a day) for experiments requiring the use of an eyetracker. Also, we might recruit disabled people using powered wheelchair for some experiments involving a smart powered wheelchair or a powered wheelchair simulator. The recruitment is done during the 2 weeks preceding the experiment.

Recruitment process:

We recruit participants through institutional e-mails or personal and professional networks.

1.5. Locomotec

Tests with CuyBot in University Bonn-Rhein-Sieg were conducted under several conditions which were arranged informally. It should be noted that the tests were not a single event, but spread over a time span of several weeks, starting in the second week of October 2019 until mid of December 2019. Some implementation details and practical issues were updated in this period while experience was gathered during the tests, for more details it is referred to CrowdBot Deliverable **D1.4 1st Round Test Evaluation Report.**

Pedestrians in the vicinity of the robot were not explicitly informed about the ongoing robot tests. If asked, of course information about the tests, the robot and the project etc. was provided.

Tests with CuyBot in University Bonn-Rhein-Sieg were conducted under several conditions which were arranged informally. In the tests no incidents with pedestrians happened. Therefore the informal arrangement and application of safety methods as described below were considered sufficient. Actually contacts between pedestrians and robot did occur, but according to the person accompanying the robot in all cases it was due to the pedestrian, usually trying to overtake or closely pass by the robot. No harm to persons or the robot did occur.

Three main safety methods were in place:

- First of all the robot was always accompanied by a person carrying a remote control device that could stop the robot immediately. While the robot itself was driving autonomously through university, that person was walking in viewing distance to the robot and would stop it in case of unexpected behaviours or possibly dangerous situations. The role of the person walking with the robot was filled by different students from the Master Course of Autonomous Systems of the university. They were familiar with Robotics in general and the specific robot in particular. These persons were also told to avoid possibly dangerous situations for example with elderly or handicapped persons, though inside the university such situations rarely occurred.
- The robot had two emergency stops, one left and one right at the top. Any person close by the robot could press them to make the robot stop driving. During the tests these were actually not triggered (except for testing purposes).
- The navigation algorithm of the robot also included a safety region around the robot. If any object was detected inside that region the robot would not move by itself. This restriction should not be necessary anymore with the developments from the project, but during this first test phase cuyBot did not try by itself to get into contact with people or objects.

All data collected by the robot was saved on the robot's hard disk to enable investigation if any incidents would occur. Data collection was handled according to GDPR in the sense that all data processing was done anonymously without identification of people. While the robot used cameras for people tracking, all recorded data is kept strictly confidential. For the conducted tests as well as for upcoming experiments, no pictures or videos including people would be made publicly available without asking for explicit consent from university.

In addition, statistics were gathered to collect data such as distance travelled, time to reach certain points, average velocity, etc. Particular incidents, like failures of the robot or unexpected behaviours, were noted down manually by the accompanying persons. Also, here no personal data or elements which would make it possible to identify single individuals was collected.

2. ESAB Meetings

Four ESAB meetings have taken place since the project start:

- 1st ESAB teleconference meeting on April 16th, 2018
- 2nd ESAB teleconference meeting on January 25th, 2019
- 3rd ESAB teleconference meeting on December 19th, 2019
- 4th ESAB teleconference meeting on October 7th, 2020

For the involvement of ESAB we have used video conference platforms.

2.1. Meeting on April, 2018

ESAB Members: Raja Chatila, Armin Seyfried, Erica Palmerini, Nicola Christie, Gianmarco Veruggio, Aude Billard and Pericle Salvini

CrowdBot project members: Julien Pettre and Ceilidh Hoffmann

n-attendee Comments: Peter Kahn, Alan Winfield and, Nicola Christie

Agenda:

- Introduction by Julien Pettre of CROWDBOT project
- CROWDBOT Ethics scope by Aude Billard
- CROWDBOT scenario slides walk-through by Pericle Salvini

Topics under discussion:

- Preliminary list of potential hazards related to CROWDBOT robots.
- CROWDBOT scenarios. Three examples were proposed for discussion:
    1) *Emergency auto-piloting:* During a mass event, such as a musical concert, a person is not in the condition to drive his/her wheelchair, because he/she is sick or panicking. Thus, the driver activates the emergency autopilot. The wheelchair navigates autonomously towards the (emergency) exit among the other people. The exit is clogged and the wheelchair should make its way in the crowd without hurting anybody, but also without being pushed away.
    2) *Searching, protecting and rescuing humans in an emergency situation:* During an emergency evacuation, the robot searches for fallen people. If someone is found lying on the ground, the robot positions itself against the crowd flow, so as to shield the person and avoid him/her to be trampled on by other people. The robot informs the central station of the person, informs the surrounding crowd of the presence of an injured person, and, if possible, guides him/her toward a safe area or remains in the shielding position until an emergency rescue team arrives.
    3) *Assistant in a hospital*: The cuyBOT robot transports medicines/samples/medical records from one area of the hospital to another along a long, very busy corridor characterised by a bi-directional flow of people.

Summary of comments of ESAB members during and after the meeting

- It could be interesting to look at real crowd behaviour. For instance crowd behaviour in terrorist events. Is a robot better than a human? If not, why the need?
- The focus is about safety rather than ethics. You are mainly addressing physical and psychological dangers of robot; yes there may be ethical concerns arising from safety but what about general ethical issues such as compliance to values, less so of social norms etc. the general test scenarios and global context description is confusing real ethical questions at hand

- You are considering only “friendly” scenarios; what if the robot itself is perturbing the environment? What about mixed crowd with unpredictable reactions or misbehaving humans?
- A wheelchair is different from a conventional robot. How will people know it is running in (semi) autonomous mode?

