Safe and efficient entry into a roundabout

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***Abstract*—The development of a fully autonomous driving vehicle (AV) requires various traffic situations to be handled efficiently. One of the most common driving manoeuvres which we experience in daily traffic is yielding (giving way) to other traffic participants. The yielding areas may include roundabouts, intersections and unprotected turns. In this paper, we propose a simple and yet efficient method of yielding that we tested and incorporated into one of the widely famous autonomy stacks called Autoware. We focus on one specialize scenario of yielding i.e. yielding while entering a roundabout. Our method successfully handled different yielding scenarios while entering a roundabout and can be extended further to handle more complex yielding scenarios.**

***Index Terms*—autonomous vehicles, motion planning, behaviour planning, yielding, roundabout, road intersections, autoware.**

I. Introduction

Research in autonomous vehicle industry has been very active since the past decade. With many automotive giants jumping in and introducing production level AV's mainly more advance driver assistance systems (ADAS) into the market. For an AV to co-exist with other manually driven vehicles in real life traffic, it has to understand the traffic rules and efficiently navigate different traffic scenarios such that it closely mimics a normal human driver. One of a common challenging traffic scenario that an AV should handle is navigating yielding or give way signs. The most notable yielding areas include roundabout entry, giving-way to a priority lane, unprotected turns and merging into traffic etc. Most driving assist systems now a days such ACC, LKA, FCW increase human driver's comfort, the idea of this research is to enhance these automated systems with the capability of navigating yielding areas without driver's intervention.

In order to build this functionality we turn towards open-source autonomy stacks. Now a days most entry level AV companies build their autonomy stack on top of some pre-existing open-source solution. One of the most notable and modular open-source autonomy stack is Autoware [1] by Autowarefoundation. Companies such Apex.AI and Tier.IV contribute in this stack. This stack is also supported by a decent number of AV developers community. The two most notable versions of Autoware i.e. Autoware.AI and Autoware.Auto make use of ROS and ROS2 respectively. In this research, we use Autoware.Ai as our autonomy stack. While Autoware gives us very strong baselines to start working with, it still lack in terms of different AV functionalities. Yielding for other vehicles is one of the missing functionalities.

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II. Related work

By definition a roundabout is a type of circular intersection which helps to reduce signalized intersections also decreasing the probability of collisions compared to normal t-intersections as there are no left turns. Some of the studies that address AV's roundabout navigation and yielding are as follows.

[2] discusses a trajectory planning algorithm for automated yielding maneuvers. It propose four steps of trajectory planning algorithm for yielding region i.e. determining longitudinal & lateral safety corridors and longitudinal and lateral safety trajectory. For a certain traffic scenarios where ego vehicle does not have right-of- way, the corresponding space is divided into three regions: Pre, Peri, and Post. These are shown in figure-1. The authors define Pre region as region in which ego vehicle should account for vehicles and other objects while approaching the the Peri region. The Peri region is region where ego does not have the right of way and traffic participants the ego vehicle must consider before doing a certain type of maneuver e.g. roundabout entry etc. Lastly, the post region includes the traffic participants which the ego should account for before leaving Peri region.

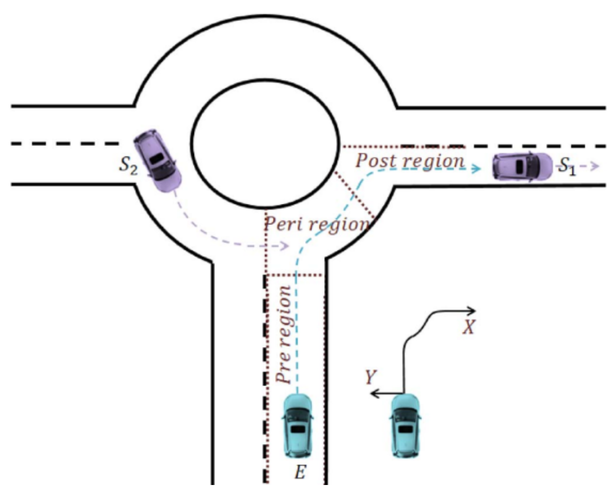

Fig. 1. Regions of automated yielding maneuvers [2]

