**This document is for the experiment part of paper:** [**Trust-aware motion planning for human-robot collaboration under distribution temporal logic specifications**](https://ieeexplore.ieee.org/abstract/document/10610874/) **(ICRA 2024)**

**Paper Abstract:**

**Recent work has considered trust-aware decision making for human-robot collaboration (HRC) with a focus on model learning. In this paper, we are interested in enabling the HRC system to complete complex tasks specified using temporal logic formulas that involve human trust. Since accurately observing human trust in robots is challenging, we adopt the widely used partially observable Markov decision process (POMDP) framework for modelling the interactions between humans and robots. To specify the desired behaviour, we propose to use syntactically co-safe linear distribution temporal logic (scLDTL), a logic that is defined over predicates of states as well as belief states of partially observable systems. The incorporation of belief predicates in scLDTL enhances its expressiveness while simultaneously introducing added complexity. This also presents a new challenge as the belief predicates must be evaluated over the continuous (infinite) belief space. To address this challenge, we present an algorithm for solving the optimal policy synthesis problem. First, we enhance the belief MDP (derived by reformulating the POMDP) with a probabilistic labelling function. Then a product belief MDP is constructed between the probabilistically labelled belief MDP and the automaton translation of the scLDTL formula. Finally, we show that the optimal policy can be obtained by leveraging existing point-based value iteration algorithms with essential modifications. Human subject experiments with 21 participants on a driving simulator demonstrate the effectiveness of the proposed approach.**

1. **Instructions about the experiment for participant:**

This experiment is designed to evaluate human drivers’ trust in self-driving vehicles. At the beginning of the simulation, the car starts in self-driving mode, which shows ‘Autopilot: ON on the screen. The driver’s starting trust level on the self-driving car is shown as ‘Trust level: 4 out of 7’. And the range of trust level is from 1(worst) to 7(best).

During the simulation, the car will drive you around a town with the route decided by itself. You will encounter different instances on the road, some are dynamic and some are static, like trucks, pedestrians, and bicycles. The car will detect such objects and take action to avoid collision by itself, if necessary.

Please put your hands on the steering wheel and feet on the pedals all the time.

There are a total of 4 routes in the experiment. For each route, there are 2 tasks you need to pay attention to at the same time as below. Before experiments, there will also be a warm-up route to help you get familiar with the operation. And there will be a short questionnaire after each route.

1. **Driver’s task 1: take over and drive manually when feeling necessary, and switch back to self-driving mode before reaching an intersection**.

The route is decided by the algorithm. Most of the time you just need to let the car drive. When you think you need to take action to avoid a collision or you don’t trust the self-driving car’s decision when there is an instance ahead, you can switch to manual driving by pressing button R3 on the steering wheel. Then you may use the pedals and steering wheel to drive by yourself. Remember, you can only switch on the road segment but not at the intersection. You can only switch to manual at most one time on each road segment. If you switch to manual, then you need to switch back before approaching the intersection (there is a traffic light) so the car can choose its next destination. And switch to self-driving after you go back to the right lane.

1. **Driver’s task 2: Check your trust level and adjust with corresponding buttons along the journey.**

While the car is traveling, you will need to check on your trust level of the car from time to time. If you feel like your trust level has changed (e.g. when encountering a pedestrian/oncoming vehicle/static obstacle ahead, and you are satisfied/not happy with the car’s action), please press button L2 to increase or L3 to decrease the trust level number on the screen. You can change this during self-driving, just be sure to check on this at least once on each road segment/at the intersection.

**Things that need to pay attention to:**

* Switch to manual driving only when you feel it necessary to deal with the instance (pedestrian/truck/bicycle), then back to auto.
* Switch to manual driving then back to auto at most 1 time (auto->manual & manual->auto counts as 1 time) on each road segment.
* Ensure autopilot is ‘ON’ before approaching an intersection.
* Check on your trust level from time to time when the car is self-driving (autopilot=ON), at least once on each road segment. Feel free to change by pressing L2/L3.

**Run Simulation:**

1. Run carla server in Pycharm terminal 1:

conda activate CARLA\_VIRTUAL\_ENV

cd CARLA\_0.9.13\_folder

./CarlaUE4.sh

(If it shows a message like ‘core dump’ and the simulator terminates, restart CARLA by repeating the above commands.)

1. Run python script in Pycharm terminal 2 to start the simulation:

conda activate CARLA\_VIRTUAL\_ENV

cd trust\_aware\_hrc

For each participant, run 3 trials and corresponding baseline, with a unique driver id:

**A test route:**

1. python3 manual\_control\_steeringwheel\_trust\_aware\_hrc\_fix\_route.py --sync --autopilot --trial\_id 3 --if\_baseline\_trial 0 --driver\_id 0

**Experiments with 4 routes:**

1. 1\_1:

python3 manual\_control\_steeringwheel\_trust\_aware\_hrc\_fix\_route.py --sync --autopilot --trial\_id 1 --if\_baseline\_trial 0 --driver\_id 0

1. 1\_2:

python3 manual\_control\_steeringwheel\_trust\_aware\_hrc\_fix\_route.py --sync --autopilot --trial\_id 1 --if\_baseline\_trial 1 --driver\_id 0

1. 2\_1:

python3 manual\_control\_steeringwheel\_trust\_aware\_hrc\_fix\_route.py --sync --autopilot --trial\_id 2 --if\_baseline\_trial 0 --driver\_id 0

1. 2\_2:

python3 manual\_control\_steeringwheel\_trust\_aware\_hrc\_fix\_route.py --sync --autopilot --trial\_id 2 --if\_baseline\_trial 1 --driver\_id 0

1. Trust level record data saved in the folder (there should be 5 files for each participant id)

/trust\_level\_record

1. Remember to **press TAB** when the simulation begins to switch to the driver's view.
2. Steering wheel control:

Middle pedal: Brake

Right pedal: Throttle

R2 (6): Reverse

R3 (10): switch between autopilot and manual

L2 (7): trust + 1

L3 (11): trust - 1

Please do not press other buttons, that will interrupt the route.