Introduction to Collaborative roBot

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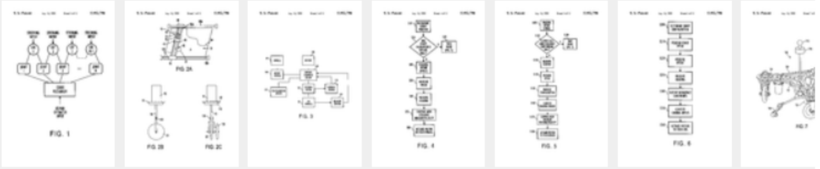
Abstract

An apparatus and method for direct physical interaction between a person and a general purpose manipulator controlled by a computer. The apparatus, known as a collaborative robot or "cobot," may take a number of configurations common to conventional robots. In place of the actuators that move conventional robots, however, cobots use variable transmission elements whose transmission ratio is adjustable under computer control via small servomotors. Cobots thus need few if any powerful, and potentially dangerous, actuators. Instead, cobots guide, redirect, or steer motions that originate with the person. A method is also disclosed for using the cobot's ability to redirect and steer motion in order to provide physical guidance for the person, and for any payload being moved by the person and the cobot. Virtual surfaces, virtual potential fields, and other guidance schemes may be defined in software and brought into physical effect by the cobot.

Images (19)



Classifications

B25J9/1656 Programme controls characterised by programming, planning systems for manipulators

US5952796A
United States

Download PDF | Find Prior Art | Similar

Inventor: James E. Colgate, Michael A. Peshkin

Current Assignee : Northwestern University

Worldwide applications

1997 • ~~US~~ 1998 • ~~AU~~ WO

Application US08/959,357 events

1996-02-23	Priority to US08/605,997
1997-10-28	Application filed by Northwestern University
1999-09-14	Application granted
1999-09-14	Publication of US5952796A
2016-02-23	Anticipated expiration
2021-02-02	US case filed in Illinois Northern District Court
Status	Expired - Lifetime

Show all events

- Cobots were invented in 1996 by J. Edward Colgate and Michael Peshkin, professors at Northwestern University.
- Their US patent entitled "Cobots" describes "an apparatus and method for direct physical interaction between a person and a general purpose manipulator controlled by a computer."
- The invention resulted from a 1994 General Motors initiative led by Prasad Akella of the GM Robotics Center and a 1995 General Motors Foundation research grant intended to find a way to make robots or robot-like equipment safe enough to team with people.

Definitions

3.10 industrial robot

- automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications
- Note 1 to entry: The industrial robot includes:— the manipulator, including actuators;
- — the controller, including teach pendant and any communication interface (hardware and software).
- Note 2 to entry: This includes any integrated additional axes.
- Note 3 to entry: The following devices are considered industrial robots for the purpose of this part of ISO 10218:— hand-guided robots;
- — the manipulating portions of mobile robots;
- — collaborating robots.
- Note 4 to entry: Adapted from ISO 8373:1994, definition 2.6.

3.11 Industrial robot system

- system comprising:— industrial robot;
- — end-effector(s);
- — any machinery, equipment, devices, external auxiliary axes or sensors supporting the robot performing its task
- Note 1 to entry: The robot system requirements, including those for controlling hazards, are contained in ISO 10218-2.
- Note 2 to entry: Adapted from ISO 8373:1994, definition 2.14.

Definitions

- **3.2 automatic mode**
- operating mode in which the robot control system operates in accordance with the task programme
- [SOURCE:ISO 8373:1994, definition 5.3.8.1]
- **3.3 automatic operation**
- state in which the robot is executing its programmed task as intended
- Note 1 to entry: Adapted from ISO 8373:1994, definition 5.5.
- **3.4 collaborative operation**
- state in which purposely designed robots work in direct cooperation with a human within a defined workspace
- **3.5 collaborative workspace**
- workspace within the safeguarded space where the robot and a human can perform tasks simultaneously during production operation

Definition

- A collaborative robot is a robot that CAN (capable) for use in a collaborative operation

- Collaborative operation – where purposely designed robots work in direct cooperation with a human within a defined workspace

Computer Supported Collaborative Work

Multiple users interacting together

- Presenting / Listening (eLearning, eMeeting)
- Cooperating (Design team at big display, email)
- Competing (Multiplayer game)
- Sharing (Video chat, Social network)

Difficult to construct

- Predictive model of interaction
- Controlled experiment

Computer Supported Collaborative Work

	Co-located	Remote
Asynchronous	Multiplayer game Project scheduling	Email, Conferences
Synchronous	Classroom Meeting room	Video Conferencing

CoBot Situations

- Coexistence: Human and robot work alongside each other without a fence, but with no shared workspace.
- Sequential Collaboration: Human and robot are active in shared workspace but their motions are sequential; they do not work on a part at the same time.
- Cooperation: Robot and human work on the same part at the same time, with both in motion.
- Responsive Collaboration: The robot responds in real-time to movement of the human worker.

CoBot Separation Distance

The stopping distance of the robot is determined according to ISO 10218-1:2011, Annex B.

The protective separation distance, S_p, can be described by Formula (1):

$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r \quad (1)$$

where

$S_p(t_0)$ is the protective separation distance at time t_0;

t_0 is the present or current time;

S_h is the contribution to the protective separation distance attributable to the operator's change in location;

S_r is the contribution to the protective separation distance attributable to the robot system's reaction time;

S_s is the contribution to the protective separation distance due to the robot system's stopping distance;

C is the intrusion distance, as defined in ISO 13855; this is the distance that a part of the body can intrude into the sensing field before it is detected;

Z_d is the position uncertainty of the operator in the collaborative workspace, as measured by the presence sensing device resulting from the sensing system measurement tolerance;

Z_r is the position uncertainty of the robot system, resulting from the accuracy of the robot position measurement system.

$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$

CoBot Separation Distance
Operator's Change in Location

The contribution to the protective separation distance attributable to the operator's change in location, S_h, is expressed by Formula (2):

$$S_h = \int_{t_0}^{t_0+T_r+T_s} v_h(t)dt \tag{2}$$

where

T_r is the reaction time of the robot system, including times required for detection of operator position, processing of this signal, activation of a robot stop, but excluding the time it takes the robot to come to a stop;

T_s is the stopping time of the robot, from the activation of the stop command until the robot has halted; T_s is not a constant, but rather a function of robot configuration, planned motion, speed, end effector and load;

v_h is the directed speed of an operator in the collaborative workspace in the direction of the moving part of the robot, and can be positive or negative depending on whether the separation distance is increasing or decreasing;

t is the integration variable in Formulae (2), (4) and (6).