Comments from non-attendee participants

- Liked emphasizes on the “freezing problem”, working across different robotic platforms (Pepper, semi-autonomous wheelchair, and cuyBot), and the focus on potential hazards.
- The scenarios proposed such as in search and rescue, hospital setting, and mass event (such as a musical concert); seem practical and societally worthy, and have benefits that will likely allow lay people and society at large to give ground on some of their concerns with the robots.
- Perhaps the document needed more background. How much funding is there over what period of time? What percentage of that is directed toward solving technical problems? What percentage is focused on these ethical concerns? What’s the workflow between the technical and the ethical?
- One framing missing from this discussion was the distinction between a single robot in a crowd, and a crowd of robots in a crowd.
- Some issues in Crowdbots could be parallel to what is beginning to happen with autonomous (and semi-autonomous) cars on the roads. It could be worthwhile to mine that literature for how they are trying to solve some of these issues – ethically, and perhaps where relevant technically.
- You ask the important question “who should be responsible in case of damage caused by an autonomous robot?” (p. 5). My sense is that that’s an evolving ethical space. It involves issues of existing law. But it’s also a psychological issue of how people understand what these robots are and whether they view them as morally responsible agents.
- Future laws will seek to extend existing laws, build from an ethical stance that accounts for the increased sophistication (and social presence) of the technology, and integrate (and take seriously) the moral psychology of how people understand their moral relationships with these technologies.
- People’s views of robots may well change quickly, so that some of the concerns you’re having to deal with now (such as people not wanting to be touched by a robot?) may become mute.
- I wanted to alert you to IEEE standard P7001, currently being drafted, see http://sites.ieee.org/sagroups-7001/. This is a new standard on transparency on autonomous systems - based on the ethical principle that it should always be possible to find out why an autonomous system made a particular decision.Transparency is not one thing, so we are in fact writing a several standards within P7001, each for a different stakeholder. For crowd bots two critical stakeholders are (1) users - i.e. people who interact directly with the robot as either supervisors of the robot, or people who come into close proximity with it, and (2) wider society including bystanders who do not come into close proximity with the robot but who nevertheless should be aware of such robots in the vicinity. We think it is really important that both stakeholder groups have an understanding of what the robot is doing and why. Those who come into close proximity should, for instance, have the option of asking the robot “why did you just do that?”. This would at least help to overcome the problem that actions might seem puzzling and the robot inscrutable, and hence not trusted.
- Another really important aspect of transparency is the ability to find out exactly what happened following an accident. The transparency needed by accident investigators suggest the need for what we call an ‘ethical black box’ - the robot equivalent of an aircraft flight data recorder.
- Recent Frontiers paper on improved robot safety through the use of a simulation-based internal model, inspired by the problem of how mobile robots could move quickly and safely through crowds of moving humans. See https://www.frontiersin.org/articles/10.3389/frobt.2017.00074/full

Table 1. Key concerns deriving from 1st ESAB meeting and CROWDBOT action/response

KEY CONCERN	PROJECT ACTION/RESPONSE	OTHER
Safety	Investigate physical as well as psychological hazards, including security aspects	
Robots should respond to social need	Open question	
Accountability (Ethical Black Box)	Open question	
Transparency of robot behaviour	Improve legibility of robot behaviour	

2.2. Meeting on January, 2019

ESAB Members: Alan Winfield, Nicola Christie, Armin Seyfried, Aude Billard and Pericle Salvini

CrowdBot project members: Julien Pettre, Ceilidh Hoffmann, Tom Carlson, Paez Granado Diego Felipe

Agenda:

- Presentation of D1.1 'Specification of Scenarios Requirements' by INRIA (5minutes) + discussion (10 minutes)
- Presentation of D1.2 'Experiment protocol and risk assessment' by UCL (5 minutes) + discussion (10 minutes)
- Presentation of D4.1 'Study of physical interaction between mobile robots and humans' by INRIA (5 minutes) + discussion (10 minutes).
- Presentation of D6.1 'Overview of Risks When Using Robots in Crowds' by EPFL (5 minutes) + discussion (10 minutes)
- Virtual Reality platform for crowd-robot interaction simulation by INRIA (5 minutes) + discussion (5 minutes)
- Organization of a workshop on ethics and safety

Topics under discussion:

- The goal of this meeting was to inform ESAB members about scenarios requirements, experimental protocols and potential risks related to CROWDBOT robots during the experimentation phases

Summary of comments of ESAB members during and after the meeting

- To pay attention to the safety of humans during the experiments that will be carried out during the CROWDBOT project and on compliance with current ethical and legal requirements.
- To obtain ethical approval for operating CROWDBOT robots in the wild.
- To focus on risks related to physical contacts are not very much covered yet by safety standards.
- It might be appropriate to refer to the relevant provisions in the GDPR for privacy and data protection. It could be useful to create a "check-list" of the requirements to comply with and to prepare the consent form.
- To consider getting an insurance to cover risks of physical damage or damage to property of the stakeholders

- In the overview of risks, you may want to include also a legal perspective in terms of who would be liable in case some of the risks that have been identified materialize and cause harm to somebody.

Table 2. Key concerns deriving from 2nd ESAB meeting and CROWDBOT action/response

KEY CONCERN	PROJECT ACTION/RESPONSE	OTHER
Privacy and data protection of subject involved in the experimental trials	Fully addressed in the ethical protocols approved	
Physical safety during experimental trials	Fully addressed in the ethical protocols approved	
Insurance for physical damage and damage to property during experimental trials	Fully addressed in the ethical protocols approved	
Ethical approval of experimental protocols	Obtained	

2.3. Meeting on December 2019

ESAB Members: Erica Palmerini,. Alan Winfield

CrowdBot project members: Julien Pettre, Aude Billard, Pericle Salvini

Agenda:

- Discussion of legal regulations and standards relevant for CROWDBOT

Topics under discussion:

- Current European legislation for robots navigating in pedestrian areas (i.e. public spaces or private for public use).
- Applicable safety standards for CROWDBOT.
- Privacy and other ethical implications emerging from CROWDBOT deployment.

Summary of comments of ESAB members during and after the meeting:

1) Current European legislation for robots navigating in pedestrian areas (i.e. public spaces or private for public use).

- Currently there is no legislation for robots servicing in public space. Although there are standards that do apply – they are voluntary, unless standards are not mandated in regulations. Law is following technology, which means that firstly we introduce robots and only then, if there are problems, we create the rules. Mobile robots are in use already. Examples in hospitals – porting robots, autonomous machines used to fetch medicines, might be able to take the lift. These robots are not regulated.