In [3] authors describe safe roundabout entry as a planning problem and formulate the problem using a POMDP

(Partially Observable Markov Decision Process) The partial observability refers to parts of the state being hidden from the agent which include whether roundabout vehicle exits the roundabout or keeps navigating the roundabout. Here, a particle filter is used to track the vehicle in the roundabout. It creates probability distribution of multiple possible states of the target vehicle afterwards the actual planning happens using the belief tree from which the potential future state trajectories of the target vehicle are sampled.

A simplified binary classification method using artificial neural network (ANN) was proposed in [4] where the authors trained network with different configurations of hidden layers to classify if an ego vehicle should enter the roundabout or stop. The tests were conducted in SUMO [5] simulator with two simulated vehicles i.e. an ego vehicle and a target vehicle.

[6] proposes a methodology to allow an AV to safely cross a multi-lane roundabout. The proposed strategy uses high definition (HD) maps and intervals representing road occupancy by vehicles, with the road being widened to reflect uncertainties in localization. A roundabout insertion strategy describes three rules to show an ideal behaviour of AV in roundabout scenario.

1) An AV must maintain a safe inter-distance w.r.t. the vehicle ahead.
2) An AV must respect the traffic rules (yield for other vehicles in giveway areas)
3) An AV must as far as possible, avoid stopping in transition zone.

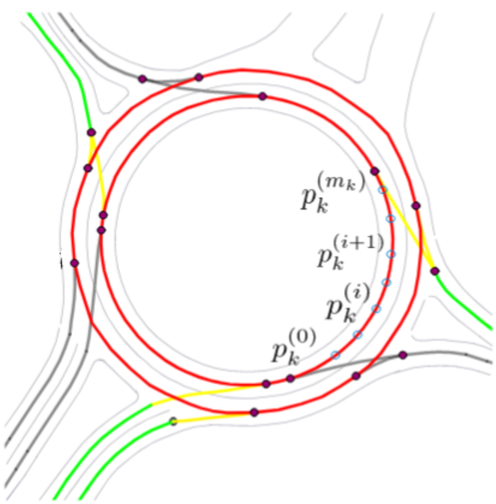

Fig. 2. Zones of a roundabout described by [3]. Here, green marked areas are decision zone, yellow marked areas are transition zone, red marked lanes are ring zone and gray marked lanes are exit zone

In accordance to the above described rules for AV, the paper decomposes a roundabout into four zones as illustrated in figure-2.

(a) The Decision Zone where AV does not have the priority over vehicles in the roundabout.
(b) The Transition Zone where AV transitions into the roundabout. This is the most critical zone in terms on roundabout entry. Here an AV must maintain safe inter-distance from the oncoming vehicles in the roundabout.
(c) The Ring Zone where an AV has completed its roundabout entry and now follows a nearest vehicle ahead of it or navigates the roundabout in normal speed if there is no other vehicle.
(d) The Exit Zone where an AV leaves the roundabout.

As discussed previously, our main objective here is to implement the yielding functionality for an AV within an autonomy stack. This will help us to test the yielding functionality not only in simulated environments but also on actual vehicle. Most of the literature discussed previously gives a theoretical aspect of solving roundabout entry maneuver and have only been experimented within simulations like SUMO and MATLAB. To best of our knowledge, the models discussed in the literature review haven't been integrated or tested into any available software autonomy stack. For this purpose we leverage the models discussed in the literature and implement a yielding maneuver in Autoware.AI. To be specific, we extend a third party motion planner called Open Planner (OP) [7] which is integrated into Autoware.AI and implement yielding functionality in it.