Cobot Separation Distance
CoBot's Change in Location

$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$

A constant value for S_h using the estimated human speed (1,6 m/s), expressed in m/s, can be estimated using Formula (3):

$$S_h = 1{,}6 \times (T_r + T_s) \qquad (3)$$

If v_h is not monitored

The contribution to the protective separation distance attributable to the robot system's reaction time, S_r, is expressed by Formula (4):

$$S_r = \int_{t_0}^{t_0+T_r} v_r(t)dt \qquad (4)$$

where v_r is the directed speed of the robot in the direction of an operator in the collaborative workspace, and can be positive or negative depending on whether the separation distance is increasing or decreasing.

Cobot Separation Distance
CoBot’s Change in Location

$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$

— if the robot’s speed is not being monitored, the system design shall assume that v_r is the maximum speed of the robot;

— if the robot’s speed is being monitored, the system design may use the current speed of the robot, but shall account for the acceleration capability of the robot in the manner that reduces the separation distance the most;

— if a safety-rated speed limit is in effect, the system design may use this speed limit if the limit is applicable to the part of the robot under consideration.

NOTE A safety-rated speed limit that only monitors the Cartesian speed of the robot TCP does not monitor other parts of the robot that might pose hazards to the operator. A safety-rated speed limit that monitors joint speeds might also be needed.

A constant value for S_r can be estimated using Formula (5):

$$S_r = v_r(t_0) \times T_r \quad (5)$$

Cobot Separation Distance
Cobot's Stopping Distance

$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$

The contribution to the protective separation distance that occurs while the robot system is stopping is expressed using Formula (6):

$$S_s = \int_{t_0+T_r}^{t_0+T_r+T_s} v_s(t)dt \qquad (6)$$

where v_s is the speed of the robot in the course of stopping, from the activation of the stop command until the robot has halted.

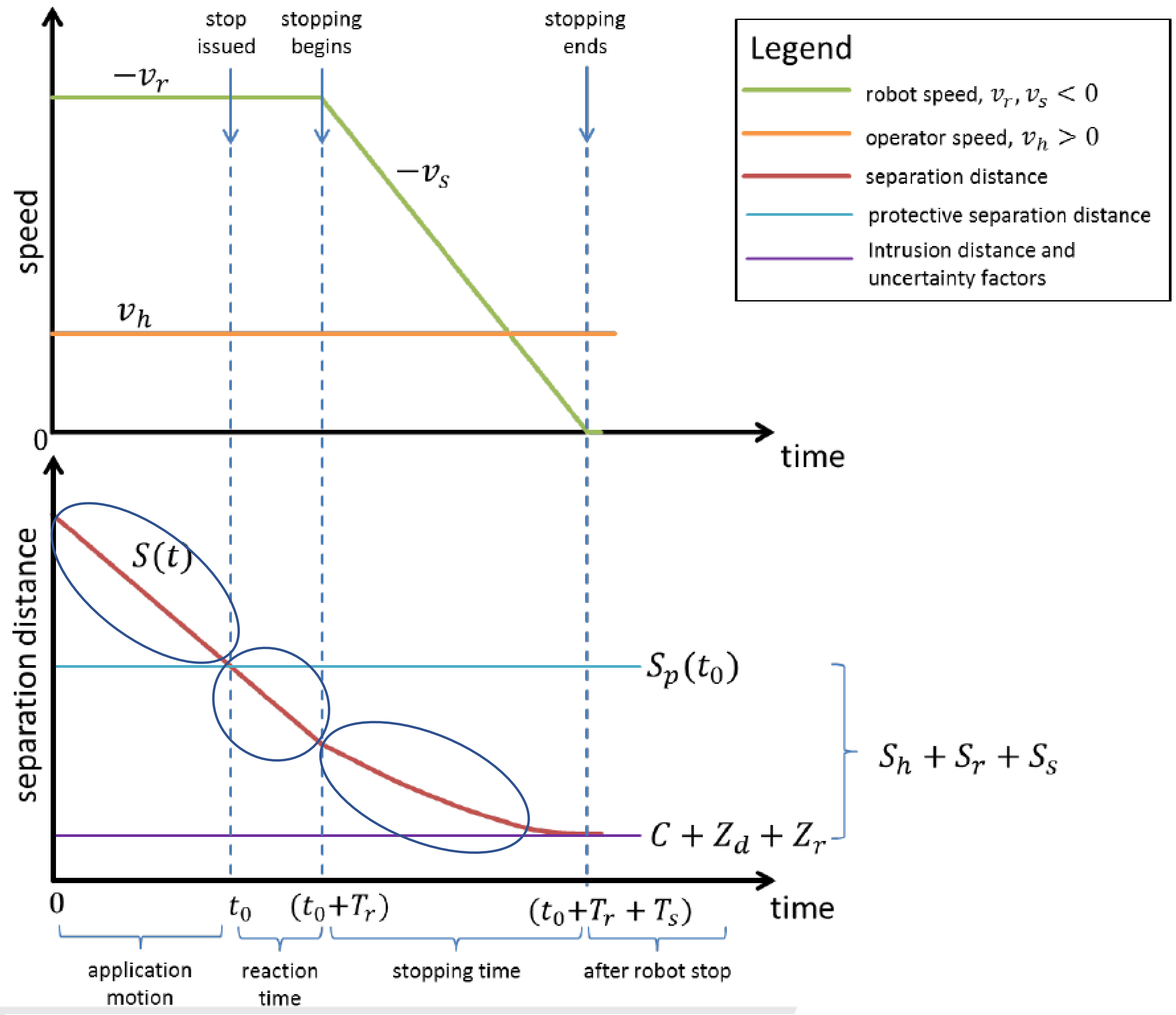
The system shall be designed to account for v_s varying in the manner that reduces the separation distance the most:

a) if the robot's speed is not being monitored, the system design shall assume that this integral is the robot's stopping distance in the direction that reduces the separation distance the most;

b) if the robot's speed is being monitored, the system design may use the robot's stopping distance from that speed, applied in the direction that reduces the separation distance the most.