- Another interesting case are the so-called personal delivery robots (PDRs), such as Starship (https://www.starship.xyz/), which are currently used in some countries in Europe and US. In the US there is no Federal legislation concerning PDRs, but only State or local laws. The first regulation and the one which has been used also in other states is the Personal Delivery Device Act, which was passed by the district of Columbia in 2016, for a pilot programme to operate delivery robots. This Act was designed after the Washington DC bike law. According to (Marks, 2019) there are differences among the several state laws and the main differences concern:
  - The robot weight which ranges from 50 to 120 pounds (22 kg to 54 Kg).
  - Speed usually 10 MpH (16 Km/h)
  - Robots rights and duties. Robots has the same right and duty of pedestrians although they have to yield to pedestrians and do not interfere unreasonably with their movement
  - Insurance. Robot operators should carry liability insurance (minimum required coverage about $100.000).
  - Identification. Robots should exhibit identification tag o plate
  - Visibility. External lights for visibility at night
  - Remote control. Although robots are fully autonomous, they should be designed to be tele-operated for safety reasons.
  - Human supervision. Must be actively monitored or controlled by human operators. As pointed out by (Marks, 2019) “The laws don’t go into much detail on what it means to be monitored. In other words, one operator could be responsible for monitoring 100 robots and meet the requirements of state statutes”.

2) Applicable safety standards for CROWDBOT.

- Existing standards apply to some aspects of CROWDBOT, but not all. ISO 13482:2014 is relevant. The standard concerns safety around navigation and around people. But do not consider privacy.
- Robots need to have insurance. It is possible to insure robots. What are the causes that caused the robot accident? All robots should be endowed with a data logger (sort of black box) if you do not have a record of what the robot was doing in timeline (speed, movements, direction these basic data) you have not ground truth, not factual information for accident investigation. Also witness accounts, CCTV footage for testimony are important. However, insurance might not have access to algorithms, unless a very serious accident occurred. We need to arrive at a culture of data sharing, for instance in aviation. Robotics should copy that kind of good practice. Unfortunately, this is not happening in self-driving cars, where companies are competing with each other. Data logging is important.
- Insurance contracts can have rules for disclosure. If the manufacturer has an insurance policy and wants to be insured, is the manufacturer her/himself that explains what happens. It is in his/her interests to do that.
- In a driverless car is not the insurance that covers the costs, is the manufacturer. Tesla deals directly with the families of the victims.
- This is strange because in the US, the legislation obliges companies testing self-driving vehicles to have insurance and with a high price.
- For CROWDBOT it should be interesting to see what an insurance company requires for the robot.
- In Europe, self-driving cars are not included in traffic law. According to traffic law, a vehicle is a machine driven by a human.
- German traffic code has been amended for allowing higher levels of autonomy. This is the only European country. In other countries, full autonomy is not allowed
- In the UK there are no high-tech safety levels for self-driving cars.

3) Privacy and other ethical implications emerging from crowdbots deployment.

- There are no privacy standards specifically designed for robotic devices, but efforts for standardization movement for data protection are being made. Indications on how to implement privacy by design are contained in European GDPR, article 25. Devices that process data have to be built in a way that is privacy compliant, such as data minimisation principle; time limits of storage data.
- British Standard BS8611:2016 “Robots and robotic devices. Guide to the ethical design and application of robots and robotic systems” gives a checklist of ethical hazards and risks and some advice on how to mitigate and reduce those risks. They are quite broad, physical and psychological harm, so for CROWDBOT can be useful to check it. For instance, “Mirror” is a robot dog with face recognition tech built in. Children were upset because the robot could not recognize the face of a child. Face recognition is not ethical.
- There are ethical and legal implications also in animal robots, because they elicit emotions and create the impression that there is a mutual relationship.
- Vision algorithms can be designed with gender bias because instructed to recognize people only if they have two legs, but this implies that whoever wears a long skirt is not recognised as “people”.
- As to robots using cameras and microphones they are not breaching the law, unless you do not store data but just process data and warn people by using signs that you are recording. For robots that move on streets there could be a sign on the robot itself or along the path it uses.
- Could be interesting to find out whether there has been any lawsuit against these robots, since there is no legislation.

Table 3. Key concerns deriving from 3rd ESAB meeting and CROWDBOT action/response

KEY CONCERN	PROJECT ACTION/RESPONSE	OTHER
Gaps in current legislation with respect to autonomous robots	Open question	Outside the scope of the project
No existence of specific standard for autonomous robots	Reference standard considered ISO 13482:2014 personal care robot	The project will propose a standard for robots operating in crowded spaces
No insurance policies for autonomous robots	Insurance companies to be involved in stakeholders’ meetings	Outside the scope of the project
No privacy standards for autonomous robots	GDPR will be used as reference framework for robot design	

2.4. Meeting on October 2020

ESAB Members: Sylvain Petitjean, Armin Seyfried, Erica Palmerini, Raja Chatila, Pericle Salvini, Nicola

CrowdBot project members: Aude Billard, Diego Paez, Julien Petre, Walter Novak, Alexander Mazel, Tom Carlson

Agenda:

- Review of current CROWDBOT project status.
- Review of Ethical and Safety Issues in Crowdbot
- General Discussion

Topics under discussion:

- Current European legislation for robots navigating in pedestrian areas (i.e. public spaces or private for public use).
- Applicable safety standards for crowdbots.
- Privacy and other ethical implications emerging from crowdbots deployment.

Summary of comments of ESAB members during and after the meeting:

- An outcome of the project is expected to provide recommendations on the robot behaviour for instance with certain crowd densities variations, from 1ppsm to 3-4 ppsm. The strategy considered for a changing crowd could be that the robot should not operate or stop.
- The CROWDBOT project tries to address crowd variations and the corresponding ethical behaviour in part through multimodal navigation, and sensing by ETHZ work.
- Nudging strategies are a nice way to communicate, but we could enhance this with other methods of a more direct communication of the robot' intention. There exists a standard on nudging for robots, by IEEE P7008
- The project might benefit from interacting with the people driving P7008. One of the members of ESAB is chairing the AI and autonomous proposals for IEEE standardisation
- Concerning the certification process for service robots, it is pointed out that it is mostly self-certification
- How the robot communicates with the people is an important aspect for safety mitigation (type of voice, visual communication, e.g. screen, however, in a crowd it is difficult to hear anything because of the high noise levels. Visual is equally limited, as very few people could observe it.
- Not many regulatory frameworks exist covering service robots moving in human-inhabited environments, in particular for addressing the physical risk of robots by wrongful behaviour. A possibility could be to amend current regulations. The EU is tackling this type of issue by amending products directives. Current directive 1985: very old. Thus, not considering multiple value change actors are not considered.
- Awareness of stakeholders' categories is important (e.g., child, elderly, pregnant women). However, it is not relevant for the robot to know the type of stakeholder, but rather the behaviour is more important. How each entity behaves is what should be taken into account.

