# CSI:Cobot

**Case study title:** CSI:Cobot (Confident Safety Integration for Collaborative Robots)

**Description**

The emergence of ‘collaborative robots’ promises to transform the manufacturing sector, enabling humans and robots to work together in shared spaces and physically interact to maximise the benefits of both manual and robotic processes. Whereas traditional, non-collaborative, processes rely on segregation of robots and workers to ensure safety, collaborative working introduces complex challenges around the monitoring and control of systems and processes; where people and robots operate in shared environments, and where physical interaction is a possibility, it becomes much harder to guard against potential hazards. Additional safety considerations are therefore required before robots can be deployed alongside people in industrial processes.

The CSI:Cobot project focuses on a complex industrial case study involving a mobile collaborative manipulator, i.e. iAM-R. These types of robots are generating increasing interest in industry in areas including machine tending, logistics, drug discovery, social care, and remote working. Our proposed case study relates to the former, and is supported by platform manufacturers, systems integrators, distributors, and end-users. The iAM-R is a mobile collaborative robot built on the MiR200 mobile robot base, and carrying a 3kg, 5kg, or 10kg 6-axis Universal Robot collaborative manipulator (the 10kg version being the focus of the existing CSI:Cobot case study). The two are combined with an Iconsys modular interface, which provides programmable control over the platform. The system has been CE marked, with the manipulator having 17 adjustable safety functions certified to PLd cat.3. The MiR base complies with EN1525 safety regulations, SICK safety lasers and PLd cat.3.

To comply with safety regulations, the iAM-R is currently limited to operation of either the mobile base or collaborative arm at any one time; before moving off the arm and payload are moved into a stowed position within the footprint of the robot. When the arm is operational, the mobile base remains parked. Significant benefit to end users would arise from being able to operate both the arm and mobile base at once, increasing the workspace of the combined robot. This is an open challenge, and a significant increase in complexity beyond that available in current collaborative robot safety controllers. A particular application for this is in opening and tending CNC machines.

**Stage of Development  (Technical contributor)**

PROOF-OF-CONCEPT, SIMULATION, MODELLING, VISION

**Expert info**

Expertise of the stakeholders involved in devising the SLEEC rules
Number of stakeholders writing the rules

| Stakeholder names | Expertise |
|---|---|
| TS-1 | Computer Science |
| N-TS-1 | Moral psychology, Law |
| N-TS-2 | Social/Moral Psychology |
| TS-2 | Engineer/Goal Modelling |

1. **Normative requirements**

   a. **Normative requirements in natural language**

*Normative requirements in natural language, in blue the corrected requirements after using N-Tool.*

| rule id | rule | impact | label(s) (social, legal, ethical, empathetic, or cultural) | stakeholder expertise | authors identifiers |
|---|---|---|---|---|---|
| 1 | Avoid bumping into human when too close to a human, or no route is available, avoid bumping into humans<br>- If the robot predicted trajectory includes bumping into a human, change it or avoid it.<br>- Whenever too close to a human, allow trajectory to be overrun.<br>- If bumping still happens, ask human if they are ok. | +N<br>+S | Legal<br>Social | Social/Moral Psychology | N-TS-2 |
| 2 | Account for human behavioral unpredictability | +N | Legal | Engineer/Goal Modelling | N-TS-2, TS-2 |