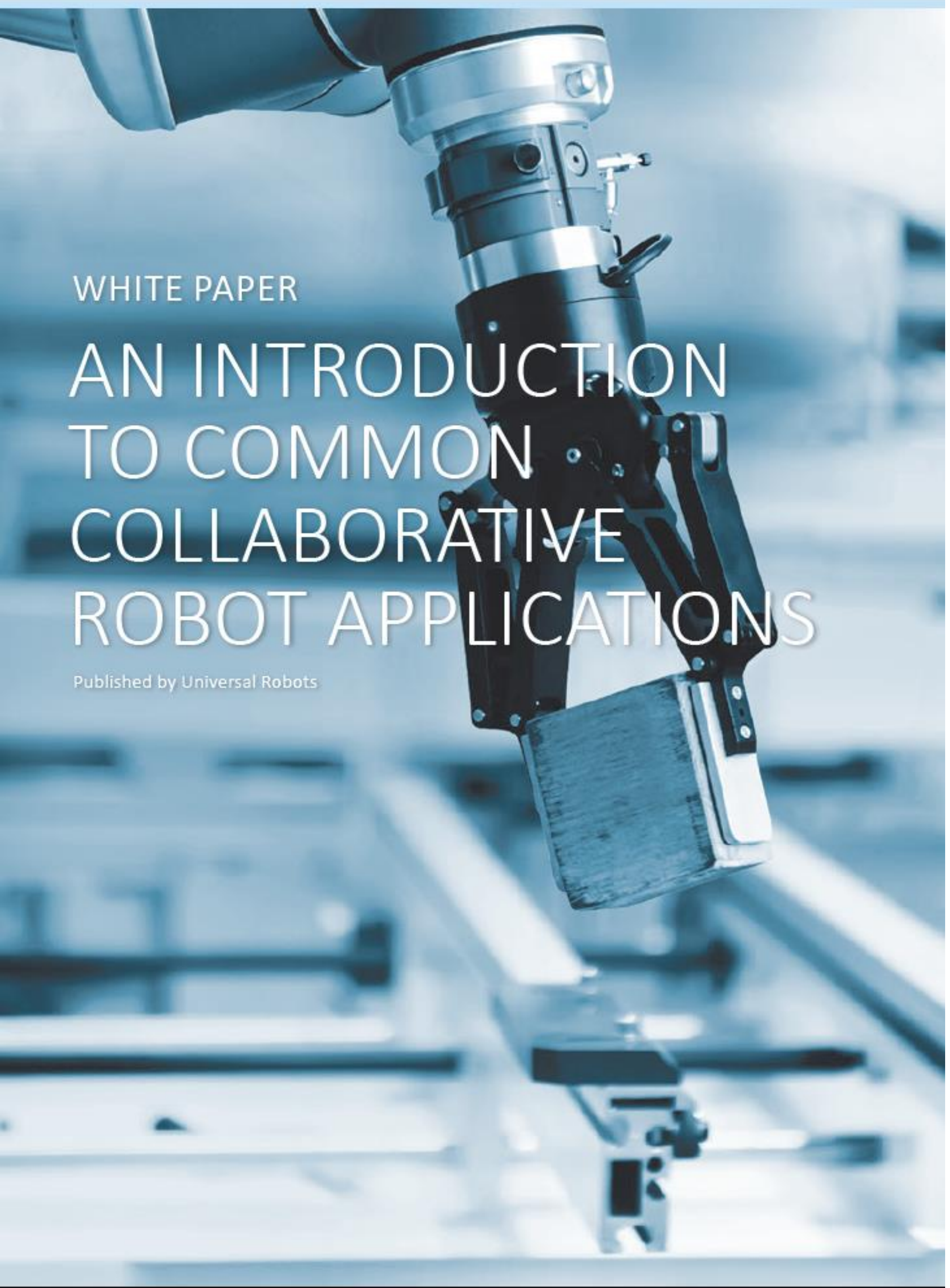
Values for S_s should be obtained from the data provided in accordance with ISO 10218-1:2011, Annex B.

CoBot Situation



$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$

UNIVERSAL ROBOTS

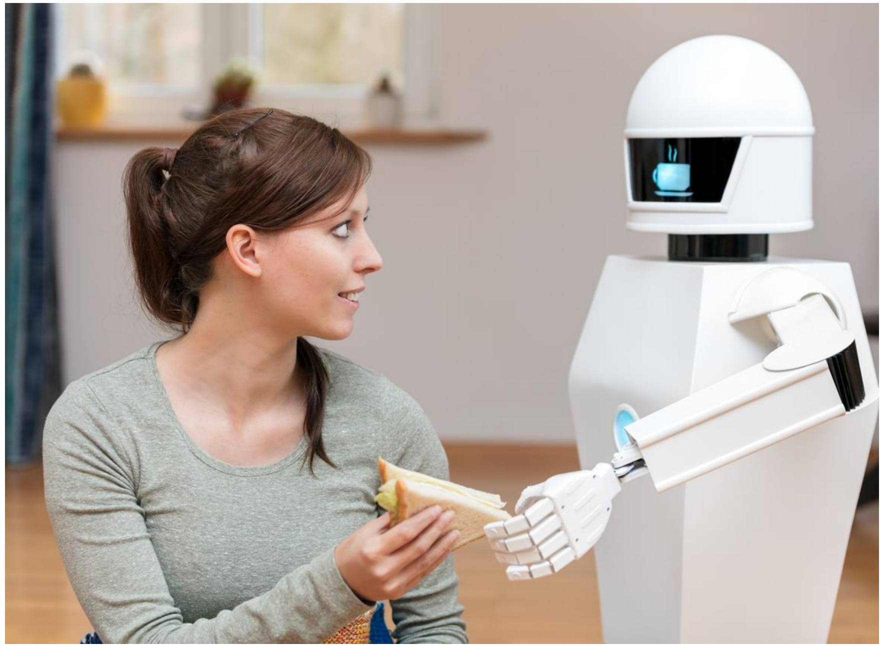


Industrial Applications

- Pick And Place
  - Manual pick and place tasks are often the most repetitive and mundane tasks in a production environment, with the dull nature of the task often leading to mistakes or decreased efficiency if workers are not frequently rotated.
  - These are generally some of the least enjoyable tasks that can also entail a risk of repetitive strain or other injury if the object is of substantial weight.
- Machine Tending
  - The cost of a cobot is usually significantly lower than the machine it is tending. By allowing the machine to run 24 hours of back to back cycles, this will likely pay for the cobot tending it in a very short period.”
- Packaging And Palletizing
  - The benefits of automating a packaging task are similar to generic pick and place – increased productivity over multiple shifts.

Industrial Applications

- Process Tasks (Gluing, Dispensing Or Welding)
  - In a process task, whether it's gluing, dispensing or welding, the key details are the same: the robot moves a tool through a fixed path while the tool interacts with the workpiece.
  - In each of these process tasks, it takes a significant amount of time to train up a new employee to be able to control the numerous variables required to attain an excellent quality finish.
  - If this control can instead be copied directly from one robot to another, it becomes a considerably more straightforward process.
- Finishing Tasks (Polishing, Grinding Or Deburring)
  - As with a process task, the possibility for sharp productivity and quality improvements are immediately clear when automating a finishing task with a cobot.
- Quality Inspection
  - A machine vision system will usually have a faster, more consistent output than a person inspecting a product, leading to improved quality and productivity.