Table 4. Key concerns deriving from 4th ESAB meeting and CROWDBOT action/response

KEY CONCERN	PROJECT ACTION/RESPONSE	OTHER
Safety in high density environments	Over certain density the robot will stop	
Transparency of robot behaviour	In order to improve direct communication of the robot' intention, the IEEE standard P7008 on "Nudging" will be considered	
Safety certifications needed	Open question	
Safety in case of collision	Bumpers and post collision compliance (passive) devices will be used in robot design. Moreover, crash	

	tests with dummies are planned with CROWDBOT robots	
Lack of regulatory framework	To propose new regulations and amend current ones	
Liability	Open question	
Liability in shared control	Open question	
Safety with respect to different types of pedestrians	Crash tests with special dummies representing a child and woman are planned with CROWDBOT robots	

2.5. Wheelchair Users Roundtable

External Participants:
Moderator: Felipe Ramos Barajas (UCL)
Attendees: 1 end-user from UK, 1 end-user from Switzerland and 1 end-user from France.

CrowdBot project members:
Pat Zhang (UCL), Catherine Holloway (UCL), Solenne Fortun (INRIA), Diego Paez-Granados (EPFL)

Topic: Ethics of using shared control wheelchair in crowds
Objective: Getting input from potential end-users
Platform: Zoom
Time: 3 March, 2021 (14:00-15:00)

Agenda

- What are the difficulties and needs of wheelchair users in mobility assistance in busy environments, such as airports, malls, museums, and train stations? [10 mins]
  a. Do you limit yourself to avoid crowded places?
  b. What issues have you encountered? How did you manage these?
  c. What potential assistance could be helpful?

  1.1. Introduce our wheelchairs -- images, videos etc [5mins]

- Scenarios [10 mins]

  Imagine there is a new wheelchair and this wheelchair can help people with situations where controlling a standard wheelchair is difficult. For example, if a person's hand spasms and locks into the turn right position, the wheelchair could see that they are heading for the wall and course correct. Or for example, when going through a tight door frame, it could slightly correct a user's input to help make it through the door without hitting the door frame. In crowds, it could help take a smooth path without hitting people.

  How does this sound to you?

  <u>Additional prompt questions:</u>

  Would you be worried that it might get things wrong?

  When would you like the wheelchair to help your inputs to make a course, and when would you not?

- **Detailed ethical questions [15 mins]**
  d. What if sometimes the wheelchair does not follow your intention?
  e. Under what situation would you find it acceptable/or not?
  f. How would you feel if a wheelchair decides to ignore your command to move forward when you don't perceive any danger, but the autonomy seems to perceive something and takes a detour?
  g. What would you think if a wheelchair stops abruptly, then you realize it has avoided a collision with a running child?

- Do you think it is ethical for a wheelchair to share the control for a route?
- Open discussion? [10mins]
- Closing [5mins]

Summary of the roundtable:

The aim of this roundtable was to understand electric wheelchair user's needs and their ethical concerns in using a shared-controlled wheelchair in crowds. Three experienced current electric wheelchair users coming from three different European countries (UK, Switzerland, France) shared their views.

- **Difficulties and needs of end-users on crowded environments:**

We began by asking them about general scenarios where they find driving a standard wheelchair to be difficult and what they think would be helpful in dealing with these difficulties. Although all of them had experienced collisions with other people and admitted driving in crowds is a problem, they thought the problem is more associated with people's lack of awareness and understanding of the wheelchair than the control of the wheelchair itself.

P1 described this as common in many crowded scenarios. "*If you are in a wheelchair, you become invisible and people just don't see you….*". He also gave an example of how able-bodied people expected him to move sideways on a narrow road showing no understanding of the wheelchair's kinematic limitations.

Some of them shared their experience in dealing with “unresponsive people”. “Speed is the key. In a music festival, you just need to keep driving so people can notice you and they may even split out.” (P2). “Especially in places such as airports and train stations, people may not see you and they may fall on you.” P3 elaborated on his experience and raised some concerns related to speed. He mentioned that sometimes he is not sure whether he should drive faster so that people can see him, or drive slower to have a comparable speed to the others.
In addition to increasing people’s awareness, they think designing the wheelchair in a way that takes people’s driving capability into account would be useful. P1 thought their wheelchairs are manufactured in a way to fit most average wheelchair users and the wheelchair dynamics is not desirable for him. For example, the delay between the joystick command and the wheelchair movement could be useful for beginners due to the safety consideration, but this makes the skilled drivers feel the wheelchair is not acting as they intended and is experienced as frustration for them.

- **Crowdbot technologies and users' perspectives:**

To better understand their needs for navigation assistance (especially in crowds) and their view on our robots, we then introduced our shared-control mobility devices to the participants by showing two short videos demonstrating the wheelchair navigating in simulated scenarios and the QOLO navigating in an actual crowded environment. General questions such as “What do you think about these devices” and detailed scenario questions were asked.

Not surprisingly, all three participants admitted it can be useful for people who have severe impairment and cannot control a standard wheelchair using a joystick, but rather not for themselves. Even though these three participants may not be potential users for a shared-controlled wheelchair, we tried to learn from their experience and summarized their view of potential challenges and design requirements into four points.

- **The level of autonomy and navigation assistance should depend on the user’s capability**.