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| 3 | Ensure that the location of all nearby humans is being tracked and avoided. | +N<br>+S<br>-P | Legal | Engineer/Goal Modelling | N-TS-2, TS-2 |
| 4 | When performing any tasks, ensure that humans are aware of a nearby robot.<br>- Produce noises, lights, and stimuli that facilitate awareness.<br>- ~~Ensure that humans understand the robot's end goal for that task.~~ | +N<br>+S | Social<br>Empathetic | Social/Moral Psychology | N-TS-2 |
| 5 | If a human requests the robot to stop, stop it immediately. | +N<br>+S<br>+A | Social<br>Legal | Social/Moral Psychology | N-TS-2 |
| 6 | Before moving the base, inform humans that the robot's base will be moved.<br>- If robot encounters a human in the way, try to get around them. If there are no paths available, ask the human for permission to pass by. | +S<br>+N | Social | Social/Moral Psychology | N-TS-2 |
| 7 | If object, including humans, is sensed (via sensors) in the robot arm’s range of motion or in the path of robot’s base, lock robot’s movement immediately<br>- Robot can only resume moving once human physically re-enables it after obstacle is removed | +S<br>+N | Social<br>Legal | Psychology<br>Law | N-TS-1 |
| 8 | Speed of robot arm and base movement must be set at a level that does not cause harm upon impact with other objects<br>- Weigh pros and cons of quick movement (efficient work vs accidents) when determining speed to set | +S<br>+N | Social<br>Legal | Psychology<br>Law | N-TS-1 |
| 9 | Robot must not be assigned to complete tasks originally | +A<br>+S | Social<br>Empathetic | Psychology<br>Law | N-TS-1 |

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| | allocated to the human without the human's knowledge and consent to the change<br>- Clear division of labor required to ensure safety | | | | |
| 10 | Allocation of liability for different kinds of accidents must be established prior to beginning human-robot collaboration<br>- Must be clear which party is to blame when different accidents occur<br>- Human must always understand how much/how little responsibility they have over a particular robot action outcome | +A<br>+S<br>+T | Social<br>Legal<br>Ethical | Psychology<br>Law | N-TS-1 |
| 11 | Robot design and physical appearance must not mislead the human into assuming it is more competent than it actually is | +S<br>+T<br>+N | Social<br>Legal<br>Ethical | Psychology<br>Law | N-TS-1 |
| 12 | Human-CSI:Cobot collaboration must not be unnecessarily prolonged and must not completely replace human-human collaboration<br>- Human-Human contact must be prioritized at regular intervals<br>- Lack of human interaction is psychologically detrimental to humans. Negative emotions lead to carelessness and accidents | +S<br>+N<br>+B<br>+SR<br>+PH | Ethical<br>Social<br>Empathetic | Psychology<br>Law | N-TS-1 |
| 13 | If an accident occurs, the robot must stop the task and report the accident immediately | +S | Legal | Engineer/Goal Modelling | TS-2 |
| 14 | Prior to working with humans, the robot must ensure that it can communicate with all humans at work (through signs, common language, etc.) | +S<br>+CS<br>+SR<br>+E | Legal<br>Ethical<br>Empathetic<br>Cultural | Engineer/Goal Modelling | TS-2 |

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| 15 | When the robot is unable to complete a task due to some obstacle or malfunction, it will stop the action report to a human supervisor<br>- So that accidents do not occur from repeated attempts | +S<br>+N | Legal | Engineer/Goal Modelling | TS-2 |
| 16 | When robot is working and human is in range, too close, or there is no route available, or if the robot bumps into a human, then the robot should not continue its current task | +S<br>+N | Legal | All stakeholders | All stakeholders |
| 17 | When a human's actions are random or unpredictable (i.e deviates from normal), then the robot should stop its current action | +S<br>+N | Legal | All stakeholders | All stakeholders |
| 18 | When the human's actions are random or unpredictable (i.e deviates from normal), then the robot should ask permission to move | +S<br>+N | Legal | All stakeholders | All stakeholders |
| 19 | When the robot is asking permission to move, it should not be moving | +S<br>+N | Legal | All stakeholders | All stakeholders |
| 20 | When the human's actions are random or unpredictable (i.e deviates from normal) and there is a route available, then the robot should move away from the human | +S<br>+N | Legal | All stakeholders | All stakeholders |
| 21 | When a human is too close, the robot should inform the human | +S<br>+N | Legal | All stakeholders | All stakeholders |
| CONCERN | | | | | |
| c1 | When the robot is working and human is in range, too close, or the robot bumps a human, or there is not a route available, the robot continues its task | | | | |
| c2 | When the robot is working and human is in range, too close, or there is not a route available, the robot does not avoid bumping into a human | | | | |
| c3 | ~~When the robot is working and human is in range, too close, or there is not a route available, the~~ | | | | |