Social Robotics

CoBot Research Topics

Safe Distance Maintenance

- AI
- Computer Vision

Efficiency vs Empathy

Automation vs Collaboration

Case Study

Gaze Controlled Safe HRI for Users with SSMI

International Conference on Advance Robotics, 2021

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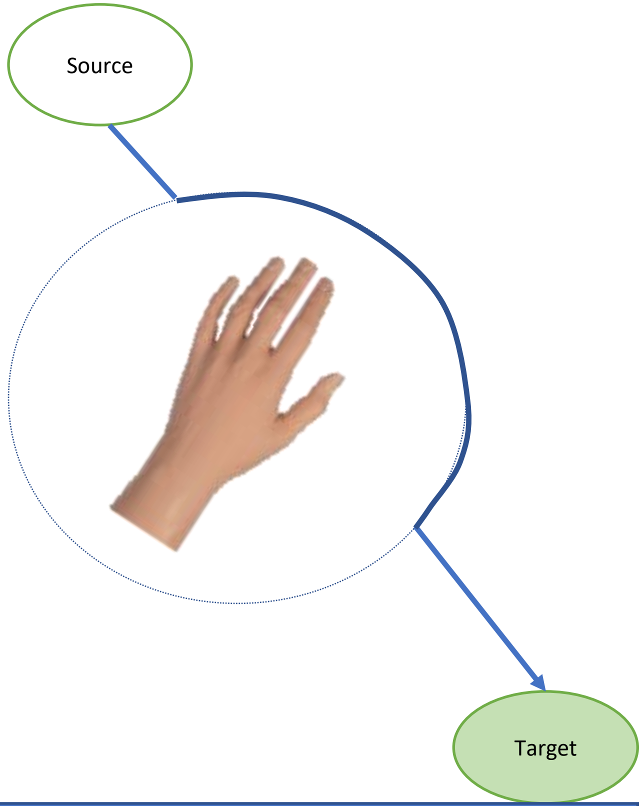
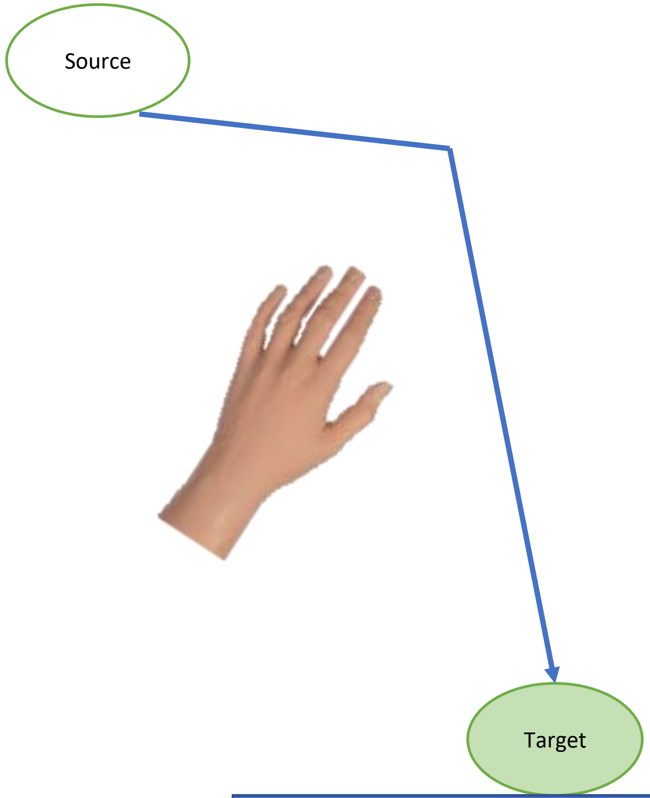
Avoiding Obstacles