As they have the ability to drive the wheelchair, they don’t feel like using such assistance. Even though they find driving in crowds is a problem and may result in collisions, they don’t restrain themselves from going there. To them, such scenarios can be better solved by increasing other people’s awareness and improving the wheelchair dynamics instead of adding navigation assistance. However, they admitted that such assistance can be very useful for people who cannot control the wheelchair properly. “One of my friends can only use a head array to control the wheelchair. For her, it can be helpful if the chair can bring her from A to B without collisions.” (P1).

- **It should take into account the user’s driving style and preference.**

Based on the roundtable and our previous studies results, we found wheelchair users who prefer to have more user autonomy can be categorized into two types: one prefers to be in control due to their driving style. “I hate automatic cars, I like to drive and I drive sportively.” (P3), while one wants to be in control due to psychological needs. This is also one of the supporting arguments for shared-control, compared to fully-autonomous devices, it allows users to have more authority in the driving decision-making process. While the level of autonomy should be designed based on the user's capability for the sake of their safety (as mentioned in the last point), it should also be designed in a way that is desirable to the user. As each individual is different, the shared-control should always be user-centered and allows the user to tune the assistance as they desire.

- **It should be able to deal with randomness in the environment such as crowds.**

P1 thinks it is not easy to deal with the crowds scenario as people’s trajectories are usually random and they are very difficult to predict. In our previous study, one participant raised the same concern and suggested that a simple people following function could be used as a starting point.

- **Ethics of shared-controlled wheelchairs should be considered differently from that of autonomous vehicles**.

Communication to the user and the pedestrians could be useful in reducing the confusion and building the trust. Compared to the usual ethical questions related to autonomous vehicles, shared-control adds another ethical concern: As the system has the ultimate say, what if its decision is different from the user's intention when it tries to avoid a collision? In general, the participants think it depends on the situation. If it would not result in danger for the user, it is acceptable. However, if it takes extreme actions such as stopping abruptly, even to avoid running into a child, it may result in danger for the wheelchair users. *"My safety comes first..."(P3)*. Different from self-driving cars where a collision may result in severe consequences, collision with wheelchairs at low speed may be tolerable to most people. *"At the end of the day, a child running into a wheelchair is no more different than a child running into for example a shopping trolley.."* (P1). P3 raised a concern about how shared-control may affect other people's feelings. *"When the wheelchair does something out of my intention and that causes unhappiness of other people, I don't want people to think it is what I intend to do and I'm a bad guy."* It is in agreement with previous interviews done in UCL where the wheelchair users think a feedback system could be useful both to them and the surrounding pedestrians.

Finally, through this roundtable discussion, we have learned potential design requirements and challenges from three skilled wheelchair users. For future study, we believe it is important to reconsider:

- The importance of increasing people's awareness and understanding of the wheelchair, both from the safety and ethical point of view. As mentioned by most participants, sometimes the collision may not be due to human error in control but lack of awareness in the surrounding pedestrians. For a shared-controlled wheelchair, the communication between the system and the surrounding people becomes more important. The question that needs to be answered is how to provide suitable signals to the pedestrians to increase their awareness but not make them or the user uncomfortable.

- What are the characteristics of a potential user for shared-control? and what is shared-control trying to achieve?
  As the participants said, shared-control could be most suitable for people who are not able to control a standard electric wheelchair. Navigation assistance could help them to achieve what they could not, and improve their driving independence. It is important to understand their view on our devices and we hope to interview some of them in the future.
  Initially, we believe adding navigation assistance could also be useful for current wheelchair users to deal with complex environments such as crowds. It is similar to the case of autonomous cars. They are not only designed for people who cannot drive. The main conveyed benefit of an autonomous car is that it would eliminate human errors and improve the safety of both the passengers and the pedestrians. In the case of a shared-control wheelchair, we can see it is slightly different in the sense that the user is involved in the decision loop and in terms of vulnerability of both parties as well as the consequences of collisions. Therefore, it is important to consider what is truly needed for current wheelchair users based on their driving capability and preference. How much control/authority should be given to the user? This question is related to the previous one and does not have a single answer for all. It should be considered based on the user's capability, environment, and ethical requirements.

In general, our findings are consistent with the results from other studies, and raised some more interesting questions to be answered. This roundtable only presents the view from skilled electric wheelchair users and we are interested to see how the view may change for different groups of people.
One limitation of such a study is that the participants' understanding of a shared-controlled wheelchair is solely based on our description and the video demonstration. It could be difficult for them to imagine their response

without actually experiencing such a device. In the future, we will recruit participants to try our wheelchair in a simulated environment and hopefully in an actual environment as well.