| | |
|---|---|
| | ~~robot does not adjust its route~~ |
| c4 | When the human's actions are unpredictable or random and the human is in range or too close, the robot does not stop action |
| c5 | When the human's actions are unpredictable or random the robot is still moving |
| c6 | When the human's actions are unpredictable or random and there is a route available, the robot does not move away from human |
| c7 | When tracking location and a human is too close, the robot does not inform the human |
| c8 | When the human says stop then the robot does not stop its action |
| PURPOSE | |
| p1 | When the robot is working and there is a human in its route, it must not bump human or let human too close |
| p2 | When the robot is working and human must be able to be in range |
| p3 | When the robot is continuing its task and human must be able to be in range |
| p4 | The robot must be able to stop action when human is in range |
| p5 | The robot must be able to stop action when human is too close |
| p6 | The robot must be able to adjust its route when human is too close |
| p7 | The robot must be able to inquire a human's safety when the risk is greater than medium |
| p8 | The robot must be able to stop action when accounting human randomness |
| p9 | The robot must be able to move at a safe speed when accounting human randomness |
| p10 | The robot must be able to inform the human when it senses that a human is too close |
| p11 | The robot must be able to stop when a human says stop |
| p12 | The robot must be able to ask permission before a human task is assigned to a robot |
| p13 | The robot must be able to increase its speed when a human is not too close |
| p14 | Liability must be able to be taken when preparing to deploy the robot |
| p15 | The robot must be able to report an accident |
| Impact keys: A = autonomy, PH = psychological health (non-maleficence), P = privacy, E = explainability, T = transparency, CS = cultural sensitivity, SR = social requirement, B 'beneficence' (doing good), N 'non-maleficence' (preventing/avoiding harm), and S 'safety'.<br>''+" and "-" for positive and negative impacts respectively. | |