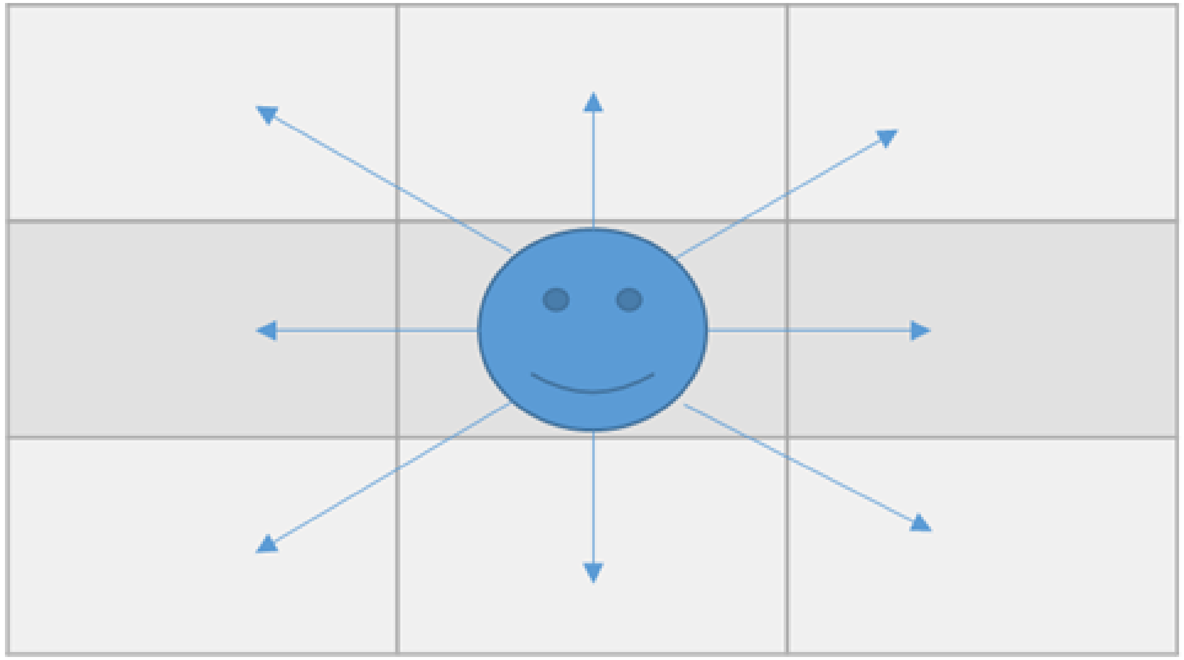


Navigation path with naïve geometry based algorithm

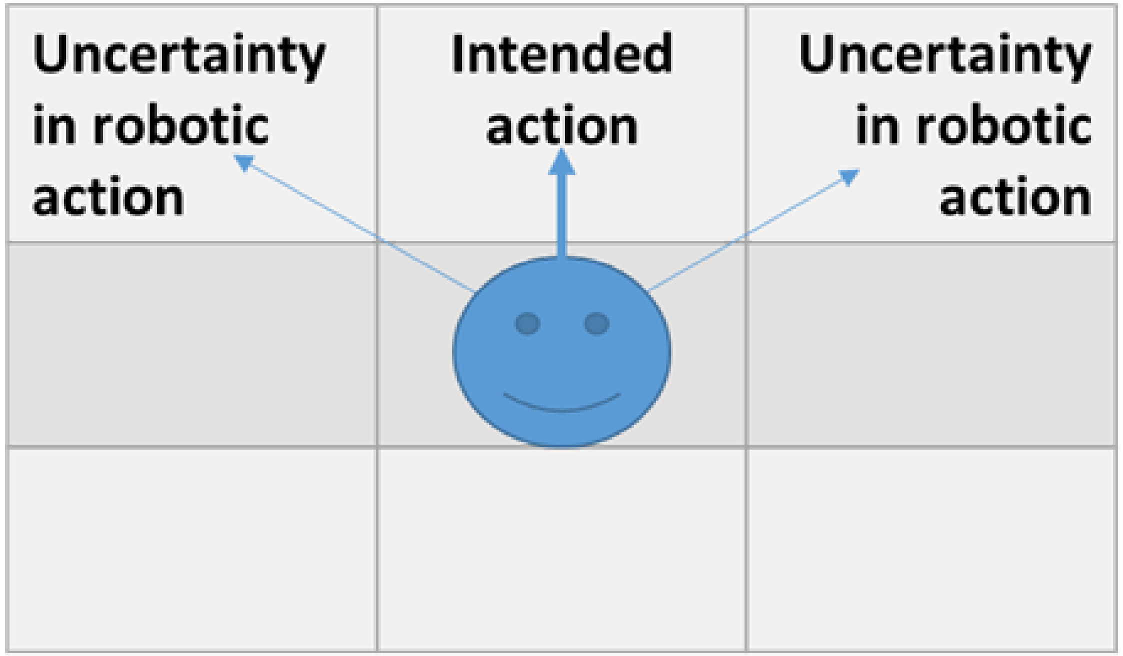


Navigation path with intelligent algorithm

Uncertainty Modelling

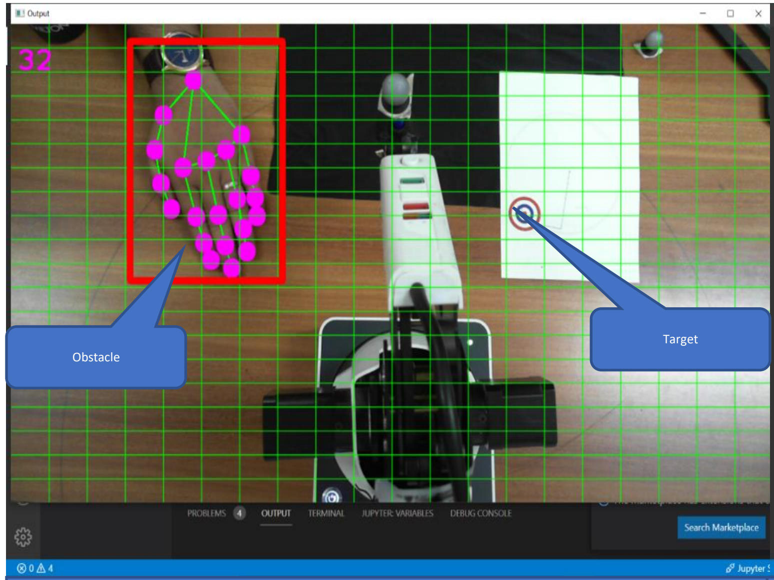


Eight possible actions of robotic agent

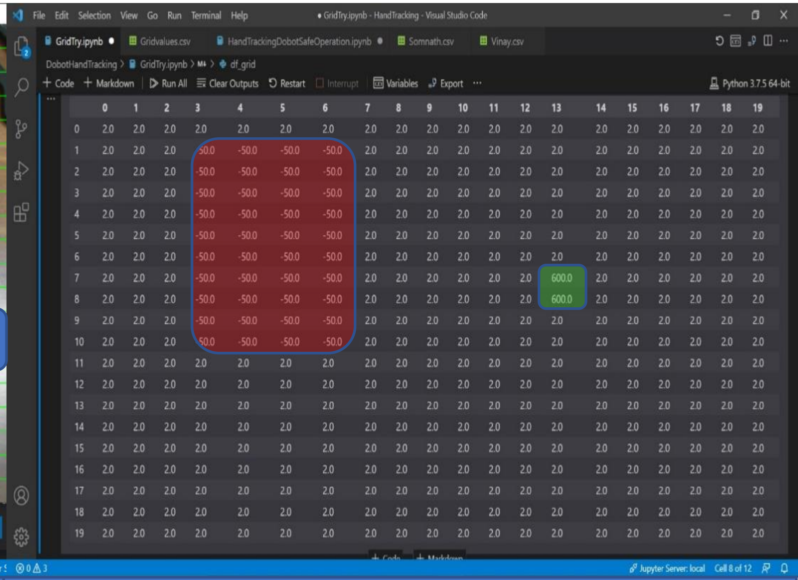


Modelling uncertainty in robotic action

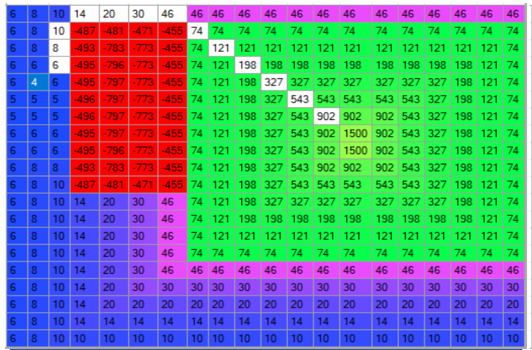
Proposed State Space Model & MDP



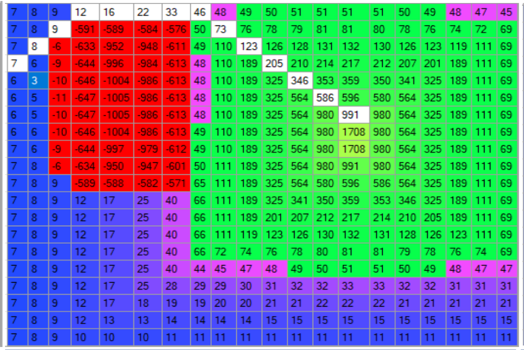
a. Screenshot of actual set up



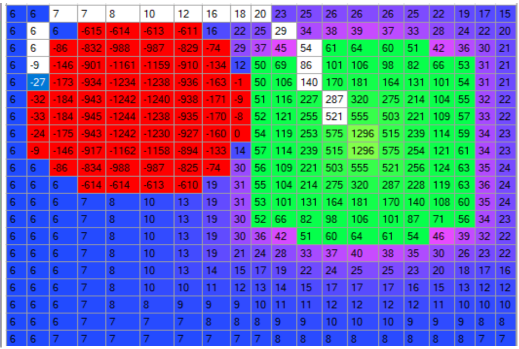
b. State space model with initial reward



c. Navigation path with no uncertainty in robotic movement

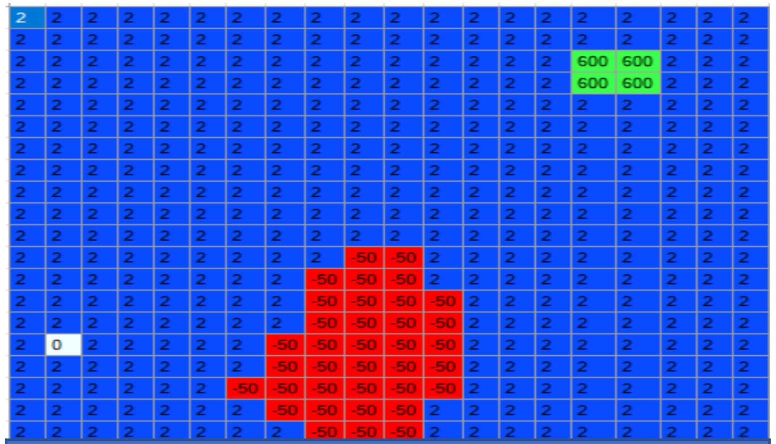


d. Navigation path with 0.05 uncertainty in robotic movement to move on neighbouring cells