III. Methodology

Open planner predicts future motion estimates and trajectories of other vehicles using particle filter and fuses HD map information into the prediction. The planner keeps track of the behaviour state machine and switches between defined states based on certain conditions. Figure-3 shows a some of the abstract behaviour states which are currently implemented within OP. As an example, consider TRAFFIC LIGHT STOP state. An AV transitions from FOLLOW or FORWARD state to TRAFFIC LIGHT STOP when AV encounters a red traffic light. In this state the car starts decelerating until it reaches zero velocity. Once the zero velocity is achieved (and the traffic light is still red) the behaviour state transitions from TRAFFIC LIGHT STOP to TRAFFIC LIGHT WAIT state where the AV waits in a full stop until the traffic light signal turns green.

Following a similar stop and wait state machine architecture, we propose two new states in OP as illustrated within dotted area in figure-3.

- **YIELD STOP:** AV switches from FOLLOW or FORWARD state to this state and starts decelerating to zero velocity when AV's future trajectory has potential collision with vehicle (s) of interest (VOI) or AV's planned trajectory and VOI's predicted future trajectory has intersection within some time-to-collision (TTC) safety bounds.
- **YIELD WAIT:** AV switches from YIELD STOP to this state if the conditions mentioned in YIELD STOP persist and AV has come to a full stop.

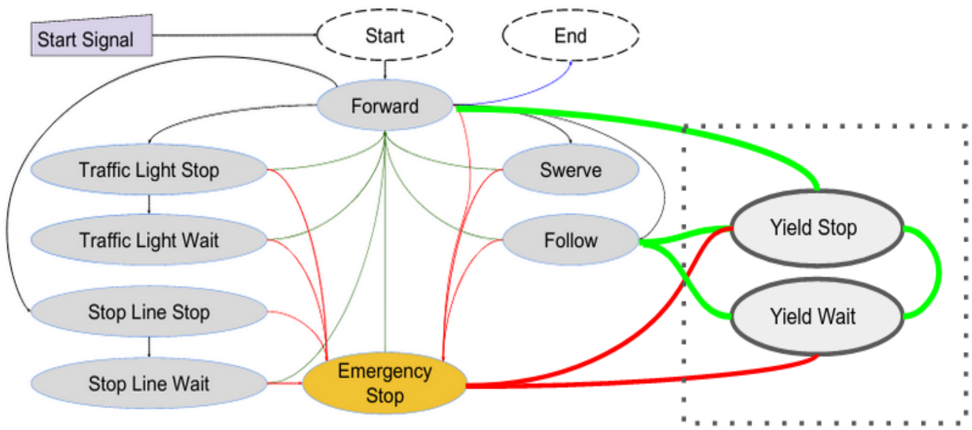

Fig. 3. Behaviour state machines of Open-planner [7]. Here, the newly implemented states are shown in dotted area.

The above proposed states are integrated into the OP. The following flow-chart summarizes the complete yielding functionality algorithm.

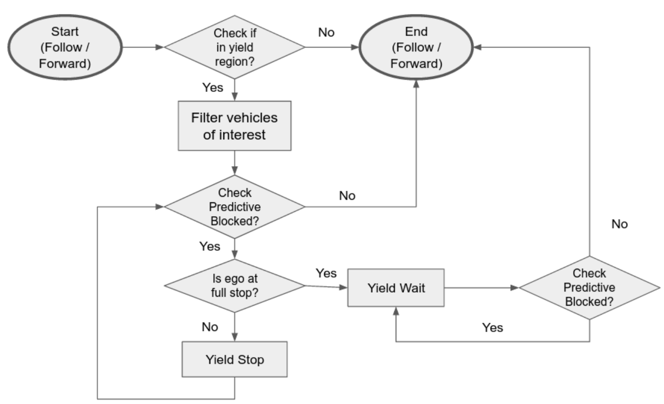

Fig. 4. Flow chart of yielding algorithm.