3. Workshop at IEEE ROMAN-2020 Conference

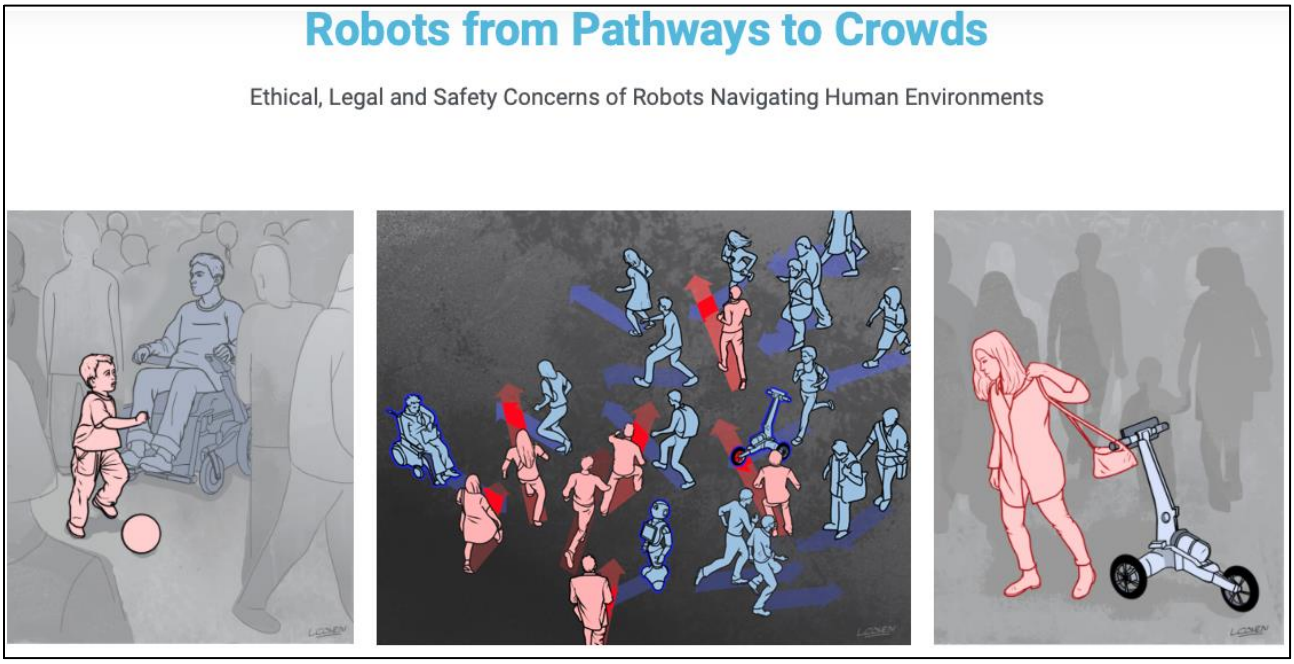

Figure 8. Head of workshop webpage

This workshop aimed at providing an overview of the challenges in navigating through highly dynamic human environments and a better understanding of potential sources of physical and psychological hazards. From robot-human crowd interaction simulation, robot navigation control, to an overview of the main ethical, legal and societal implications emerging from research and deployment of robots in such unconstrained environments with humans.

To this end, the workshop brought together a set of well-known experts on standards and safety for robots moving close to people, as well as a group of experts on ethics, law and social sciences. Herewith, focusing on an audience of both researchers and industrial roboticists with an interest in human-robot interaction, autonomous driving robots, robot control and navigation, design and safety of robot operation. While fostering involvement between the audience and speakers in an open and interactive discussion for sharing awareness of both technical and social challenges.

The workshop was held within the 29th IEEE International Conference on Robot and Human Interactive Communication (ROMAN 2020), Virtual Conference, August 31-September 4, 2020.

Full Workshop website: http://crowdbot.eu/workshop-roman2020/

Online Attendance record: ~ 70 people at some points.

Recordings of the Workshop: https://youtube.com/playlist?list=PLGE3BytxPSbMhS6iWlfPVihXn-s2kXRyC

Organizers: Diego Paez-Granados, Pericle Salvini, Aude Billard, Tom Carlson, and Julien Pettre

List of Invited Talks:

Title: *Hazards deriving from properties of the public environments*
Speaker: Prof. Takayuki Kanda, Kyoto University. Japan.
Available Online: https://youtu.be/gRzoyZZJzYI

Social robots are coming to appear in our daily lives. Yet, it is not as easy as one might imagine. We developed a human-like social robot, Robovie, and studied the way to make it serve people in public space, such as a shopping mall. On the technical side, we developed a human-tracking sensor network, which enables us to robustly identify locations of pedestrians. Given that the robot was able to understand pedestrian behaviours, we studied various human-robot interactions. We faced many difficulties. For instance, the robot failed to initiate interaction with a person, and it failed to coordinate with environments, like causing a congestion around it, and "robot abuse" problem. Toward these problems, we have modeled various human interactions. Such models enabled the robot to better serve for individuals, and also enabled it to better coordinate with people's crowd behaviour.

Title *Psychological safety: Perceptions of safety of social robots*
Speaker: Professor Elizabeth Broadbent, The University of Auckland, New Zealand
Available Online: https://youtu.be/mNCQAVuGprY

Safety is a critical issue in human-robot interaction. People must be confident that robots will not cause any harm to themselves or to others. This is especially important in healthcare, where robots will interact with patients in sick and often vulnerable conditions.

In general, perceived safety refers to feeling safe and comfortable in a particular situation, and it is related to low perceptions of risk of harm. The definition of safety can be extended in healthcare, where perceptions of safety not only relate to physical safety but also to advice given by robots and keeping private information safe.

Theoretical models of safety have mostly been developed for industrial robots. For example, the Robot Safety Acceptance Model, which shows that separation of workers from robots can increase team identification and trust, and increase perceived safety (You et al., 2018). However, unlike industrial robots, social robots have to operate in the same spaces as humans, so alternative models must be considered.

Perceived safety in robotics has historically been assessed in three main ways: (a) questions about people's affective states, e.g. anxiety and fear (b) measures of physiological arousal, e.g. heart rate (c) direct questions about how safe people think a robot is (Bartneck et al., 2009). The perception of trust is a related construct.

This talk considers aspects of the robot and the user that can influence perceived robot safety in healthcare, using the Model of Robot-Patient Interaction (Broadbent et al., 2018). This model describes robot, human, and communication factors that can impact patient outcomes. Relevant outcomes include satisfaction, engagement, compliance, and health status, as well as perceived safety.

Recent research has investigated how manipulation of several robot-related factors in the Model of Robot-Patient Interaction can impact perceived safety and related outcomes. For example, recent work has shown that the use of verbal humour by a healthcare robot significantly increased perceptions of safety (Johanson et al., in press). In other work, robot smiling was shown to increase perceptions of robot friendliness and better attitudes towards robots (Johanson et al., 2020). Other research has shown that people trust advice from a robot more than from a computer tablet, and think the robot is more likely to keep their information private, which may be due to the robot's more humanlike appearance (Mann et al., 2014). Yet, in other research, expectations of robot humanlike-ness have been associated with greater physiological arousal (Stafford et al, 2010; Broadbent et al., 2011). This and other research on robots in healthcare facilities will be summarized and related to the model.

Research in this area is important because low perceptions of safety can result in lower acceptance rates and lower use of robots. Reassurance regarding robot safety may allow more people to benefit from healthcare robots. Ideally, perceptions of safety of healthcare robots would mirror objective indicators, so that users have accurate assessments. The conclusion to this talk will consider how this may ethically and practically be achieved.