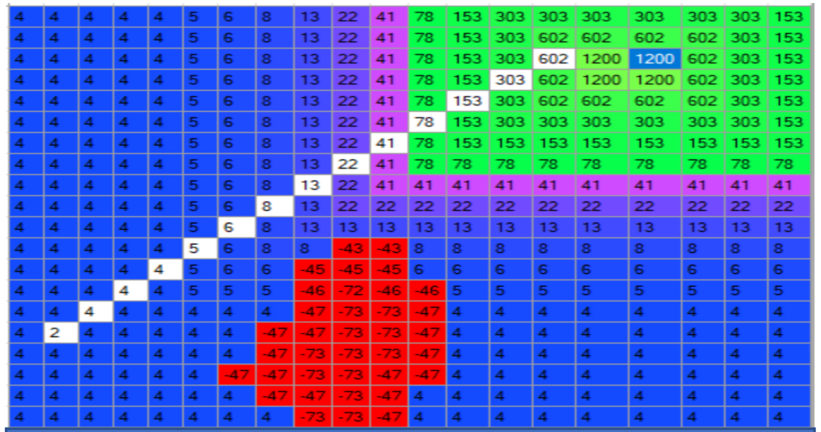


e. Navigation path with 0.3 uncertainty in robotic movement to move on neighbouring cells

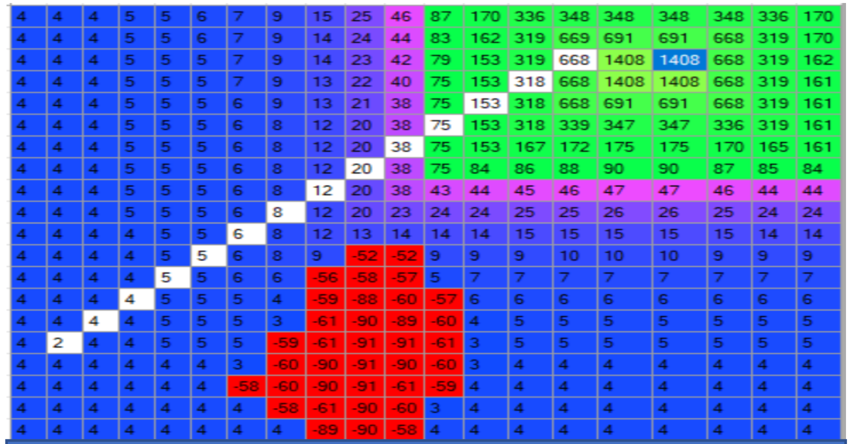
Navigation Under Uncertainty



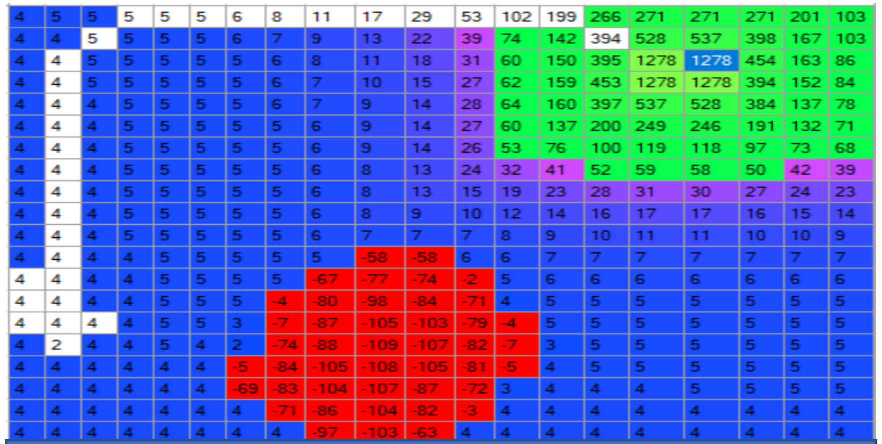
a. Source, target and hand region



b. Navigation path with no uncertainty in robotic movement



c. Navigation path with 0.05 uncertainty in robotic movement to move on neighbouring cells



d. Navigation path with 0.3 uncertainty in robotic movement to move on neighbouring cells

Remembering Past Positions

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a. Source, target and hand region

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b. Navigation path

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c. Hand position moved to right