Here, the check yielding region condition checks if the AV has a yielding stop sign in its path within some threshold distance ahead which is currently set to 50 meters. Once true, then the next stage filters VOI. Filtering VOI takes into account the geometrical shape of road lanes and all surrounding vehicles. For example if a vehicle is directly ahead of us in our lane then we shouldn't be yielding for it. Similarly, if there is vehicle directly behind us then we shouldn't be yielding for it either even if its potential future trajectory intersects the AV's planned trajectory. Lastly, a vehicle in the roundabout which is far enough such that it's predicted future trajectory doesn't intercept the ego's planned trajectory should also be filtered out.

Once the VOI is acquired, the next step is to verify if TTC with VOI is not less than some nominal TTC threshold. In other words, we check if the AV's planned trajectory is not being blocked by predicted trajectory of VOI. If its blocked then state machine transitions to YIELD STOP state and later transitions into YIELD WAIT if AV reaches a full stop. If any of the conditions in illustrated flow-chart fail, then AV switches to its prior behaviour state depending on whether AV was following a vehicle or just moving forward with no vehicle ahead.

IV. Experiments

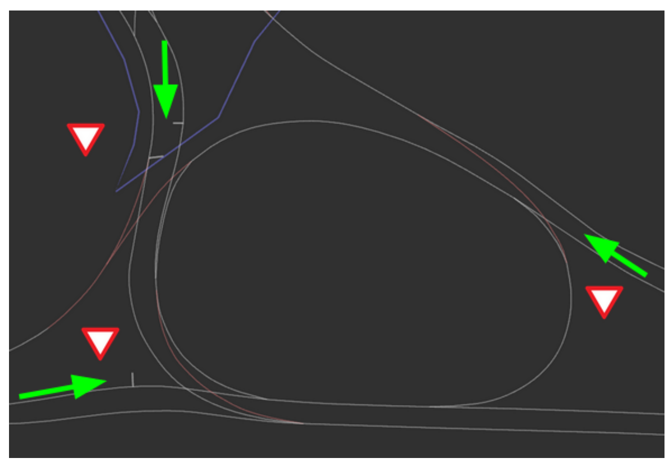

Fig. 5. An illustration of Autoware's vector map of Delta building roundabout we used for testing yielding scenarios. Here, green arrows show possible entry points with give-way sign on each entry

To validate the yielding functionality in roundabout we use Autoware's vector map format of delta roundabout in front of our institute's building. The roundabout has 3 entry zones as illustrated in figure-4. We carefully devised roundabout yielding scenarios and successfully tested them in OP simulation. These scenarios are listed in Table-1

V. Conclusions

In this report we did literature review of existing solutions for automated yielding in roundabouts and other yielding areas. We implemented the yielding functionality in Autoware.AI and successfully tested it in OP simulation over different yielding scenarios in a roundabout. In future, we intend

TABLE I
LIST OF SIMPLIFIED GENERIC SCENARIOS OF YIELDING IN A ROUNDABOUT

1	Roundabout entry from any side. No leading vehicle. At Least 1 vehicle to yield in the roundabout.
2	Roundabout entry from any side. No leading vehicle. At Least 2 or more vehicles to yield in the roundabout.
3	Roundabout entry from any side. At Least 1 leading vehicle ahead of us before the yielding stop line and at Least 1 vehicle to yield in the roundabout.
4	Roundabout entry from any side. At Least 1 leading vehicle ahead of us before the yielding stop line and At Least 2 or more vehicles to yield in the roundabout.
5	Roundabout entry from any side. At Least 1 leading vehicle ahead of us before the yielding stop line, 1 trailing vehicle behind us and At Least 2 or more vehicles to yield in the roundabout.

to test this functionality of over real vehicle and compare its performance with the simulation results. We also intend to expand our work and incorporate other types of yielding areas such as unprotected left turns and lane change etc.

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