Title: *Social-robot accident investigation: a case study in responsible robotics*
Speaker: Prof. Carl Macrae, Nottingham University Business School, UK
Available Online: https://youtu.be/0dkDn8a2Wmc

Robot accidents are inevitable. Although rare, they have been happening since assembly-line robots were first introduced in the 1960s. But a new generation of social robots are now becoming commonplace. Often with sophisticated embedded artificial intelligence (AI) social robots might be deployed as care robots to assist elderly or disabled people to live independently. Smart robot toys offer a compelling interactive play experience for children and increasingly capable autonomous vehicles (AVs) the promise of hands-free personal transport and fully autonomous taxis. Unlike industrial robots which are deployed in safety cages, social robots are designed to operate in human environments and interact closely with humans; the likelihood of robot accidents is therefore much greater for social robots than industrial robots. This talk sketches a draft framework for social robot accident investigation; a framework which proposes both the technology and processes that would allow social robot accidents to be investigated with that same rigour that we expect of air or rail accident investigations.

Title: Safe Physical Human-Robot Interaction.
Speaker: Prof., Sami Haddadin, Technical University of Munich, Germany
Available Online: https://youtu.be/L7DdqugvX58

Focused on how to reduce the risks of contact; ensure safe contacts between humans and robots and distinguish between different types of contacts (intentional, unintentional and cooperative). Currently, the only available safety standard that would include robots navigating around humans is the ISO13482:2016. However, the standard does not provide any requirements for hazards deriving from the presence of human crowds.

Title: *Responsible Research and Innovation.*
Speaker: Dr. Rene Von Schomberg, European Commission, BELGIUM
Available Online: https://youtu.be/m7GsIALk9_k

Expert in responsible research, innovation and ethics for emerging technologies – focused on ethics for responsible research and innovation.

Overall Workshop Schedule:

8:30 - 8:45	**Welcome coffee** (Opening virtual space and connection for audience) Demo Videos of Crowdbot topics
8:45 - 9:00	**Welcome Address** CROWDBOT: Robots from Pathways to Crowds
9:00 - 9:30	**Prof. Takayuki Kanda (University of Kyoto, Japan)** Hazards deriving from properties of the public environments
9:30 - 9:35	*Short talk 1:* Anna M. H. Abrams (RWTH Aachen University, Germany) *Field observation: interactions between pedestrians and a delivery robot*
9:35 - 10:05	**Prof. Elizabeth Broadbent (The University of Auckland, New Zeeland)** Psychological safety, focusing on hazards deriving from low levels of perception
10:05 - 10:10	*Short talk 2: D.G. Sorrenti (University of Milan - Bicocca, Italy)* Interaction autonomous vehicle - pedestrian: dynamic vehicle behaviour as a function of subjective safety perception
10:10 - 10:15	*Short talk 3: Luca Marchionni (PAL Robotics, Spain)* Robot control and navigation: ARI's autonomous system
10:15 - 10:45	**Prof. Sami Haddadin (Technical University of Munich, Germany)** How to reduce the risks of contact ensure safe contacts between humans and robots
10:45 - 10:50	*Short talk 4: Diego Paez-Granados (EPFL, Switzerland)* Physical Safety in Collisions Between Robots and Pedestrians
10:50 - 11:00	***VIDEO DEMO*** EPFL: Qolo Robot / Locomotec: CuyBot / ETHZ: Pepper Robot / UCL Wheelchair

11:00 - 11:05	*Short talk 5:* Janderson Ferreira (POLI-UPE, Brazil) Analysis of CNN encoder and Deep Reinforcement Learning to Active Learning in Social Robotic Navigation
11:05 - 11:35	**PhD Rene Von Schomberg (EU Commission, UK)** Ethics for responsible research and innovation
11:35 - 11:40	*Short talk 6: Ben Wright (US Naval Research Laboratory, US)* Crowd Polarization as Environmental Alignment Heuristic
11:40 - 11:45	*Short talk 7: Henry Eberle (UCL, UK)* Autonomy vs. Safety in Shared Control Crowd Navigation
11:45 - 12:15	**Prof. Carl Macrae (Nottingham University Business School, UK)** Social-robot accident investigation, from expertise on ethical hazards
12:15 - 13:00	***Open Discussion with Speakers and Audience***

4. Summary of Safety Standard ISO-13482:2014

Since 2014, EN ISO13482:2014 has become the specific standard dedicated for the safety certification of personal care robots, which operates in close proximity to humans: information providers, object transporters, personal mobility carriers, and security patrollers. Among these robots, there are also those investigated in the CROWDBOT project. EN ISO13482:2014 is a European harmonized standard that affects the Machinery Directive (Directive 2006/42/EC). In other words, the application of EN ISO 13482:2014 provides a presumption of conformity with Machinery Directive and therefore it can facilitate the entitlement of CE marking. This means that in case of legal disputes, conformity to EN ISO 13482 can help to determine if a product is at no fault.

So far, a few robots have already been certified and obtained CE mark with EN ISO 13482:2014. They include guide robots (https://www.nsk.com/company/news/2017/press0404a.html), delivery robots (https://news.panasonic.com/global/topics/2016/45099.html), walking assistant robots (https://pressreleasejapan.net/2018/01/26/honda-walking-assist-device-receives-ec-certificate-medical-device-directive-mdd-utilizing-jqa-iso-13482-certification/), and wheel-based humanoid robots (https://www.iso.org/news/Ref2169.htm).

Among the most innovative aspects of EN ISO13482:2014 is that it deals with robots that move and work among humans without guards; with a certain degree of autonomy, namely without human intervention and it considers the possibility of close human-robot interactions as well as physical contacts between humans and robots. Annex A of the standard contains a list of hazard items that are considered typical of personal care robots although not “all-inclusive”.

However, since its release in 2014, there have been a few concerns among scholars regarding the scope and contents of EN ISO 13482:2014. According to Scassellati, the release of the standard was premature and hazardous since at the time of its publication there was little knowledge on the risks and opportunities of care as performed by robots: “we don’t have a clear understanding of the basic science behind human-robot interaction, about the roles care robots should play, the kind of support should provide, the impact on users”(Cole, 2014). In (Fosch Villaronga, 2016), the author performs a critical review of EN ISO 13482:2014, pointing out, among other aspects, the lack of semantic clarity in the terminology used, the lack of a precise definition of care robot; the confusing categories of robots present in the standard and the consequences of such ambiguities from a legal standpoint. Other studies highlight, for instance, the absence of a method to determine protective stop space, regardless of the robot model (Kim et al., 2017); the lack of a test evaluation technology and certification system for verification and validation of a robot stability (Gwon et al., 2019); the lack of guidance on certification of collaborative robots with a decisional layer (Guiochet et al., 2017); and the lack of concerns for risks related to cognitive or psychological hazards (Salem et al., 2015).