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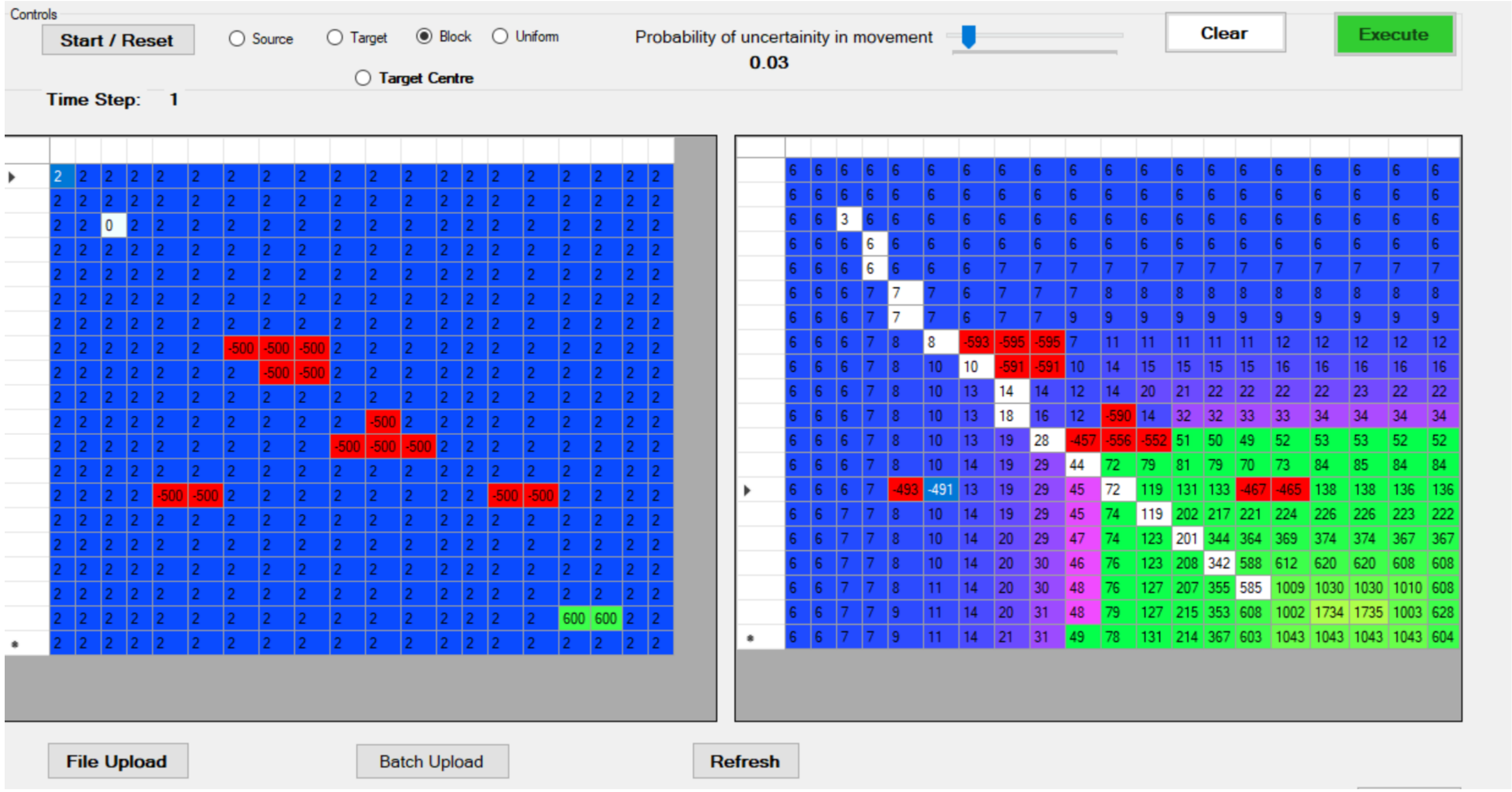
5	5	-5	-57	-58	-48	-48	4	4	5	5	5	5	5	5	5	5	5	5	5
5	-5	-58	-64	-84	-84	-59	-47	-47	5	5	5	5	5	5	5	5	5	5	5
-4	-5	-64	-89	-89	-83	-58	-46	-45	6	6	6	6	6	6	5	5	5	5	5
-8	-9	-62	-86	-81	-57	-45	7	7	7	7	7	7	7	7	7	6	5	5	5
-5	-5	-57	-52	-52	-41	10	10	10	10	10	9	9	9	9	8	6	5	5	5
3	4	4	4	15	15	15	15	15	15	15	15	14	14	13	8	6	5	5	5
23	23	24	25	25	26	26	26	26	25	25	25	24	22	13	9	6	5	5	5
23	41	44	45	46	47	48	48	47	47	46	45	41	22	13	9	6	5	5	5
23	41	80	86	88	90	92	92	90	89	87	80	41	23	13	9	6	5	5	5
23	42	81	162	171	175	179	179	176	173	162	81	42	23	13	9	6	5	5	5
24	43	83	163	333	346	354	354	348	333	163	83	43	23	13	9	7	5	5	5
24	44	84	168	335	687	704	704	687	335	168	84	44	23	14	9	7	5	5	5
25	44	86	169	346	691	1425	1425	691	346	170	86	44	24	14	9	7	5	5	5
24	45	87	175	348	715	1432	1432	715	348	175	87	45	24	14	9	7	5	5	5

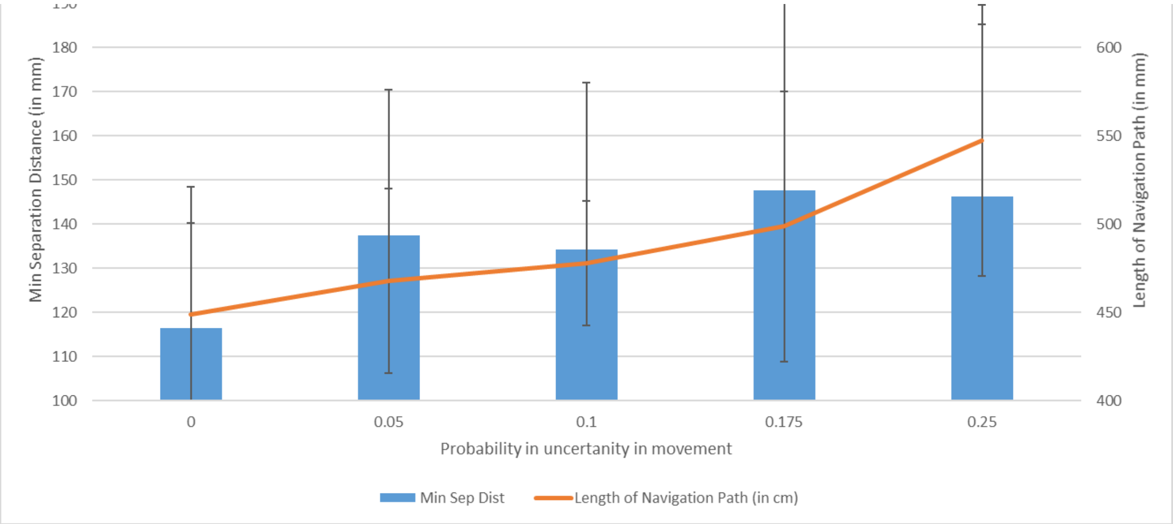
d. Navigation path remembering previous position