1. **Rules in the SLEEC DSL**

The stakeholders corrections after analyzing the well-formedness of the rules using our N-Tool are commented and in blue.

```
def_start
    // Events
    event RobotMoving //Includes arm and base movement
    event RobotWorking
    event RobotContinueTask
    event RobotStopAction
    event AvoidBumping
    event AdjustRoute
    event InquireSafety
    event AccountHumanRandomness
    event TrackHumanLocation
    event InformHuman
    event HumanSaysStop
    event AskPermission
    event MoveAtSafeSpeed
    event IncreaseSpeed
    event PreparingRobot
    event AssignToRobot
    event AssignLiability
    event ConsiderAppearance
    event ReportIncident
    event MinimizeCobotCollaboration
    event PrioritizeHumans
    // Added events during the resolution process
    event ActionHumanRandom
    event Communicate
    event MoveAwayFromHuman

    // measures
    measure humanInRoute: boolean
    measure humanInRange: boolean
    measure bumpHuman: boolean
    measure humanTooClose: boolean
    measure routeAvailable: boolean
    measure humanReEnables: boolean
    measure risk: scale(low, medium, high)
    measure efficiency: scale(elow, emedium, ehigh)
    measure isHumanTask: boolean
    measure humanConsents: boolean
    measure accident: boolean
    measure humansPresent: boolean
    measure obstaclePresent: boolean
def_end
```

```
rule_start
        R1 when RobotMoving then AvoidBumping
        unless {humanInRoute} then AdjustRoute
        unless {humanTooClose} then AdjustRoute
        unless {bumpHuman} then InquireSafety

//** Resolve the concern c2: (ADD a rule)
// ** uncomment R1b
// R1b when RobotMoving and ({humanInRange} or ({humanTooClose} or (not {routeAvailable}))) then
AvoidBumping
//******************************************************************************************


  R2 when RobotMoving then AccountHumanRandomness

  R3 when RobotMoving then TrackHumanLocation

  R4 when RobotWorking then InformHuman

  R4b when RobotWorking then InformHuman

 // resolve redundancies comment R4b

  R5 when HumanSaysStop then RobotStopAction

  R6 when InformHuman then RobotMoving unless {humanInRoute} then AdjustRoute
        unless (not {routeAvailable}) then AskPermission

  R7 when RobotMoving and {humanInRange} then RobotStopAction
         unless {humanReEnables} then RobotContinueTask

  R8 when RobotMoving then MoveAtSafeSpeed
         unless (({efficiency} = elow) and ({risk} = low)) then IncreaseSpeed

  R9 when PreparingRobot and {isHumanTask} then not AssignToRobot
         unless {humanConsents}

  R10 when PreparingRobot then AssignLiability

  R10_1 when PreparingRobot then InformHuman

  R11 when PreparingRobot then ConsiderAppearance

  R12 when PreparingRobot then MinimizeCobotCollaboration

        R12_1 when PreparingRobot then PrioritizeHumans

  R13 when RobotWorking and {accident} then RobotStopAction

  R13_1 when RobotWorking and {accident} then ReportIncident

  R14 when PreparingRobot and {humansPresent} then InformHuman

  //**  Correct redundancy 2 (comment r14, delete rule)
```

```
   // R14v when PreparingRobot and {humansPresent} then Communicate
   //*****************************************************************************************

   R15 when RobotWorking and {obstaclePresent} then ReportIncident

   R15_1 when RobotWorking and {obstaclePresent} then RobotStopAction

  //** Resolve concern c1 (ADD rule R16, uncomment R16)
  // R16 when RobotWorking and ({humanInRange} or ({bumpHuman} or ({humanTooClose} or (not
{routeAvailable})))) then not RobotContinueTask
   //*****************************************************************************************

  //** Resolve concern c4 (ADD rule R17 + event, uncomment R17)
  // R17 when ActionHumanRandom then RobotStopAction
  //*****************************************************************************************

//** Resolve concern c5 (ADD rules R18, R19, uncomment R18 and R19)
// R18 when ActionHumanRandom then AskPermission
// R19 when AskPermission then not RobotMoving

 //*****************************************************************************************

//** Resolve concern c6 (ADD rule R20, uncomment R20)
// R20 when ActionHumanRandom and {routeAvailable} then MoveAwayFromHuman
//*****************************************************************************************

//** Resolve concern c7 (ADD rule R21, uncomment R21)
R21 when TrackHumanLocation and {humanTooClose} then InformHuman
//*****************************************************************************************

rule_end

concern_start
        // Safety
        c1 when RobotWorking and ({humanInRange} or ({bumpHuman} or ({humanTooClose} or (not
{routeAvailable})))) then RobotContinueTask
        c2 when RobotMoving and ({humanInRange} or ({humanTooClose} or (not {routeAvailable}))) then not
AvoidBumping
        //** Resolving c3, spurious, adjusting route requires routeAvailable, comment c3
        c3 when RobotMoving and ({humanInRange} or ({bumpHuman} or ({humanTooClose} or (not
{routeAvailable})))) then not AdjustRoute
        c4 when ActionHumanRandom and ({humanInRange} or {humanTooClose})
        then not RobotStopAction
        c5 when ActionHumanRandom then  RobotMoving
        c6 when ActionHumanRandom and {routeAvailable} then not MoveAwayFromHuman
        c7 when TrackHumanLocation and {humanTooClose} then not InformHuman
        c8 when HumanSaysStop then not RobotStopAction
concern_end

purpose_start
   p1 exists RobotMoving  and ({humanInRoute} and ((not {bumpHuman}) and (not {humanTooClose})))
   p2 exists RobotWorking and {humanInRange}
   p3 exists RobotContinueTask and {humanInRange}
   p4 exists RobotStopAction and {humanTooClose}
```

```
   p5 exists AvoidBumping and {humanTooClose}
   p6 exists AdjustRoute and {humanTooClose}
   p7 exists InquireSafety and ({risk} > medium)
   p8 when AccountHumanRandomness then RobotStopAction
   p9 when AccountHumanRandomness then MoveAtSafeSpeed
   p10 when TrackHumanLocation and {humanTooClose} then InformHuman
   p11 when HumanSaysStop then RobotStopAction
   p12 when AskPermission then AssignToRobot
   p13 when TrackHumanLocation and (not {humanTooClose}) then IncreaseSpeed
   p14 when PreparingRobot then AssignLiability
   p15 exists ReportIncident and {accident}
purpose_end
```