In addition to previously identified concerns, with respect to the robots developed in the CROWDBOG project, we do not consider EN ISO 13482:2014 suitable for guaranteeing people’s safety when robots operate in public spaces. The guideline implicitly assumes private spaces, such as households and offices, present the same hazards as in public spaces.

We highlight the existence of at least three properties peculiar to public spaces: 1) the presence of crowds; 2) the existence of social norms and proxemics rules and 3) the occurrence of misbehaviours by people. These properties impact robots’ safety. Moreover, the standard is focused on robot users or operators, but it lacks requirements to protect pedestrians and bystanders.

Crowd density:

Public spaces can become crowded. An environment is considered crowded when its density is above 4 people per square meter for moving crowd and 2 people per square meter for static crowd . The density of people present in the environment has not been considered as a source of hazards in EN ISO 13482:2014. Although EN ISO 13482:2014 acknowledges the presence of pedestrians and bystanders – referred to as “safety related object” – it does not take into account a specific attribute of people, namely the possibility of density variation, in particular high peaks, for instance during rush hours.

The density of people can be a condition requiring special technical capabilities for ensuring robots safety and task efficiency (Moussaïd et al., 2010). Among these features are the ability to operate safely in the face of numerous pedestrians; the ability to monitor and recognize the formation of crowds and react rapidly to changes in the dynamics and the ability to operate in a safe and socially compliant manner to the crowd, just to mention a few. Failure to cope with these aspects may bring about new hazardous situations, such as obstructing the crowd flow, creating crowd movements, or disrupting the crowd organisation.

Social and proxemics rules:

In public spaces, people tend to behave socially, namely they move and interact with other people by respecting social norms and proxemics rules. Moreover, it is typical of human beings to attribute social features to objects, including robots, as if they were social actors/agents (Reeves and Nass, 1996). This phenomenon, also known as anthropomorphism, implies that humans may expect that robots behave socially (Takayama and Pantofaru, 2009). As pointed out in section 2.1.2.1, EN ISO 13482:2014 does not take into account socially aware navigation requirements. According to the standard, the human beings present in the environment should be treated as “safety-related objects” namely as objects to be avoided, likewise animals.

As far as navigation and localization are concerned, EN ISO 13482:2014 recommends that the generated path of the robot avoids the positions of any pre-known “safety-related obstacles” without causing any unacceptable risk of collision and mechanical instability. The only requirement provided in case of human detection is that the robot should stop in case a human (i.e. a safety-related object) enters the protective stop space. ISO/TR 23482-2:2019 adds that in order to achieve a safe state, the protective stop is not the only option available. Other options can be adjusting the robot speed with respect to the distance or relative speed of an obstacle. Although EN ISO 13482:2014 considers the hazards deriving from robot motion and navigation errors, and those related to the lack of awareness of robots by humans (e.g. silent operations can increase the risk of collisions), we argue that it fails to acknowledge the hazards deriving from the lack of awareness of humans (not objects!) by robots. As pointed out by (Rios Martinez et al., 2015) humans should no longer be perceived only as dynamic obstacles, but also as social entities. As a matter of fact, it goes without saying that humans are different from the other “objects” present in the environment, because they have goals, obey to social norms and may react to the presence of the robot (Che, Okamura and Sadigh, 2018) and have expectation concerning its behaviour (i.e. adherence to social norms).

In other words, we argue that designing robots that navigate among human beings implies taking into account the physical as well as the social properties of the operative environments, such as social norms and proxemics rules. The lack of awareness of social behaviour can be a source of hazards.

Vandalism:

Contrary to what happens in private spaces, such as factories and domestic environments, or in professional relationships (i.e. surgical robots), where humans and robots collaborate with each other, in public spaces it is not always possible to assume that humans’ intentions towards robots will be good. Where access is open to everyone, it is not possible to exclude the presence of people with bad intentions. Vandalism is a case in point. Indeed, the risk of attacks to robots can be very high, as illustrated in several studies (Salvini et al., 2014), (Brscić et. al. 2015), (Keijsers and Bartneck, 2018) and (Romero, 2018). In fact, most of the robots in public spaces are operated in autonomous mode, unsupervised by humans, and work in environments which may be difficult to control.

Given the fact that personal care robots are meant to carry out services which imply close interactions and even physical contacts with people, a robot vulnerable to attacks by people with evil intents can represent a hazard for users, bystanders, and the environment. Planning against robot vulnerabilities should be an integral part of the robot design process and a requirement in safety assessment.

Nevertheless, EN ISO 13482:2014 does not consider the eventuality of acts of vandalism targeted to personal care robots. We will address this issue in more detail in the next section.

We argue that it is necessary to raise stakeholders' awareness on individuals' safety when robots are deployed in public spaces and discuss remedies, i.e., integrating the gaps present in EN ISO 13482:2014 or by creating a new dedicated standard.

In conclusion, in addition to those identified in EN ISO 13482:2014, we point out that new hazards should be considered for pedestrians and passers-by, as a consequence of the introduction of CROWDBOTS in public environments. It is possible to distinguish these new hazards in three main classes:

- Hazards deriving from physical human robot interactions, such as:
    - Hazardous human reaction to robot touch
    - Hazardous robot reaction to human touch
    - Physical contact with human body parts not intended for tactile interaction
- Hazards deriving from non-physical human robot interactions (not involving physical contacts), such as psychological hazards (stress, anxiety, fear, etc.) deriving from robot motion and appearance such as:
    - Hazards due to lack of social awareness (during navigation)
    - Hazards due to lack of legibility of robot intentions
    - Hazards due to lack of perception of safety
    - Hazards due to intrusion into one's privacy
- Hazards deriving from security threats to robots, which can be distinguished in two types:
    - Hazards due to internal vulnerability
    - Hazards due to external vulnerability

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