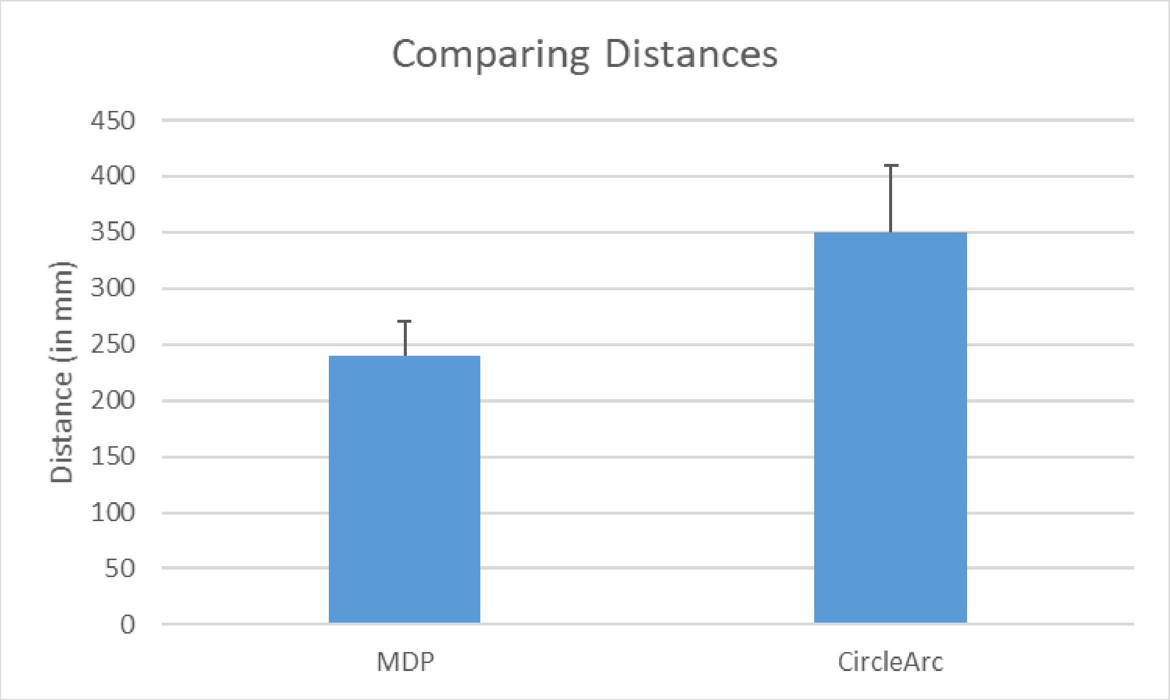
$$U^*(s, t) = U^*(s, t) + \alpha\, U^*(s, t-1),\ 0 < \alpha < 1$$

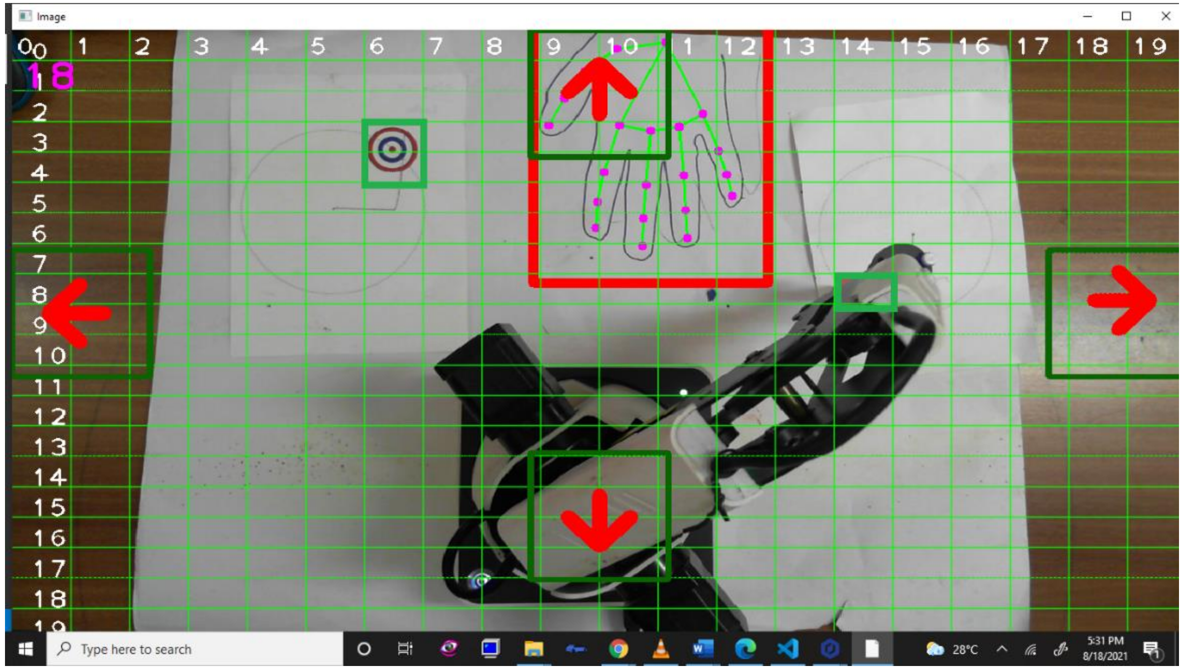
Multiple Obstacles



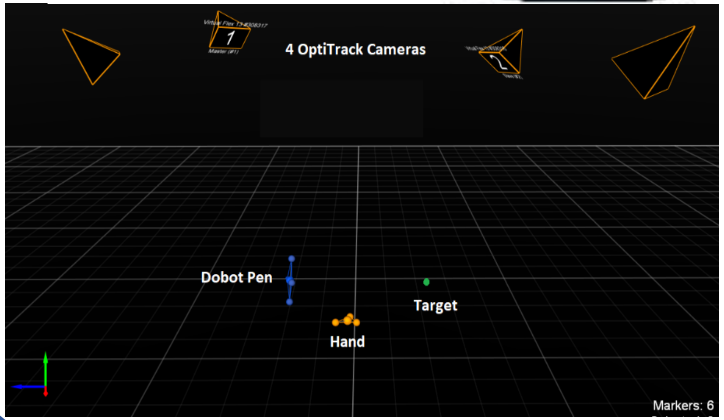
Simulation Result

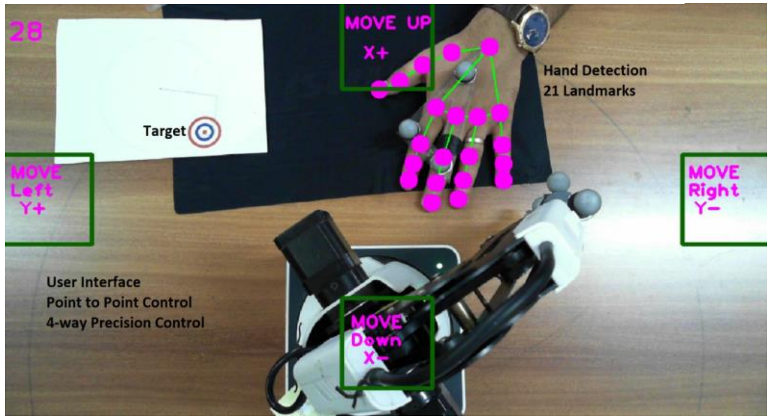






Experiment Set Up





Gaze Controlled Safe HRI for Users with SSMI

User Study

- 12 Users (5 users with SSMI and 7 able-bodied users)
- Dobot Magician System
- Two reachability tasks for randomly positioned target
- Significant main effect of *Trial Number*
  - *F(1,11)=8.648, p<0.05, η²=0.44*
- Significant main effect of *Participant Type*
  - *F(1, 11)=106,16, p < 0.05, η²=0.906*